FMU Rep. No. III - 3·7
(OCTOBER 1972)

INDIA METEOROLOGICAL DEPARTMENT

FORECASTING MANUAL

PART III

DISCUSSION OF TYPICAL SYNOPTIC WEATHER SITUATIONS

3·7 : SOUTHWEST MONSOON - TYPICAL SITUATIONS OVER KONKAN AND COASTAL MYSORE

BY

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Part III - Discussion of Typical Synoptic Weather Situations

3.7 Southwest Monsoon - Typical Situations over Konkan and Coastal Mysore

by

V. Srinivasan, S. Raman, S. Mukherji and K. Ramamurthy

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1. Introduction

1.1 This report deals with typical synoptic situations associated with active and weak monsoon conditions over Konkan* (including Goa) and Coastal Mysore during the Southwest Monsoon season. After reviewing the meteorological conditions over the area, a survey of the synoptic conditions which affect the weather in Konkan and Coastal Mysore is made. This is followed by a detailed discussion of seven typical synoptic situations leading to active and weak monsoon conditions in these sub-divisions.

2. Southwest Monsoon over Konkan and Coastal Mysore

2.1 General features

2.1.1 The Southwest monsoon normally advances along Coastal Mysore during the first week of June; its further advance into Konkan occurs within a week of its onset over Coastal Mysore. However, there are large variations in the date of onset from year to year.

2.1.2 An examination of the actual dates of onset of monsoon during the past two decades (1952-1971) shows that on about two-thirds of the occasions, the onset in Coastal Mysore was between 28 May and 10 June, in South Konkan between 2nd and 12th June and in North Konkan between 6th and 15th. Generally the monsoon advances into Coastal Mysore within 5 days of its advance into Kerala. On a large number of occasions (over 60 per cent) it advances into South Konkan also within 2 or 3 days of its advance into Coastal Mysore. From South Konkan to North Konkan it takes another 1 to 3 days. During the last two decades, the earliest advance into Coastal Mysore and South Konkan has been on 19-20 May(1962) and into North Konkan on 29th May (1956 and 1962); the most delayed advance in Coastal Mysore was on 14th June (1958), south Konkan on 19 June (1957) and North Konkan on 25 June (1959).

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* Reference to "Konkan" wherever made in this report may be taken to include 'Goa' also.

2.1.3 The onset of the monsoon over Bombay and its suburbs during the past 93 years (1879-1971) is given in Appendix I. The dates of onset have also been shown in the form of histogram (Fig. 2.1). Though the normal date is 10th June, the Table shows that the actual date has been as early as 24th May (in 1879 and 1918) or as late as 25th June (in 1905 and 1959). The standard deviation is seven days (i.e. a week). On 60% of the occasions, the onset has been between 6th and 15th June (i.e. during the second week of June). It may be also noted that the advance before the second week (i.e. before 6th June) has been more frequent (28% of the occasions) than after the second week (i.e. after 15 June) (only 12%).

2.1.4 The withdrawal of monsoon from Konkan and Coastal Mysore takes place towards the end of September or in the beginning of October.

2.2 Rainfall

2.2.1 The mean monthly, seasonal and annual rainfall in Konkan and Coastal Mysore together with number of rainy days are given in Table I.

TABLE - I

Mean rainfall (cm) and number of rainy days - Konkan and Coastal Mysore*

	Jun.	Jul.	Aug.	Sept.	Season's Total (Percentage of annual rain indicated in parenthesis)	Annual
1. Konkan						
Rainfall (cm)	62	108	63	37	270(94%)	287
Rainfall as percentage of season's total	22	40	24	14		
No. of rainy days	17	27	24	16	84(90%)	93
2. Coastal Mysore						
Rainfall (cm)	84	110	63	28	285(87%)	326
Rainfall as percentage of season's total	29	39	22	10		
No. of rainy days	23	28	25	16	92(82%)	112

*From Memoirs of I. Met. D. Vol.XXXI Part - III.

The Southwest Monsoon season is the wettest period of the year in Konkan and Coastal Mysore. About 90% of the annual rainfall occurs during the southwest monsoon period (June to September). The rainfall in May is about 10-15 cm in Coastal Mysore and less than 5 cm in Konkan. With the onset of the monsoon, the rainfall suddenly increases in June to about 70-100 cm in Coastal Mysore and 40-80 cm in Konkan. In contrast with Kerala, we find that in Coastal Mysore and Konkan, the rainfall in June is almost one order of magnitude more than in May. The rainfall increases further in July. This is the rainiest month of the year, and accounts for nearly 40% of the season's rainfall. By August, there is a marked decrease in rainfall and the mean rainfall drops to about 60 cm in both Coastal Mysore and Konkan; that is, the rainfall in August is only about ~~50 to 55%~~ 60 % of the rainfall in July. In September, the rainfall decreases still further - the decrease being more in Coastal Mysore.

2.2.2 The Figures in Table I are the mean values for the sub-division. But, there are large variations of rainfall within the sub-division and the isohytes generally run in a north-south direction (Fig. 2.2). The rainfall is less along the coast and increases rapidly as we proceed eastwards towards the Ghats; the rainfall figures almost double from the coast to Ghats (in a distance of hardly 100 km). This is a remarkable effect of orography on rainfall. The following Table (Table II) gives typical examples of stations more or less along a same latitude, but at increasing distances from the coast and at increasing altitudes. The decrease in rainfall on the lee of the Ghats is represented by Wadgaon and Medha.

TABLE - II

Mean Monthly Rainfall (in mm) for July

Station	Lat. (N)	Long. (E)	Rainfall
1. Alibag	18° 38	72° 52'	601
2. Pen	18 44	73 06	1053
3. Karjat	18 55	73 20	1313
4. Lonavala	18 45	73 24	1765
5. Khandala	18 46	73 22	1951
6. Wadgaon	18 44	73 39	429
7. Harnai	17 49	73 06	873
8. Dapodi	17 46	73 12	1247
9. Khed	17 43	73 24	1317
10. Mahabaleshwar	17 56	73 40	2546
11. Medha	17 47	73 50	724

From "I.Met.D. Memoirs Vol. XXXI - Part III"

2.2.3 Konkan and Coastal Mysore have a small coefficient of variation of rainfall. For the southwest monsoon season as a whole the co-efficient is less than 20%; it is one of the few regions in India with a very low co-efficient of variation. In individual months, however, they are somewhat higher, being 30 to 50% in the mid-monsoon months of July and August.

2.2.4 Heavy to very heavy rainfall is a feature of the weather over Konkan and Coastal Mysore during the monsoon season. However, phenomenally heavy falls of the order of 50 to 75 cm have occurred only over North Konkan and adjoining South Gujarat State: such amounts have not been reported from South Konkan and Coastal Mysore. Such phenomenally heavy rains occuring on relatively flat terrain in South Gujarat Region and the adjoining North Konkan is a point of considerable interest.

2.2.5 Although July is the rainiest month, and heavy falls are also most frequent during this month, very heavy falls also occur in the other months. For instance, the record fall* (55 cm) at Bombay occurred in September (10 Sept.1930). Another point of interest is that while the record fall* at Bombay was 55 cm, the record fall* at Mahabaleshwar** (over the Ghats) was much less (38 cm) and occur- in July 1958. Record falls at selected stations in Konkan and Coastal Mysore are available in the departmental publication "India Weather Review - Oct.-Dec. 1963 Heavy falls are more frequent in Konkan and Coastal Mysore during the first half of the monsoon. An analysis of rainfall at Bombay (representative of Konkan) and Mangalore (representative of Coastal Mysore) for the 50 years period 1901 to 1950 shows that nearly 70%-80% of the occasions of heavy or very heavy rain was between the onset of monsoon and the end of July. There is a distinct decrease in August. While such heavy falls also continue in September in Bombay, their frequency becomes practically negligible at Mangalore. Heavy falls in Konkan during September is generally due to the westward movement of depressions and lows from the Bay across the north Peninsula.

2.3 Monsoon Activity

2.3.1 Table III gives the percentage frequency of occurrence of vigorous+ strong, normal and weak monsoon days in Konkan and Coastal Mysore during the monsoon season. A significant feature is the occurrence of active to vigorous monsoon more frequently (nearly 20-25%) in the first half of the season than the second half, when the frequency is about 5 to 10%.

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* These amounts refer to the 24 hrs. period ending at 0830 hrs IST.

** This Figure refers to the heaviest fall at the present observatory site since 1929. Prior to this date, at the state raingauge station at a different site, the record was 46 cm (in July 1896).

\+ "Vigorous, Strong, Normal and Weak" refer to Appendix-II.

TABLE - III

Percentage frequency of occurrence of Vigorous*, Strong, Normal and Weak Monsoon days over Konkan and Coastal Mysore (based on data of 1966-70)

Sub-division	June					July					August					September					June to September				
	V	S	N	W	D	V	S	N	W	D	V	S	N	W	D	V	S	N	W	D	V	S	N	W	D
Konkan	1	18	35	33	13	1	20	42	34	3	3	3	36	57	1	4	5	38	35	18	2	12	38	39	9
Coastal Mysore	2	16	42	34	6	1	24	51	24	0	3	9	44	39	5	4	7	39	23	27	2	14	44	30	10

* V - Vigorous; S - Strong; N - Normal; W - Weak Monsoon with some rain D - Weak monsoon without any rain (Dry)

2.3.2 In the first half of the season, normal and weak monsoon conditions occur on nearly the same number of occasions (about 40% each) in Konkan. However, in the latter half of the season, weak monsoon conditions are more preponderant, occuring on 55% to 60% of the occasions. In Coastal Mysore, however, normal and weak monsoons occur with almost the same frequency, except in July when a weak monsoon is appreciably less frequent. Of the four months, June to September, July has the minimum number of weak monsoon days in both Konkan and Coastal Mysore; dry days are most frequent in September.

2.4 Pressure

2.4.1 During the monsoon season, there is a south to north oriented pressure gradient+along the west coast, with lower pressures to the north. The average seasonal pressure gradient along the Konkan and Coastal Mysore (i.e. represented by the pressure difference between Veraval and Mangalore) is about 5-6 mb in the first three months of the season, being slightly more in July. In September, however, the gradient decreases to about 2 to 3 mb only.

+ Note: In this connection a reference is invited to the discussion on the pressure gradient along the west coast at the time of onset of the monsoon in para 3.4 of FMU Rep. No. IV-18.2.

2.4.2 On individual days, there can be wide variations in this gradient. In the mid-monsoon months of July and August, the pressure difference between Veraval and Mangalore varies from 2 to 12 mb, the more frequent values being between 4 and 8 mb (Table IV). The pressure gradient is slack when there is a sea level trough off the coast, though to the south of the trough the gradient may be strong. The gradient is also weak when the Arabian Sea branch of the monsoon is weak. The gradient in the Arabian Sea and along the coast may build up either in association with a monsoon depression or a low, or even when the seasonal trough is well marked, and is slightly south of its normal position.

TABLE - IV

Frequency of Pressure Gradient at 03 GMT between Veraval and Mangalore during July and August (1966-1970)

Pressure Gradient (in mbs.)	-2 to 0	0.1 to 1.9	2.0 to 3.9	4.0 to 5.9	6.0 to 7.9	8.0 to 9.9	10.0 to 11.9
No. of occasions	4	13	58	111	91	21	2

2.5 Thunderstorms

2.5.1 Thunderstorms occur only on a small number of occasions in Coastal Mysore and Konkan during the monsoon season. These occasions are mostly in June. They are more frequent near about the time of advance of the monsoon. After the monsoon has advanced, there is a distinct decrease in thunderstorm activity. The minimum of thunderstorm activity is reached in August. A favourable synoptic situation for the occurrence of thunderstorms is the presence of a wind discontinuity line over Konkan, with or without a low pressure system over the north Peninsula. Although aircraft reports have shown the existence of towering Cu and Cb clouds during active monsoon conditions, reports of thunderstorms are relatively small in number.

2.6 Squalls

2.6.1 Squalls are characteristic of the monsoon along the west coast. Heavy showers during the monsoon are generally accompanied by squalls. These squalls are mainly from westsouthwest/west. The frequent peak velocities reached during the squalls are between 50 to 65 kmph, though, occasionally, they reach velocities of the order of 80 kmph. Squalls occur more frequently at the height of the monsoon season (i.e. in July and the first half of August). When the winds at low levels (upto 1.0 km) are 30 knots or more, squalls have been reported more frequently than when the winds are weaker.

2.6.2 Winds also become gusty and squally when the Arabian Sea monsoon becomes strong to vigorous along and off the coast.

2.7 Upper Winds

2.7.1 The upper winds over Bombay and Goa are representative of the wind regime over Konkan and Coastal Mysore. The mean upper winds for Bombay from May to October are given in Fig. 2.3

2.7.2 During the southwest monsoon season, westerlies prevail over Konkan and Coastal Mysore in the lower and mid-troposphere upto 500 mb. In the mean they are 20/25 knots strong in the mid-monsoon season in the lower troposphere, with their speed decreasing with height. The layer between 500 and 300 mb, is a transition layer where the winds are light and variable. The light wind regime in the mid-troposphere often presents difficulties in uniquely identifying the mid-tropospheric disturbances and tracing them from one chart to another. At 400 mb the easterlies make their appearance, and they gradually increase with height reaching a strength of 60-80 knots between 150 and 100 mb. The surface of the maximum wind has a slope; it is between 14 and 15 km over the south Peninsula and slightly higher in north Peninsula. This reversal in the wind regime from the westerlies in the lower levels to easterlies in the upper levels is caused by the north-south temperature gradient across the Peninsula with colder air to the

south throughout the troposphere.

2.7.3 In the mean, the core of the Easterly Jet Stream lies near about the latitude of Trivandrum, at a height of about 14.5 to 15.0 km and has a strength of about 80-85 knots. However, on the daily charts, the upper easterly jet shows periodic strengthening and weakening, as well as north-south movement across the Peninsula. The maximum occasionally reaches a strength of 100-120 knots; and on very rare occasions they have reached 140-150 knots. Sometimes, the easterly jet has two maxima, one over the south Peninsula and the second one at a slightly higher latitude.

2.7.4 In the lower troposphere, the westerlies along Konkan and Coastal Mysore frequently become very strong, particularly when there is a strengthening of the Arabian Sea current, which is usually associated with the formation and movement of a depression or a low from Bay of Bengal across the central parts of the country. Occasionally, even without a depression or low, when the monsoon trough is well-marked over the country, this feature may be noticed. These strong winds over the Peninsula have a core at a height of about 1.5 km a.s.l., with core speeds of the order of 40-60 knots. Quite often, this low level jet persists for a few days, with a certain amount of north-south movement. The core of the jet is often across the central and southern parts of the Peninsula. It very rarely shifts to the north Peninsula.

2.8 Upper Air Temperature and Humidities

2.8.1 The monthly mean tephigrams of Bombay are given in Fig. 2.4 to show the temperature and humidity structure of the atmosphere over Konkan during the monsoon. A similar structure may be expected over Coastal Mysore also. The curves for May are indicated to show the contrast between pre-monsoon and monsoon months. Significant changes may be noticed between May and June as the monsoon sets in; particularly changes in the humidity content are very large. The air is cooler during the monsoon (compared to the pre-monsoon month) in the lower

troposphere (below 700 mb); above this level, the air becomes slightly warmer during the monsoon. There is no difference between July and August. However, by September, the humidity decreases at all the levels.

2.8.2 The mean tephigrams of Bombay for strong to vigorous, normal and weak monsoon days in Konkan are given in Fig. 2.5. As has been noticed in the cases of other stations discussed in earlier Forecasting Manual Reports, there is hardly any change in dry bulb temperature at all levels, whatever may be the monsoon activity. Significant differences are noticed in the humidity content between 800 mb and 400 mb. In this layer, a weak monsoon is characterised by a sharp decrease of humidity with height (particularly between 800 mb and 650 mb) while on days of strong monsoon, the ~~dew point~~ wet bulb curve practically follows the saturated adiabat. On individual occasions of weak monsoon, even an inversion may be noticed at the lower tropospheric levels. The humidity distribution during normal monsoon shows a feature intermediate between active and weak monsoon conditions. Below 850 mb, there is practically no change in the dew point curve whatever be the monsoon activity.

2.8.3 Individual days' tephigrams of Bombay, typical of active and weak monsoon conditions are shown in Fig. 2.6 (A-Active monsoon - 8 July 1970 and B-Weak monsoon - 15 July 1970). The following features in the tephigrams are noteworthy.

i) 8 July 1970 - Active monsoon. Nearly saturated air upto very high levels

ii) 15 July 1970 - Weak monsoon. The layer of moist air upto about 750 mb with dry air above and a stable lapse rate at the transition levels.

3. Survey of Synoptic Systems affecting Konkan and Coastal Mysore

3.1 The synoptic situations associated with a strengthening of the monsoon over Konkan and Coastal Mysore are the following:-

i) A trough of low pressure off the coast on the surface chart and in the low levels

ii) Formation of a depression or low over North Bay of Bengal and its westnorth-westward movement across the country

iii) Presence of a cyclonic circulation off Konkan or Coastal Mysore or over South Gujarat State particularly between 700 mb and 500 mb.

iv) Strong cyclonic shear due to speed variation in the low level westerlies along the coast

v) Strong pressure gradient along the coast

3.2 Trough of Low

3.2.1 A trough of low pressure off Coastal Mysore and Konkan is a common synoptic feature associated with monsoon activity over these areas. In the case of Konkan, nearly half the number of active to vigorous monsoon situations is associated with a trough off the west coast, while in Coastal Mysore the number of such occasions is even more, being nearly three quarters of the total number of occasions. The trough usually forms in situ along the coast, while in some cases, the formation may be under the influence of a low or depression moving westwards across the Peninsula. The trough may travel northwards along the coast (sometimes from Kerala coast to Gujarat) and the heavy rainfall belt* also shifts northward along with the trough. Pressure changes associated with such troughs may not be very large; however, the pressure departures are, sometimes, substantial. The trough is seen on the surface isobaric charts, and in the upper air below 1.0 km. It may be possible at times to draw a closed low of small extent embedded in the trough. On some occasions, there may not be a trough in the upper wind chart, but only a region of light winds and/or strong cyclonic shear due to speed variation. In a general way, we may say that a trough which

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* The region of heavy rainfall along the coast, in association with a trough, is generally at the southern end and also to the south of the trough.

is noticed in the surface as well as in the upper air, may cause more rainfall than the one seen only on surface charts. Even on the surface charts, the trough may be better marked in the morning (00 or 03Z) charts than in the evening (1200Z) chart. Absence of adequate observations to the west over the Arabian Sea poses a problem in locating the troughs, as we have to go by the coastal observations only. A light southerly wind or a light wind with some easterly component along the coast on the surface chart and in the lower levels is a very significant observation in locating the trough on the chart.

3.3 Depression or a low

3.3.1 The formation of a low or depression over the north Bay of Bengal, and its westnorthwestward movement across the country, ~~is another synoptic condition under~~ ~~which the monsoon strengthens along the west coast of the Peninsula.~~ ~~A little~~ ~~prior to the formation of the depression or low, there is strengthening of the~~ ~~surface and lower tropospheric westerlies in the Arabian Sea and the Peninsula,~~ ~~which leads to an increase in rainfall in Konkan and Coastal Mysore. If, at the~~ ~~same time, a mid-tropospheric cyclonic circulation also develops over Gujarat~~ ~~State, Konkan and adjoining areas, or if the upper air circulation associated~~ ~~with the depression is extensive and covers the above mentioned areas, there is~~ ~~good probability of the monsoon becoming active to vigorous in Konkan and~~ ~~Coastal Mysore. In such situations, a well-marked convergence zone between~~ ~~the northerlies and westerlies can be noticed over South Gujarat and Konkan (particularly from 700 mb to 400 mb) sloping southward with height. The wind discontinuity can be seen in the lower levels also when the depression comes~~ ~~nearer. These developments are more common in the earlier part of the monsoon~~ ~~season.~~

3.3.2 The above conditions prevail when the depression/low is either over the Bay or sufficiently far away from Konkan and Coastal Mysore. However, when

the depression or low moves nearer and is centred over West Madhya Pradesh, Gujarat or interior Mabarashtra State, the sub-divisions of Konkan and Coastal Mysore may come directly under the depression field and heavy to very heavy rain may occur over these sub-divisions. The convergence zone between northerlies and westerlies becomes quite pronounced over South Gujarat and Konkan in the lower troposphere.

3.3.3 It is also seen that depressions and lows that take a northwest/northerly track do not generally cause strong or vigorous monsoon along Konkan. Such tracks are more likely towards the second half of the monsoon season.

3.3.4 In the case of some monsoon depressions, when they are far to the east, over the Bay of Bengal, Orissa or East Madhya Pradesh, a pronounced ridge extending from Konkan to Rajasthan and southwest Uttar Pradesh develops at the surface and in lower troposphere; then monsoon does not strengthen along the west coast.

3.3.5 Towards the end of the monsoon season, when the monsoon depression (and low) forms at more southerly latitudes and moves westwards across the north Peninsula, the strengthening of the monsoon along the west coast becomes conspicuous, because in the absence of such systems, the monsoon activity in September is usually weak in Konkan and Coastal Mysore. Another point to be noted in the case of the late monsoon depression is the restricted area of heavy rainfall associated with the disturbance in contrast to the earlier part of the monsoon, when the rainfall in association with the system is spread over a much larger area.

3.3.6 Some of the monsoon depressions weaken by the time they reach East Madhya Pradesh. Though the depression is no longer seen on the surface chart, the associated upper air cyclonic circulation may persist and continue to move west; even in such cases the monsoon may be activated along the west coast.

3.3.7 On very rare occasions a depression or low moving in a westerly direction, emerges into sea area off Gujarat ~~Stata~~ or north Maharashtra coast and active monsoon conditions may prevail in Konkan and Coastal Mysore.

3.4 Upper Air cyclonic circulation over Gujarat, Konkan and neighbourhood

3.4.1 A feeble cyclonic circulation over Gujarat and Konkan and neighbourhood in the mid-troposphere is a common feature during the monsoon season. This circulation is even noticeable in the mean monthly charts. When it becomes well-marked, and extends through a fairly deep layer of the atmosphere, a strengthening of the monsoon takes place along the coast. On such occasions, either a trough or a cyclonic circulation in the lower troposphere is usually noticed off the coast. In some cases, large negative pressure departures may be noticed over the area, even though there may not be a surface isobaric low. As mentioned earlier in para 3.3.1, another depression or low may be simultaneously present over North Bay or Orissa and the two may be embedded in an east-west oriented trough extending from the north Bay to north Arabian Sea across the Peninsula. On such occasions, there is extensive rainfall over the country from Orissa to Konkan. A study of a typical mid-tropospheric low off Gujarat and Konkan with research aircraft data during the IIOE period, has shown it to be one of cold core.

3.4.2 We have seen in para 2.7.2 that the mid-troposphere is a layer of transition between the lower tropospheric westerlies and upper tropospheric easterlies. Hence, winds at these levels over South Gujarat, Konkan and Coastal Mysore are light and unsteady. This feature may sometimes make it difficult for the analyst to identify the mid-tropospheric cyclonic circulations, and in maintaining consistency in his analysis. But, it is a point to be kept in mind that mid-tropospheric circulations causing strong monsoon are generally associated with a circulation/trough through a fairly deep layer extending into the lower troposphere. Further work is required to understand the role of the mid-

troposphere systems over the west coast, and their relationship with lower tropospheric systems.

3.4.3 Satellite pictures on occasions of such cyclonic circulation over Konkan, Gujarat and adjoining Arabian Sea show a well-developed mass of heavy overcast clouding over the area. The cloud system extends westwards over a very large portion of the Arabian Sea (sometimes even almost upto the Arabian coast).

3.5 Cyclonic shear in low level westerlies

3.5.1 Even without any of the synoptic situations discussed in the Sections 3.2 to 3.4 being present, we often notice on a few occasions a pronounced cyclonic shear in lower tropospheric westerlies along the coast, with weak winds to the north and strong westerlies to the south; under such conditions the monsoon strengthens over the limited area of the strong shear zone. Such shear zones usually do not persist for long (say more than 24-48 hrs).

3.6 Strong pressure gradient

3.6.1 In association with the formation and movement of monsoon lows and depressions and when the seasonal trough is well-marked and is slightly to the south of its normal position, there is general strengthening of the monsoon over the country. The pressure gradient in the Arabian Sea and along the west coast increases, and the lower tropospheric westerlies along the west coast also strengthen considerably. On such occasions, even though the rainfall may increase in the coastal areas of Konkan and Coastal Mysore, the monsoon may not be strong or vigorous. But, the increase of rainfall over the Ghats is found to be more significant with heavy to very heavy falls at a number of places. An analysis of the daily rainfall at Mahabaleshwar (representative of the Ghats) and the strength of the westerlies (as represented by westerly component of the wind at 0.9 km over Bombay) is given in Table V.

TABLE - V

Frequency of wind speeds at 0.9 km over Bombay and rainfall (in cm) at Mahabaleshwar 1957-70 (July and August)

Wind speed (Westerly component) (mps)	Rainfall in cms. 0.1 to 3.0	3.1 to 6.0	6.1 to 9.0	9.1 to 12.0	12.1 to 15.0	15.1 to 18.0	18.1 to 21.0	21.1 to 24.0	24.1 to 27.0	27.1 to 30.0	30.1 to 33.0	33.1 to 36.0	36.1 to 39.0
-5.1 to -10.0	1	1	0	0	0	0	0	0	0	0	0	0	0
-0.1 to -5.0	8	2	0	0	0	1	0	0	0	0	0	-	-
0.1 to 5.0	73	18	2	3	2	2	1	0	0	0	0	-	-
5.1 to 10.0	120	75	39	14	7	6	5	0	1	2	0	0	-
10.1 to 15.0	47	72	51	30	19	13	19	0	6	2	2	0	1
15.1 to 20.0	10	23	25	11	18	6	8	0	1	1	1	0	0
20.1 to 25.0	3	8	5	10	2	7	2	0	2	2	0	0	0
25.1 to 30.0	0	2	3	2	3	0	0	0	0	0	0	0	1
30.1 to 35.0	0	0	1	1	0	3	0	0	0	1	0	0	0

The correlation coefficient works out to be 0.41, which suggests a significant association between the wind speed and rainfall.

3.6.2 In departmental weather reports, the monsoon activity for Konkan and Coastal Mysore is based on the rainfall reports of plain stations only, leaving out the hill stations. This classification may not truly reflect the rainfall over the Ghats, because there are occasions when very heavy rains occur over the Ghats, with relatively less rain along the coast, as well as occasions when heavy

rains occur along the coast with less intense rainfall over the Ghats. It is necessary to distinguish the two types of situations to enable the forecaster to issue warnings for heavy rainfall over specified small areas, as for instance, over the catchment areas of rivers or for hydroelectric projects etc. The strength of the westerlies appear to be a good indicator of the intensity of rain over the Ghats, particularly when there is no major synoptic system over the area. However, when major synoptic systems are present over or near the area, the coast as well as the Ghats may be influenced to an equal degree.

3.6.3 While in the case of sub-divisions, such as Orissa, Madhya Pradesh, Rajasthan etc., it was possible to isolate a single synoptic factor responsible for monsoon activity on any particular day, it was not so clear cut in the case of Konkan and Coastal Mysore. Particularly in the case of Konkan, more than one synoptic system was found to be simultaneously present on occasions of active monsoon - such as a mid-tropospheric low and a Bay depression or a trough of low along the coast and Bay depression. Consequently, it was found difficult to prepare any table giving the percentage number of occasions of active or vigorous monsoon with each type of synoptic situation.

3.6.4 To sum up, a low level trough along the coast, mid-tropospheric circulations, Bay depressions or lows are the features responsible for days of active monsoon over Konkan; while over Coastal Mysore, a trough along the west coast is present on occasions of increased monsoon activity.

4. Weak Monsoon Conditions

4.1 Weak monsoon conditions prevail in Konkan and Coastal Mysore when none of the synoptic conditions listed in Section 3 above prevail. During typical "break monsoon" periods, the monsoon is weak along Konkan, though further south in Coastal Mysore, rainfall may occur in association with westward moving low pressure areas across the south Peninsula. Monsoon is also weak along Konkan and Coastal Mysore when the western end of the axis of the monsoon trough is

towards the foot hills of the Himalayas, even though the eastern end may be near its normal position, or even extend into the north Bay of Bengal. Such an orientation in the trough position is more common towards the latter half of the monsoon season.

4.2 When the monsoon is weak along Konkan and Coastal Mysore, the westerly wind regime over the Arabian Sea and Peninsula is usually weak. The depth of westerlies also decreases. The tephigrams of Bombay may show marked drying of air above 850 mb and even an inversion. A pronounced ridge extending from Konkan and Coastal Mysore northwards to East Rajasthan and sometimes even upto West Uttar Pradesh (on surface charts and in the lower tropospheric levels) is another synoptic feature noticed during periods of weak monsoon in Konkan and Coastal Mysore.

4.3 The satellite cloud pictures on weak monsoon days generally show a cellular pattern of stratocumulus or cumulus clouding over the Arabian Sea, without any overcast area. Large masses of heavy overcast areas are characteristic of active monsoon conditions. In the following sections, a few typical cases of active and weak monsoon conditions will be discussed.

5. Typical Synoptic Situations--Trough of low pressure off West Coast

5.1 Trough of low pressure off Coastal Mysore travelling north along the coast - 11 to 17 July 1969

5.1.1 On the morning of 11th, a trough of low pressure appeared off Kerala and Coastal Mysore on the surface chart (Fig. 5.1). This was accompanied by a strengthening of the winds over the Laccadives area in the lower troposphere. The trough could not be seen on the upper wind charts, except as a region of relatively very weak westerlies along Coastal Mysore (Fig. 5.2). Along with the appearance of the trough, there was an increase in rainfall in Coastal Mysore. In the middle troposphere, an east-west oriented trough extended from the West Central Bay to East Central Arabian Sea across the central parts of the Peninsula.

5.1.2 By the next morning (12th), the trough shifted northwards along the coast, when it lay off Coastal Mysore and adjoining south Konkan (Fig. 5.3). Light easterly winds at the surface were reported by one or two stations along Coastal Mysore; due to rain there were no pibal observations along Mysore and the south Maharashtra coast. It was difficult to judge whether the trough extended also in the upper air. The winds over Laccadives continued to be strong with speeds of the order of 35 to 45 knots. At 850 mb, the strong monsoon westerlies were noticed over Arabian Sea Islands, Peninsula and the Bay of Bengal, to the south of 15°N (Fig. 5.4).

5.1.3 With the shift of the trough northwards, the monsoon strengthened in south Konkan; it also strengthened further in Coastal Mysore. Very heavy rainfall occurred in these sub-divisions, the highest amount being 19 cm at Panjim. The evening's 24 hr. pressure change chart showed relatively larger pressure fall over Konkan and Saurashtra-Kutch, which suggested that the trough may shift further north and become more marked.

5.1.4 By the 13th morning, the trough shifted to a position off the Maharashtra coast and was noticeable in the upper air upto 0.9 km (Fig. 5.5). The mid-tropospheric trough across the Peninsula was also well-marked. The maximum pressure changes were off South Konkan coast. The monsoon continued to ~~strengthen~~ be strong in Coastal Mysore and south Konkan and a number of places received heavy rain. It is a point to be noted that while heavy rains extended northwards upto Harnai along the coast, the Ghats had only light rain. Nimbus 3 picture (Orbit 1206) for the 13th also showed heavy clouding along the west coast south of 17°N, and considerably less cloudiness to the north of it (Fig. 5.6). However, the heavy clouding associated with the trough extended westwards to the sea upto 67°E. The evening upper wind charts showed that the system off Konkan extended almost vertically upto the mid-troposphere, being seen as a trough upto 900 m and as a cyclonic circulation above this level, upto 500 mb.

5.1.5 By the 14th morning the trough shifted further north and linked up with a low pressure system over Northwest India and adjoining Gujarat State. However, the cyclonic circulation over Saurashtra and off Konkan continued to be well-marked, extending upto the mid-troposphere (Fig. 5.7). The monsoon continued to be strong in Coastal Mysore and Konkan, the heaviest falls being 20 cm at Mangalore Airport and 17 cm at Ratnagiri. Even on this day, the Ghats had only light to moderate rainfall, the highest amount being only 2 cm.

5.1.6 On the 15th, the trough lay off north Maharashtra coast and over Gujarat State (Fig. 5.8), while at 2.1 km and above, the cyclonic circulation continued well-marked extending to the mid-tropospheric level (Fig. 5.9). The pressure generally rose over the country to the west of 80°E, the pressure rise being relatively more along South Konkan and Coastal Mysore. While the monsoon continued to be strong in Konkan, it became normal in Coastal Mysore. A few heavy falls were reported from south Konkan. As the trough moved northwards, and the westerlies strengthened along the Maharashtra coast, rainfall increased in Konkan (note the strengthening in Bombay winds in the lower troposphere and the increase in pressure gradient along the Maharashtra coast between 14th morning and 15th morning). The satellite picture for the day (Fig. 5.10) showed extensive cloudiness from the Konkan coast westwards to about 60°E. Such extensive heavy masses of cloud over the central and north Arabian Sea have been frequently noticed with mid-tropospheric circulation systems.

5.1.7 The trough weakened by the 16th morning. On the surface chart it was becoming indistinct; but in the lower troposphere (upto 1.5 km) (Fig. 5.11), it was still noticeable. The cyclonic circulation at higher levels was also becoming less marked. There was a large pressure rise over Peninsula as a whole, with a somewhat larger rise along Konkan.

5.1.8 In the lower troposphere, moderate to strong westerlies spread over the whole of the Peninsula (south of 20°N). This may be compared this with the winds

on 12th, when the strong winds were only reported upto 15°N. The pressure gradient along Konkan also continued to be strong (about 6 mb per 5° lat.). As the trough moved northward and weakened, and as the westerlies strengthened, the monsoon activity decreased along the coast and became normal, while over the Ghats the rainfall increased. By the 17th the trough had completely weakened.

5.1.9 The following are the main points to be noted in this case:-

i) The case history discussed in this section shows the formation of a trough off the north Kerala coast, and its slow movement northward upto Gujarat State, carrying the rainfall belt to the north. The 24 hours pressure changes gave a fair indication of the movement, intensification and the final dissipation of the trough

ii) The formation of the trough was accompanied by strengthening of westerlies over the Laccadives. In the early stages while the trough was seen on the surface isobaric chart, it was only noticed as a region of weak winds in the upper air (in the lowest levels). With the strong westerlies to the south, the region of the trough was, therefore, one of strong cyclonic shear. However, as the trough moved north to a position off the Maharashtra coast on 13th, it became noticeable not only on the surface chart but also in the upper winds upto 0.9 km.

iii) Over the region of the sea level trough, a mid-tropospheric trough line/low was also located. After the 13th, the system extended from the sea level upto the mid-troposphere. It could be discerned as a trough at the surface and upto 900 m, and also as a cyclonic circulation upto 500 mb. The weakening of the surface and the mid-tropospheric systems occurred nearly at the same time. This lends support to the inference that the two may be two aspects of one and the same phenomenon.

iv) As the trough moved north along the coast, the westerlies in the latitudes to the south strengthened. When the trough reached Gujarat, the stronger lower tropospheric westerlies covered the entire Peninsula.

v) In the beginning of the period, the axis of the seasonal trough ran from north Rajasthan to the head Bay of Bengal. A cyclonic circulation moved along the trough from Bihar Plateau and East Uttar Pradesh to South Rajasthan and north Gujarat State between the 11th and 14th. The trough of low pressure travelling northwards along the west coast got linked up with the low over Rajasthan and Gujarat State on the 14th.

vi) An interesting aspect of the rainfall distribution in coastal areas of the Konkan and the Ghats in association with the trough is a point to be noted. When the trough was off the Mysore and Maharashtra coasts, the significant rainfall amounts were confined to the coastal areas, but the Ghats section of Maharashtra State had relatively much less rain. However, when the trough moved to Gujarat and a strong pressure gradient set in along the Maharashtra coast, the rainfall decreased along the coast and increased considerably over the Ghats. This aspect should be taken note of when the forecaster has to distinguish between the Ghats and the coastal strip to the west of the Ghats, while issuing forecasts for small areas.

6. Typical Synoptic Situations - Bay Depressions

6.1 Strong monsoon conditions over Konkan caused by a Bay depression moving upto north Gujarat State - 26 to 31 July 1967

6.1.1 During the second half of July 1967, a series of disturbances moved westwards across the central parts of India, which maintained the monsoon activity evenly over the country. In this section we will discuss the case of one of these disturbances, a deep depression, which moved from the Bay of Bengal to north Gujarat State, causing a spell of strong monsoon conditions in the Konkan. Its effect in Coastal Mysore was not much.

6.1.2 On the morning of 25 July 1967, a low pressure area lay over the north Bay of Bengal and concentrated into a depression by the next morning (26 July), with its centre about 50 km south of Sagar Island (Fig. 6.1.1). Simultaneously,

a low pressure area moved westwards from south Rajasthan to the southern parts of Pakistan. Monsoon activity over the country was maintained by these two systems.

6.1.3 It is a common feature during such periods of good monsoon over the country, that (i) the westerly wind regime to the south of the axis of the seasonal trough is strong both at the surface and in the lower troposphere and (ii) the seasonal trough is slightly south of its normal position. On this day (26 July), the lower tropospheric westerlies over the Peninsula were strong, reaching upto 50 kt (Fig. 6.1.2). Ships in the Arabian Sea north of Lat.15°N reported winds of strength varying between 25 knots and 40 knots. The pressure gradient along Konkan and Coastal Mysore was a little more than normal. Though rainfall was widespread along Coastal Mysore and Konkan, it was only of moderate intensity. But, heavy to very heavy rains occurred over the Ghats. ESSA-2 picture showed (Fig. 6.1.3) that while Ghats were covered with heavy clouding, along the west coast and out at sea the cloud cover was much less and mainly of cumuliform type. Strong lower tropospheric westerlies over sea areas, not associated with any perturbation, are found to give rise to cumuliform streets of clouds. The rainfall along the coast and over the Ghats was primarily the result of strong lower tropospheric westerlies, as the zone of convergence associated with the depression was still over Orissa and Madhya Pradesh.

6.1.4 The depression deepened during the course of the day, crossed coast and lay over Orissa on 27th morning centred near Keonjhargarh. The available data showed that the lower tropospheric westerlies over the Peninsula continued to be strong. The upper air circulation associated with the depression extended upto 400 mb and covered Vidarbha on the western side. Above 700 mb, even Bombay winds were under the influence of the depression and they veered during the previous 24 hrs from west to northwest/north.

6.1.5 Rainfall continued to be widespread along Coastal Mysore and Konkan; the amounts also increased in Konkan where rainfall upto 6 cm was recorded along

the coast; very heavy falls of the order of 25 to 30 cm were recorded over the Ghats. There was an extensive rainbelt over a large part of the country, from Bihar Plateau, Gangetic West Bengal and Orissa in the east to Gujarat State, Konkan and Coastal Mysore in the west. The 24 hr. pressure changes and the deep easterly current (which extended upto Rajasthan even in the lower troposphere) suggested a continued westward movement of the depression. The deep depression moved in an almost westerly direction and reached the central parts of Madhya Pradesh on 28 morning (Fig. 6.1.4) when it was centred near Chhindwara. Its intensity was almost the same as in the previous day, though the depression had been moving over land. The cyclonic circulation associated with the deep depression was well-marked and extended upto 400 mb level, with a slight southwestward tilt with height towards the cold air (particularly above 700 mb), as inferred from the changes in the winds over Nagpur (Fig. 6.1.5). By this time, Konkan and Coastal Mysore came well within the depression field and the zone of convergence in the lower troposphere between northerlies and westerlies was over West Madhya Pradesh, South Gujarat State and the adjoining north Konkan. The lower tropospheric westerlies over the Peninsula continued to be strong, reaching upto 45 knots in strength.

6.1.6 As the depression approached, rainfall further increased along the Konkan coast and the monsoon became strong there on the 28th. A number of stations reported heavy rain, the highest being 11 cm. Over the Ghats rainfall of the order of 20-30 cm continued. Compared to the previous day, the rainfall increase was mostly along the coast. The heavy falls were just to the south of the lower tropospheric convergence zone (referred to already). The 1200Z 24 hr. pressure changes gave an indication that the depression may take a more northwesterly track.

6.1.7 By the 29 morning the deep depression weakened into a depression and lay over extreme northwest Madhya Pradesh, and adjoining Rajasthan and Gujarat

Region (Fig. 6.1.6). The pressure gradient along the Konkan coast increased considerably. Between Surat and Karwar over a distance of 6° lat, the pressure difference was 10 mb (i.e.) nearly 2 mb per degree, which is quite high. Ships in the Arabian Sea (between 15°N and 20°N) reported wind speeds reaching upto 35/40 knots. Though the depression weakened, the associated cyclonic circulation in the upper air extended upto 300 mb (Fig. 6.1.7). Apparently the lower tropospheric zone of convergence had moved northwestwards to north Gujarat state (although due to lack of upper wind data from Konkan and Gujarat state, it is difficult to locate the zone definitely). The lower tropospheric westerlies over the Peninsula continued strong reaching upto 50 knots. Pressure changes suggested further northwestward movement of the depression.

6.1.8 The rainfall increased still further over Konkan. North Konkan had vigorous monsoon conditions, with Bombay (Colaba) recording 18 cm and Santacruz 20 cm. Over the Ghats very heavy falls of the order of 40/45 cm were recorded.

6.1.9 By 30th the depression moved further northwest, weakened and merged into seasonal low. As the depression moved away and pressures rose heavily over Maharashtra and Gujarat states, rainfall considerably decreased in Konkan. A fresh low was forming over northeast Bay and the lower tropospheric winds over the Peninsula continued to be strong. Although rainfall decreased in the coastal belt, it continued to be heavy to very heavy over the Ghats, because of the persistence of strong westerlies striking the Ghats almost at right angles. On 31st, there was still further decrease of the rainfall in Konkan including the Ghats.

6.1.10 The main points brought out by this case history are:-

i) When a depression forms over the Bay of Bengal, there is general strengthening of the lower tropospheric westerlies over the Peninsula, with speeds usually of the order of 30-40 knots and reaching upto 50 knots occasionally. Over Arabian Sea, particularly north of Lat. 15°N, winds strengthen, with

ships reporting speeds of the order 30-40 knots. The pressure gradient along Konkan and Coastal Mysore becomes considerably more than normal.

ii) At this stage, the lower tropospheric zone of convergence associated with the depression is over Orissa and/or Madhya Pradesh; it is far away from the west coast. However, there is an increase in rainfall along the west coast, particularly between 15°N and 20°N. The rainfall is usually fairly well distributed, though there may not be many heavy falls. However, over the Ghats, where strong westerlies blow almost perpendicular to the Ghats, rainfall is heavy to very heavy. On such occasions, it becomes necessary to distinguish between the coast and the Ghats, particularly while issuing heavy rainfall warnings for specified areas.

iii) The results of the International Indian Ocean Expedition (1965) lend support to the view that the increase in rainfall along the Konkan coast may be due to the presence of a tongue of warm sea water just off the coast. When stronger winds from a cold area to the west, pass across the warm sea surface, it leads to development of clouds and precipitation.

iv) When the depression arrived over the central parts of Madhya Pradesh, the lower tropospheric convergence zone directly affected Konkan, and the rainfall increased considerably along the coast. Rainfall upto about 20 cm was recorded along the coast, while over the Ghats the rainfall was of the order of 40 cm. The heavier falls were mostly in the northern parts of Konkan (both along the coast and over the Ghats), probably because of their close proximity to the depression field.

v) Though there was widespread rainfall in Coastal Mysore, the falls were generally light to moderate. The heavy falls in this sub-division on 30-31st was not due to the depression, but due to a feeble trough off Coastal Mysore.

vi) As the depression moved towards northwest and weakened, monsoon activity along the Konkan decreased. However, heavy rains persisted over the Ghats due to the strong westerly wind field in the lower troposphere.

vii) This case has brought out the necessity of predicting correctly the future motion and intensity of the disturbance, because the forecasting of heavy rainfall depends to a considerable extent on this factor. Depressions, which take a more northwesterly/northerly track before reaching West Madhya Pradesh, may not cause such spells of heavy rain over Konkan. In this case the 24 hr. pressure changes and the wind field in the lower and mid-troposphere provided useful indications of the future movement of the depression.

viii) In these synoptic conditions, strong winds, squalls and rough to high seas are to be expected over the Arabian Sea and coastal areas of Konkan and Coastal Mysore. During this spell, Colaba reported squalls from westerly to northwesterly direction when wind speeds reached between 60 and 80 kmph. (30 to 40 knots). The wind speeds reported by coastal stations are usually quite unrepresentative of the strong winds out at sea. During this period ships at sea in the Arabian Sea north of 15°N reported waves of height 3 to 3.5 m, the height oocasionally reaching upto 4.5 m.

6.2 Depression moving westnorthwestwards across north Peninsula causing increased monsoon activity in Konkan and Coastal Mysore - 8 to 11 September 1962

6.2.1 During September, monsoon depressions form over the Bay of Bengal at a lower latitude than in July or August, and they usually strike the south Orissa or the north Andhra coast. Though a large percentage of depressions in the late monsoon season tend to take a more northerly track and recurve, occasionally they travel in a west-northwesterly direction across the northern parts of the Peninsula and may even emerge into the Arabian Sea off the Maharashtra coast, causing a spell of strong to vigorous monsoon in Konkan and Coastal Mysore. But such cases occur only occasionally. In this section we will discuss a case of this type.

6.2.2 A depression which formed over West Central Bay of Bengal was centred near Lat. 16.5°N Long. 85.5°E on the morning of 8th September 1962 (Fig. 6.2.1).

The seasonal monsoon trough was in a more southerly position than normal and lay across Vidarbha, West Madhya Pradesh and southeast Rajasthan i.e. fairly north of Konkan. A sea level trough was also present off Coastal Mysore. The lower tropospheric winds were light over Konkan and a ridge prevailed below 2.1 km over Konkan. Above this level dry northeast/easterlies prevailed. (Fig. 6.2.2). Moderate to strong deep westerlies were confined to Kerala and adjoining Coastal Mysore. The monsoon activity along the coast was limited to south of Lat. 15°N To the north, there was only very light rainfall.

6.2.3 The depression moved westnorthwestwards and was over coastal Andhra Pradesh on the 9th morning, centred about 70 km east of Khammam (Fig. 6.2.3). The axis of the seasonal trough moved further south and its western half was over north Maharashtra and Gujarat States. With the approach of the depression and the southward movement of the seasonal monsoon trough, there was an increase in monsoon activity in Konkan and Coastal Mysore. The 24 hr. pressure changes on 9th morning and evening suggested a westnorthwestward movement of the depression. This was a good indication to anticipate further increase in rainfall in Konkan.

6.2.4 Moving rapidly northwestwards, the depression came over north Maharashtra coast on 10th morning and was centred near Dahanu (Fig. 6.2.4). The associated cyclonic circulation extended upto about 300 mb (Fig. 6.2.5). The westerlies in the lower troposphere along Konkan strengthened and they also became deeper. With the movement of the depression to Konkan, the rainfall considerably increased along the coast as well as over the Ghats. The monsoon became vigorous in Konkan while it was normal in Coastal Mysore.

6.2.5 On 11th the depression moved further northwest to Saurashtra coast and in the rear of the depression, pressures rose heavily in Konkan and Coastal Mysore. As the depression moved away, the winds along Konkan backed and also weakened. With the moving away of the depression and the weakening of the westerlies, rainfall considerably decreased in Konkan and Coastal Mysore; it became normal in

Konkan and weak in Coastal Mysore.

6.2.6 In this sequence we may note the following points:-

i) The depression formed at a relatively low latitude and moved across north Peninsula. Travelling across Konkan it moved further northwest to the Saurashtra Coast. The 24 hr. pressure changes on 9th provided good indication of the movement of the system towards Konkan.

ii) On 8th the westerlies along Konkan were weak and a ridge type pattern prevailed; the monsoon was weak in Konkan. The approach of the depression was accompanied by strengthening and deepning of the lower tropospheric westerlies. As the depression approached and the wind pattern changed along the west coast, the rainfall increased in Konkan and Coastal Mysore. On 9th it was normal in Konkan and strong in Coastal Mysore. By 10th when the depression passed across the sub-division, monsoon became vigorous in Konkan. As the depression moved away the rainfall also rapidly decreased in these sub-divisions.

7. Typical Synoptic Situations - Mid-Tropospheric Cyclonic Circulation

7.1 Movement of an upper air cyclonic circulation westwards across Maharashtra State causing Strong to Vigorous monsoon in Konkan - 11 to 19 June 1970

7.1.1 In this Section, we shall discuss an instance of strong to vigorous monsoon activity in Konkan, caused by the movement of an upper air cyclonic circulation westwards across West Madhya Pradesh and north Maharashtra State. The effect was very pronounced over Konkan, but was only marginal in Coastal Mysore. The upper air cyclonic circulation was the remnant of a monsoon depression which filled up over East Vidarbha and adjoining East Madhya Pradesh. The rain spell in Konkan was prolonged on account of the cyclonic circulation. It was linked up with a westerly trough in the north whose extreme southern portions moved across Rajasthan and West Uttar Pradesh.

7.1.2 A deep depression from the Bay of Bengal moving in an almost westerly direction reached southeast Madhya Pradesh and the adjoining east Vidarbha on 11th morning as a depression (Fig. 7.1). The associated cyclonic circulation extended upto 400 mb level (Fig. 7.2). On the surface and in the lower troposphere, a feeble ridge lay from Konkan to Gujarat State. The lower tropospheric winds along Konkan were also light. The rainfall associated with the depression extended westwards over the whole of Vidarbha (upto 76°E in the west). Along Konkan and Coastal Mysore, monsoon was generally weak.

7.1.3 During the next 24 hrs., the depression moved slightly westwards and also weakened into a low pressure area. However, the associated cyclonic circulation continued to be marked, extending upto 300 mb and sloping southwestwards (towards Konkan) with height. The upper air temperatures over Bombay were colder, compared to Nagpur (Fig. 7.3). The lower tropospheric winds over Konkan, became a little stronger (on 12th) compared to the previous day. On account of the cyclonic circulation extending upto Konkan in the middle troposphere, the monsoon strengthened and became vigorous in Konkan and normal in Coastal Mysore, although the depression was weakening in the surface. A few heavy to very heavy falls occurred in Coastal Mysore and south Konkan - the heaviest amount being 14 cm at Devgad. In so far as Konkan and Coastal Mysore are concerned, the significant changes in the past 48 hrs appear to have been mainly in the middle tropospheric levels, where the cyclonic circulation associated with the weakening depression was approaching the west coast.

7.1.4 On the 13th, there were no significant features on the surface chart over Madhya Pradesh and Vidarbha, except the monsoon trough. However, the upper air cyclonic circulation persisted and it was over north Maharashtra state and West Madhya Pradesh between 4.5 km and 7.2 km, centred between Bombay and Nagpur (Fig. 7.4). The major area of rainfall on this day was also over Maharashtra state and neighbourhood. The monsoon continued vigorous in Konkan

and normal in Coastal Mysore. A few heavy to very heavy falls were also reported from Konkan.

7.1.5 On 14th, the upper air circulation moved slightly westnorthwestwards, particularly below 3.6 km and lay over north Maharashtra state, West Madhya Pradesh and adjoining areas, extending upto 400 mb, with a slight southwesterly slope with height (towards the cold air side) (Fig. 7.5). The monsoon continued to be vigorous in Konkan and heavy to very heavy rain was reported from a number of stations. Along the coast, the heaviest fall was 15 cm and over Ghats it reached upto 22 cm. At this stage an upper westerly trough approached northwest India; it extended from Russian Turkistan to northwest Rajasthan (Fig. 7.6). The upper air cyclonic circulation over West Madhya Pradesh and north Maharashtra state was getting linked with the upper westerly trough.

7.1.6 The upper air cyclonic circulation persisted nearly over the same area on the 15th also, but it extended only upto 500 mb, with a southwestward slope towards Konkan (towards the cold air side) (Fig. 7.7). The upper portion of the system (i.e. above 500 mb) appears to have moved westwards into the Arabian Sea. The westerly trough further north moved a little eastwards and was extending upto northeast Rajasthan and adjoining Punjab. The monsoon was strong in Konkan and Coastal Mysore on this day. The increase in rainfall in Coastal Mysore was probably due to the appearance of a feeble trough off the sub-division on the surface.

7.1.7 By 16th, under the influence of the westerly trough, the cyclonic circulation in the lower troposphere moved to the northern parts of Madhya Pradesh and the adjoining Uttar Pradesh and was weakening (Fig. 7.8). However, monsoon continued strong on this day also over Konkan, presumably because the circulation was still affecting the area in the mid-troposphere.

7.1.8 By 17th the cyclonic circulation moved further northeast and merged into the westerly trough system and the trough system extended from the central

parts of Uttar Pradesh to off Konkan at least upto 4.5 km (Fig. 7.9). Under its influence a sea level trough also developed off Maharashtra and Mysore coasts (Fig. 7.10). This development along and off Konkan at the surface and in the lower levels led to a sudden increase in the monsoon activity over Konkan, where it became vigorous. There was fairly widespread heavy to very heavy rain in Konkan - the heaviest fall being (29 cm) at Colaba. The monsoon was also strong along Coastal Mysore due to the continued presence of the low level trough (surface and 0.3 km) off the coast.

7.1.9 During the course of the next two days, the upper air system along Konkan weakened and monsoon activity also progressively decreased.

7.1.10 The following are the main points brought out by this case study:-

i) Although a depression developed over the head Bay of Bengal and moved across Orissa and East Madhya Pradesh, the monsoon was only weak in Konkan on 11th. One of the reasons appears to be the weak lower tropospheric winds over Konkan, as well as the ridge pattern over the area in the lowest levels.

ii) The sudden increase in monsoon activity in Konkan on 12th was associated with the westward movement of the upper air cyclonic circulation towards West Madhya Pradesh and north Maharashtra state where it persisted for the next few days. This stagnation was presumably due to the effect of a westerly trough over northwest India (discussed in the next para). The monsoon activity continued over Konkan for nearly a week.

iii) By 14th, a trough in mid-latitude westerlies (in the mid- and upper troposphere) came over northwest India. Under the influence of this trough, the upper air circulation in the lower troposphere levels over south Madhya Pradesh and Vidarbha moved in a northeasterly direction to Uttar Pradesh weakened and merged into the trough. On 17th, a trough extended from central parts of Uttar Pradesh to off Maharashtra coast from 0.3 km upwards at

least upto 4.5 km. Under its influence a sea level trough was also induced off Maharashtra coast. These developments led to increased rainfall in Konkan on 17th, when monsoon became once again vigorous.

iv) The time-section for Bombay (Fig. 7.11) suggests that the upper portion of the system moved away westwards across Konkan by 15th. Below 500 mb, the circulation moved in a northeasterly direction towards Uttar Pradesh.

v) It has been pointed out in the discussions of monsoon in Gujarat and Rajasthan (FMU Rep. Nos. III-3.1 and III-3.3) how troughs in mid-latitude westerlies extending into Northwest India affect the weather in these sub-divisions. From what has been discussed in this section, we notice that their effect occasionally extends even further south, as far as Maharashtra state.

8. Typical Synoptic Situation: Steep Pressure Gradient

8.1 Steep pressure gradient over Konkan and rainfall over Ghats - 18 to 22 July 1969

8.1.1 It is well known that due to the effect of orography, rainfall over the Ghats is usually heavier than the rainfall in the coastal areas of Konkan. Wind speed, direction of the wind in relation to the mountain range, as well as the stability and humidity of the air mass are some of the conditions which determine the intensity of the orographic rainfall. As has been already mentioned in para 3.6.1, the strength of the westerly component of the lower tropospheric winds over Konkan is related to the rainfall over the Ghats. When strong westerlies strike the Ghats almost in a perpendicular direction, the contrast in rainfall between the Ghats and the coastal strip becomes very marked, the rainfall over the Ghats being heavy to very heavy while it is only light to moderate along the coast. On such occasions, we find a steepening of the pressure gradient on the sea level chart along Maharashtra coast as well as a general strengthening of the lower tropospheric westerlies over the area. Such strengthening of the monsoon current along Maharashtra coast is usually associated

with the formation of a depression or low over the north Bay of Bengal and its movement in a westerly direction. Steep pressure gradient and strong lower tropospheric westerlies may be also present along Maharashtra coast, with a well-marked low or depression over Gujarat state and the adjoining sea areas. However, when the depression or low is close to Konkan (i.e. to north Maharashtra state and neighbourhood) rainfall may become heavy in the coastal area as well.

8.1.2 In this section we will examine a spell of very heavy rains over the Ghats (between 18th and 22nd July 1969) in association with a fairly steep pressure gradient along the coast, and strong lower tropospheric westerlies. In the beginning of the third week of July 1969, the axis of the seasonal trough was slightly to the north of its normal position. With the formation of two low pressure areas in the trough and their movement westwards, the axis shifted well to the south. The first low pressure area moved from the central parts of Uttar Pradesh to northeast Arabian Sea between 18th and 23rd, and the other one moved from Bangla Desh to Bihar and adjoining Madhya Pradesh. The passage of these two disturbances maintained the monsoon westerlies to the south of the seasonal monsoon trough strong. The pressure gradient along Maharashtra coast rapidly increased between 14th and 16th July and continued to be steep for the next one week, when the pressure difference between Panjim and Dahanu (separated by about 5° of lat.) was of the order of 6 mb.

8.1.3. On the morning of 18th, the axis of the seasonal monsoon trough extended from Haryana and Himachal Pradesh to Bangla Desh (at 0.9 km asl) (Fig. 8.1), with a feeble low over central Uttar Pradesh (Fig. 8.2). The pressure gradient to the south of the axis of the trough was strong. The main rainfall belt over the country was to the north of Lat. 20°N, associated with the seasonal trough and the vortices embedded in it. Along the west coast, rainfall was only light to moderate. However, over the Ghats (off the Konkan area) heavy to very heavy rains ranging from 10 and 20 cm were reported from many stations. The satellite (Nimbus) picture for the day shows mostly cumuliform cellular type of

clouds along West coast and out in the Arabian Sea, except for a small area of heavy clouding over north Konkan (Fig. 8.3). This is in contrast to the heavy overcast areas (with tops of clouds shearing towards west) over extensive area along coast and in the sea noticed during active monsoon days.

8.1.4 During the next 4 days (19 to 22 July 1969) the axis of the seasonal trough moved well to the south of its normal position. On 21st and 22nd it passed from northwest Bay of Bengal to north Gujarat state across north Madhya Pradesh at the surface and in the lower tropospheric levels. Over Konkan, the pressure gradient was strong and the lower tropospheric westerlies also remained strong. As a result, the Ghats received heavy to very heavy rains, many stations reporting rainfall of the order of 15-20 cm, while the monsoon was only weak to normal in the coastal areas, with generally light to moderate rain.

8.1.5 The lower tropospheric wind field along Maharashtra coast on 22nd morning is interesting (Fig. 8.4). There was a cyclonic circulation over Gujarat state. To the south of this, we find considerable cyclonic shear over north Konkan (between Surat and Bombay), due to variations in wind speed. The following winds were reported by Surat and Bombay:-

	0.3 km	0.6 km
Surat	230/ 4 K	245/ 6 K
Bombay	222/34 K	231/36 K

This works out to a variation of about 30 knots across two degree of latitude. There was also anticyclonic shear to the south of Bombay (though it was not so pronounced as the cyclonic shear to the north of Bombay). We note the rainfall along the coast was higher (6 cm) to the north of Bombay than to the south (1 cm). However, over the Ghats, the rainfall was heavy to very heavy (Fig. 8.5).

8.1.6 During this period, when the pressure gradient and the lower tropospheric wind field were strong along Maharashtra coast, Bombay reported squalls reaching to about 65-80 kmph, on three occasions.

8.1.7 The main features to be noted in the sequence are:-

i) The passage of two low pressure areas in succession from east to west across the country, and a more southerly position of the seasonal monsoon trough maintained the strong pressure gradient along Maharashtra-Gujarat coast. The lower tropospheric westerlies over the Peninsula were also strong, with speeds of the order 40-50 knots.

ii) The strong westerlies striking the Ghats almost at right angles gave copious rainfall over the Ghats, while along Konkan coast the rainfall was generally light to moderate and the monsoon activity weak to normal.

iii) There are occasions when Konkan coast gets heavy to very heavy rains, while the rainfall over Ghats is not very high in comparison. The presence of low pressure systems such as a trough of low off the Maharashtra coast, with the lower tropospheric winds along the coast not having any large westerly component, leads to such a distribution of rainfall. For instance, between 13 and 15 July 1969 (refer to paras 5.1.4 to 5.1.6), a trough of low pressure lay off Maharashtra coast and the lower tropospheric wind field along the coast was light to moderate southerlies/southwesterlies. In the absence of strong westerly component of the winds, the Ghats had only light to moderate rainfall, while along the coast rainfall was more, with a few heavy to very-heavy falls in South Konkan. Fig. 8.6 shows two contrasting cases -

a) with strong westerlies and heavy rains over Ghats and light to moderate rain in the coastal strip and

b) with weak westerlies associated with a trough off Konkan coast and heavy rains along coastal strip and only light to moderate rain over the Ghats.

iv) Wind speed, wind direction in relation to the mountain range as well as stability and the humidity of the airmass are some of the conditions which determine the intensity of the orographic rainfall. Taking into account these parameters as well as the general synoptic situations, it may be

possible to distinguish between the Ghats and the coastal areas in the matter of the intensity of rainfall.

9. Weak Monsoon - Typical Situations

9.1 A ridge of high pressure along the west coast of the Peninsula causing weak monsoon in Konkan and Coastal Mysore - 14 to 16 August 1964

9.1.1 It is well known that a trough of low pressure off the west coast in the surface and in the lower tropospheric levels is associated with active monsoon conditions along the coast. On the other hand, a ridge of high pressure along and off the coast is usually associated with weak monsoon conditions. Sometimes the ridge may extend from southeast Arabian Sea, in a northnortheasterly direction upto Gujarat State and sometimes even upto Rajasthan. A ridge pattern extending northnortheastwards across Rajasthan, Punjab, Haryana would also imply the shift of the western half of monsoon trough towards Himalayas. A synoptic situation of this type viz. ridge from southeast Arabian Sea to Rajasthan, prevailed between 14th and 16th August, 1964, when monsoon was weak in Konkan and Coastal Mysore.

9.1.2 On the evening of 14th August 1964, a well-marked ridge of high pressure extended from southeast Arabian Sea to southeast Rajasthan and pressures were generally rising over this area, indicating that the ridge was intensifying (Fig.9.1.1). Pressure was also above normal over this area. In the lower troposphere also, the ridge pattern could be noticed from southeast Arabian Sea to East Rajasthan, with a northwesterly to northerly flow over the Peninsula; the winds along the west coast south of Ratnagiri were northwesterlies/northerlies (Fig.9.1.2). This resulted in weak monsoon conditions in Gujarat State and all along west coast on the next morning (15th).

9.1.3 Similar conditions prevailed on the 15th also. Ships observations on the 15th evening chart showed that the ridge was persisting from southeast Arabian Sea to Gujarat Region (Fig.9.1.3). In the lower troposphere also the

ridge was present, though it was slightly less marked than on the previous day. The monsoon continued weak along the west coast.

9.1.4 I.I.O.E. Research Aircraft on flight from Bombay due southwestwards to Lat. 16°N 68°E, (flying at 4000-5000 ft.) reported southwesterly winds, confirming the presence of the ridge off Konkan coast (Fig.9.1.4(a) The relative humidity reported was also low (about 50%). The drop-sonde at 14.8°N and 65.9°E taken by this flight showing the dryness of the air above 900 mb is also given in Fig.9.1.4(b) However, during the course of the two days (16 and 17th) the ridge pattern gradually weakened giving place to moderate to strong westerly flow over the north Peninsula in the lower troposphere and the spell of weak monsoon in Konkan and Coastal Mysore was also broken.

9.1.5 The synoptic situation on 14th and 15th August is in contrast to the case of a trough of low pressure off Konkan discussed in Sec. 5.1. It is a point to be noted that in the present case (14 and 15 August 1964) even though a depression formed over the north Bay of Bengal and moved into north Orissa during the period, still the monsoon did not strengthen in Konkan on account of the presence of the ridge from southeast Arabian Sea to Rajasthan. Another point is that while a trough of low pressure off the west coast is usually seen in the surface and the upper air, at best upto about 1.0 km, the ridge in the present case was noticed on the surface as well as in the upper air upto about 3 km.

9.2 Typical "Break" with a low pressure area moving westwards across south Peninsula

9.2.1 During the second half of August 1969, the western end of the axis of the seasonal trough was to the north of its normal position, being located close to the foot of the Himalayas on many days. In this period, the monsoon activity was generally much below normal in Coastal Mysore and Konkan.

9.2.2 During the 'Break' monsoon period, sometimes low pressure areas travel from east to west across the Peninsula. Although they cause good rainfall

activity in the south Peninsula, further north, particularly along Konkan - Coastal Mysore, the monsoon is usually weak. The low pressure area may emerge into East Arabian Sea off the Kerala coast, and move further in a northerly direction along the west coast, reviving the monsoon there.

9.2.3 During the 'break' in second half of August,1969 three low pressure systems moved westwards across south Peninsula. In this section, we will discuss a day's (25 August 1969) weather when one of the three disturbances was moving across south Peninsula, which resulted in large changes in the monsoon circulation pattern over Konkan and Coastal Mysore.

9.2.4 On the morning of 25th August 1969, a well-marked low pressure area travelling westwards across the south Peninsula emerged into the Arabian Sea off Coastal Mysore and north Kerala (Fig.9.2.1). The associated upper air cyclonic circulation was well-marked, extending upto 500 mb (Fig.9.2.2). As a result, the seasonal wind pattern in the Peninsula in the lower troposphere completely changed north of Lat. 12°N, where the normal westerlies were replaced by easterlies to southeasterlies. This change in the wind pattern resulted in almost dry weather over Konkan and Coastal Mysore, though over the north Peninsula to the east of the Ghats, there was good rainfall particularly in North Interior Mysore and Maharashtra state. Thunderstorms were reported along Konkan and Coastal Mysore as well as in the interior of north Peninsula to the east of Ghats (Fig.9.2.3). The penetration of the southeasterlies in the lower troposphere, over the north Peninsula and the rainfall pattern were more akin to a pre-monsoon situation.

9.2.5 The main points to be noted in the charts for 25th August are:

i) An almost complete reversal in the wind pattern over the north Peninsula in the lower troposphere

ii) Practically dry weather in Konkan and Coastal Mysore with rainfall activity to the east of the Ghats

iii) Thunderstorm activity in Konkan and Coastal Mysore which is very uncommon during monsoon period over these sub-divisions.

10. Conclusions

10.1 Konkan and Coastal Mysore receive nearly 90% of the annual rainfall during the southwest monsoon season; July is the rainiest month. Heavy to very heavy rainfall is a feature of the monsoon in these sub-divisions, and such falls are more frequent during the first half of the monsoon season. Similarly, strong to vigorous monsoon ~~conditions~~ is also more frequent in the first half of the monsoon season decreasing considerably during the latter half.

10.2 Orography plays a very prominent role in enhancing the rainfall over the Ghats. There is high association between intensity of rainfall over the Ghats and the strength of the lower tropospheric westerlies along the coast. Sometimes, it is possible to distinguish synoptic situations under which Ghats alone get heavy rainfall without coastal stations having heavy rains and vice-versa.

10.3 Thunderstorms are small in number during the monsoon in Konkan and Coastal Mysore except at the time of the advance of the monsoon. However, squalls are common, being more frequent at the height of the monsoon season.

10.4 The low level jet in the monsoon westerlies and the tropical easterly jet in the upper troposphere are two distinguishing features of the upper air circulation over the Peninsula during the southwest monsoon season. The core of the low level jet usually lies in the latitudinal belt of Coastal Mysore. The core is at about 1.5 km and the core speeds reach 40 to 60 knots. The core of the high level easterly jet is near about the latitude of Trivandrum, at a height of 14.5 to 15 km and has a strength of 80-85 knots sometimes a secondary jet also develops in the latitudes of Konkan.

10.5 The main synoptic systems that are associated with active monsoon over Konkan and Coastal Mysore are:

i) Trough of low pressure off the coast,

ii) Formation of a low or a depression over the Bay of Bengal and its movement in a westerly direction across the country, and

iii) The upper air cyclonic circulation over the Konkan and Gujarat.

Of these the trough of low pressure is the most common. More than one synoptic system is simultaneously noticed on active monsoon days over Konkan and Coastal Mysore.

10.6 The formation and movement of a depression or a low pressure area from the Bay causes an increase of monsoon activity over Konkan. Rainfall is generally heavy or very heavy mainly over the Ghats. However, when the depression is close to Konkan or if the circulation or discontinuity associated with the depression extends to Konkan, the rainfall is heavy along the coast as well as over Ghats. The depressions and the low pressure areas that move in a north-westerly/northerly track do not generally cause a strengthening of the monsoon in Konkan.

10.7 The upper air cyclonic circulation over Konkan, Gujarat and adjoining areas is found to be associated with an active monsoon, when the circulation extends through a fairly deep layer of the lower and mid-troposphere, and not merely present at one or two levels. A trough of low pressure off the coast is also noticed on the surface chart, when the upper air circulation is well-marked.

10.8 Weak monsoon conditions are associated with

i) shift of the western half of the monsoon trough to the foot hills of the Himalayas

ii) development of a ridge along and off Konkan and coastal Mysore, extending northeastwards. Westerlies are generally weak during weak monsoon and their depth may also decrease.

ACKNOWLEDGEMENT:

The authors wish to record their gratitude and thanks to Dr. P.K. Das, Deputy Director General of Observatories (Forecasting), for going through the article and giving many helpful suggestions.

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APPENDIX - I

Date of Onset of Monsoon over Bombay (1879-1971)

Year	Date	Year	Date	Year	Date
1879	24 May	1910	4 June	1941	5 June
1880	23 June	1911	5 June	1942	13 June
1881	6 June	1912	13 June	1943	8 June
1882	10 June	1913	8 June	1944	12 June
1883	3 June	1914	13 June	1945	7 June
1884	13 June	1915	17 June	1946	8 June
1885	11 June	1916	1 June	1947	10 June
1886	16 June	1917	4 June	1948	13 June
1887	5 June	1918	24 May	1949	31 May
1888	5 June	1919	6 June	1950	10 June
1889	6 June	1920	7 June	1951	12 June
1890	1 June	1921	9 June	1952	6 June
1891	20 June	1922	1 June	1953	13 June
1892	5 June	1923	12 June	1954	7 June
1893	28 May	1924	12 June	1955	11 June
1894	6 June	1925	28 May	1956	29 May
1895	11 June	1926	10 June	1957	21 June
1896	2 June	1927	11 June	1958	19 June
1897	6 June	1928	9 June	1959	25 June
1898	8 June	1929	2 June	1960	12 June
1899	9 June	1930	9 June	1961	10 June
1900	23 June	1931	13 June	1962	29 May
1901	6 June	1932	16 June	1963	6 June
1902	10 June	1933	1 June	1964	12 June
1903	12 June	1934	13 June	1965	15 June
1904	7 June	1935	13 June	1966	12 June
1905	25 June	1936	4 June	1967	15 June
1906	6 June	1937	12 June	1968	14 June
1907	11 June	1938	2 June	1969	5 June
1908	12 June	1939	9 June	1970	2 June
1909	8 June	1940	17 June	1971	29 May

APPENDIX - II

Specifications for the strength of Monsoon over land areas
(Taken from DDGF's Technical Circular No. 23)

Descriptive term	Specifications
Weak Monsoon	Rainfall less than half the normal
Normal Monsoon	Rainfall half to less than $1\frac{1}{2}$ times the normal (mention of 'normal monsoon' may not generally be necessary).
Active/strong Monsoon	Rainfall $1\frac{1}{2}$ to 4 times the normal (with a minimum rainfall of 5 cm along the west coast and 3 cm elsewhere).
Vigorous Monsoon	Rainfall more than 4 times the normal (with minimum rainfall of 8 cm along the west coast and 5 cm elsewhere).

Note: The minimum limit of rain prescribed for "Active/Strong" and "Vigorous" monsoon should be recorded at least at two neighbouring IMD Stations.

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DIAGRAMS

FIG. 2·1 ACTUAL DATES OF ONSET OF SOUTHWEST MONSOON OVER BOMBAY (1879-1971)

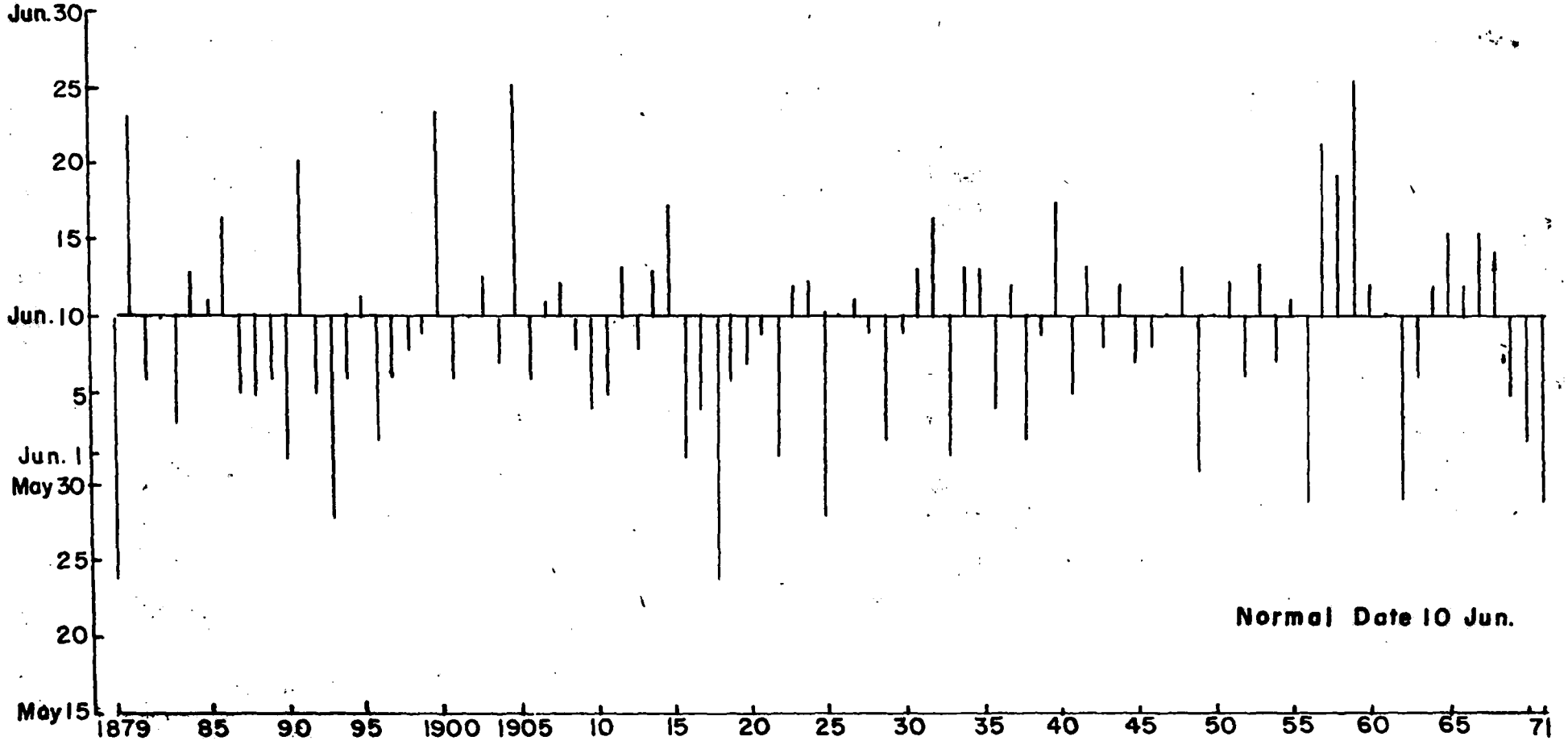


FIG. 2·2 MONTHLY MEAN RAINFALL-(cm)-Konkan & Coastal Mysore

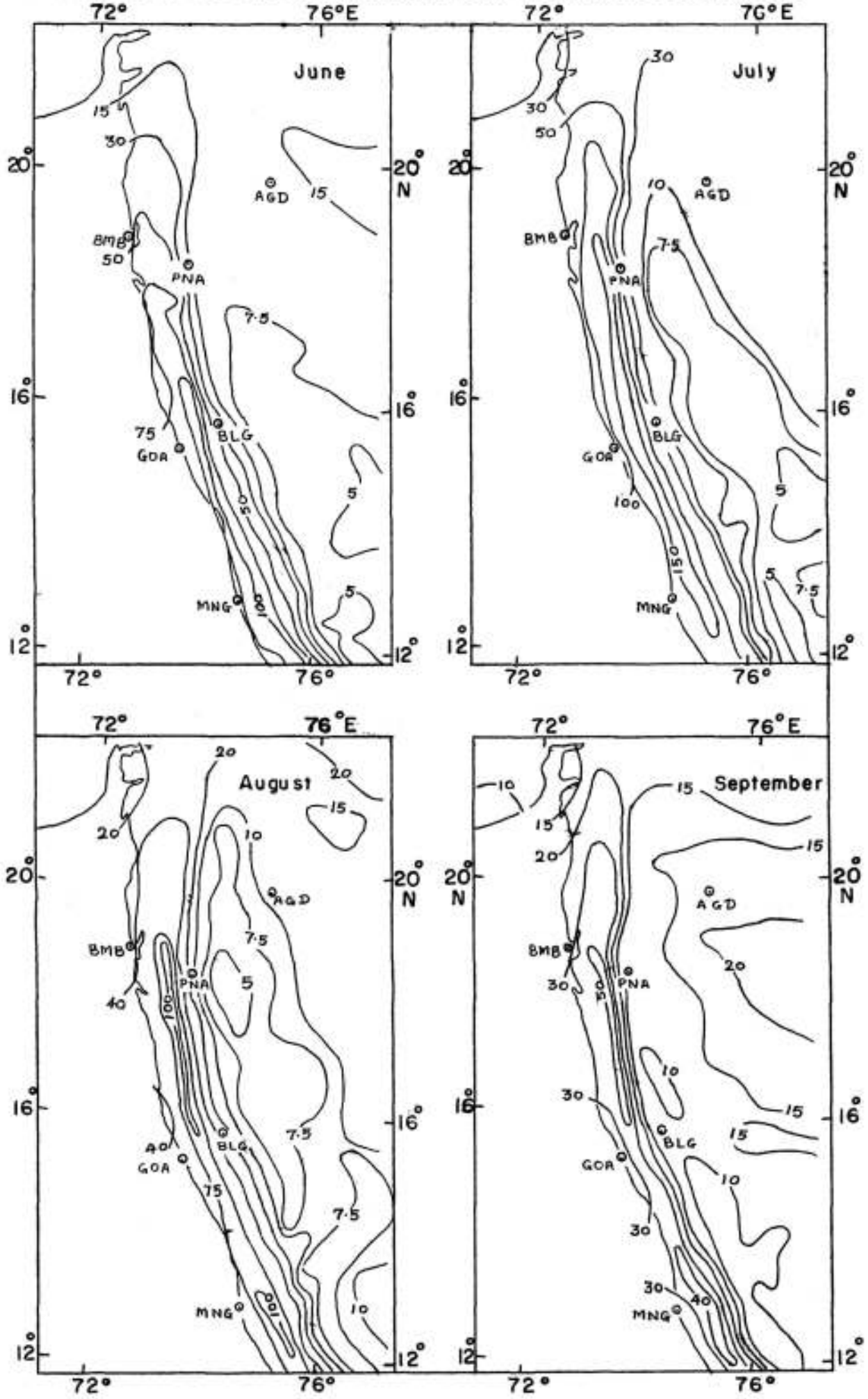


FIG. 2·3 VERTICAL PROFILE OF MONTHLY MEAN UPPER WINDS
(B O M B A Y)

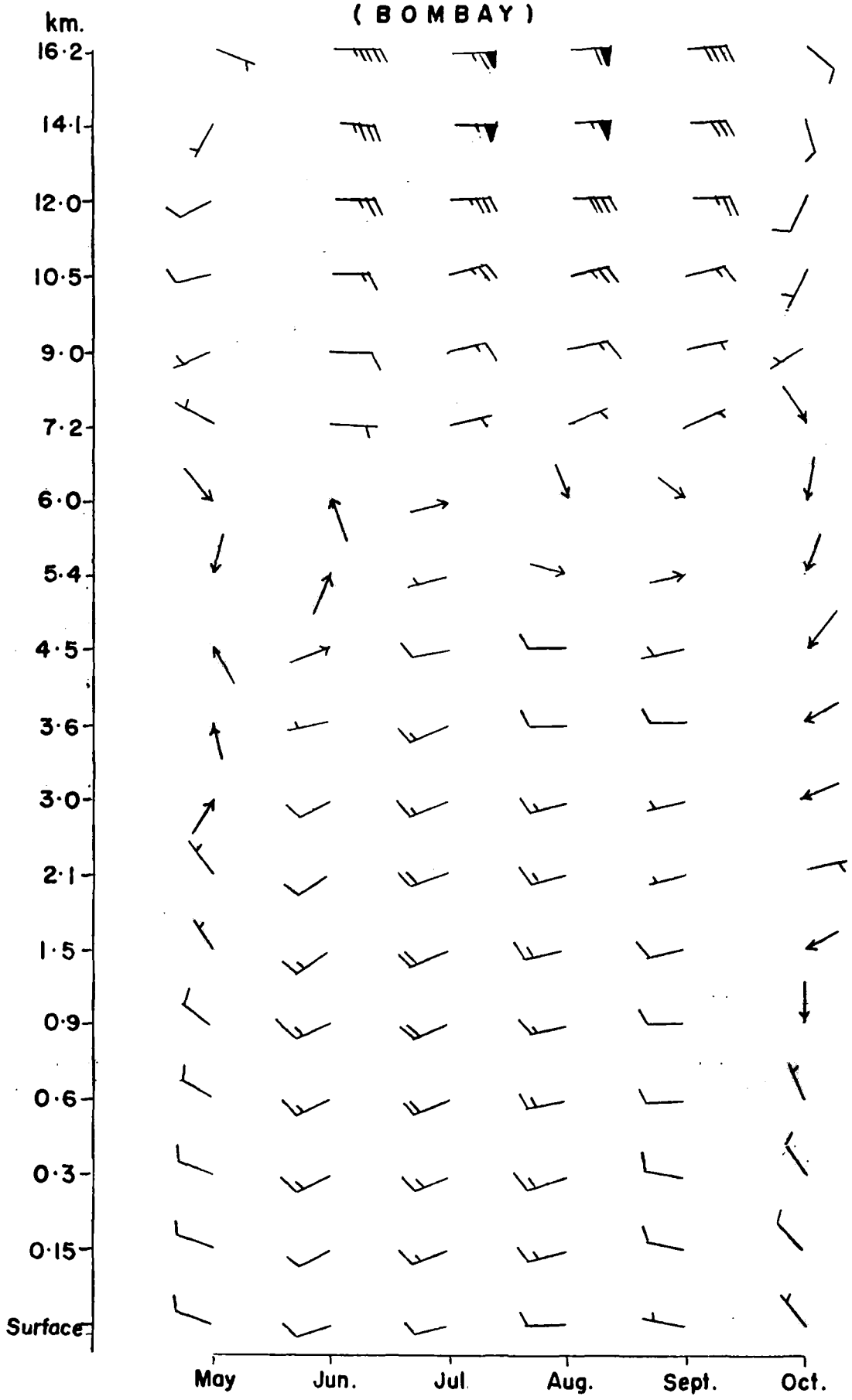


FIG. 2·4 MEAN MONTHLY TEPHIGRAMS FOR BOMBAY - May & July (00GMT)

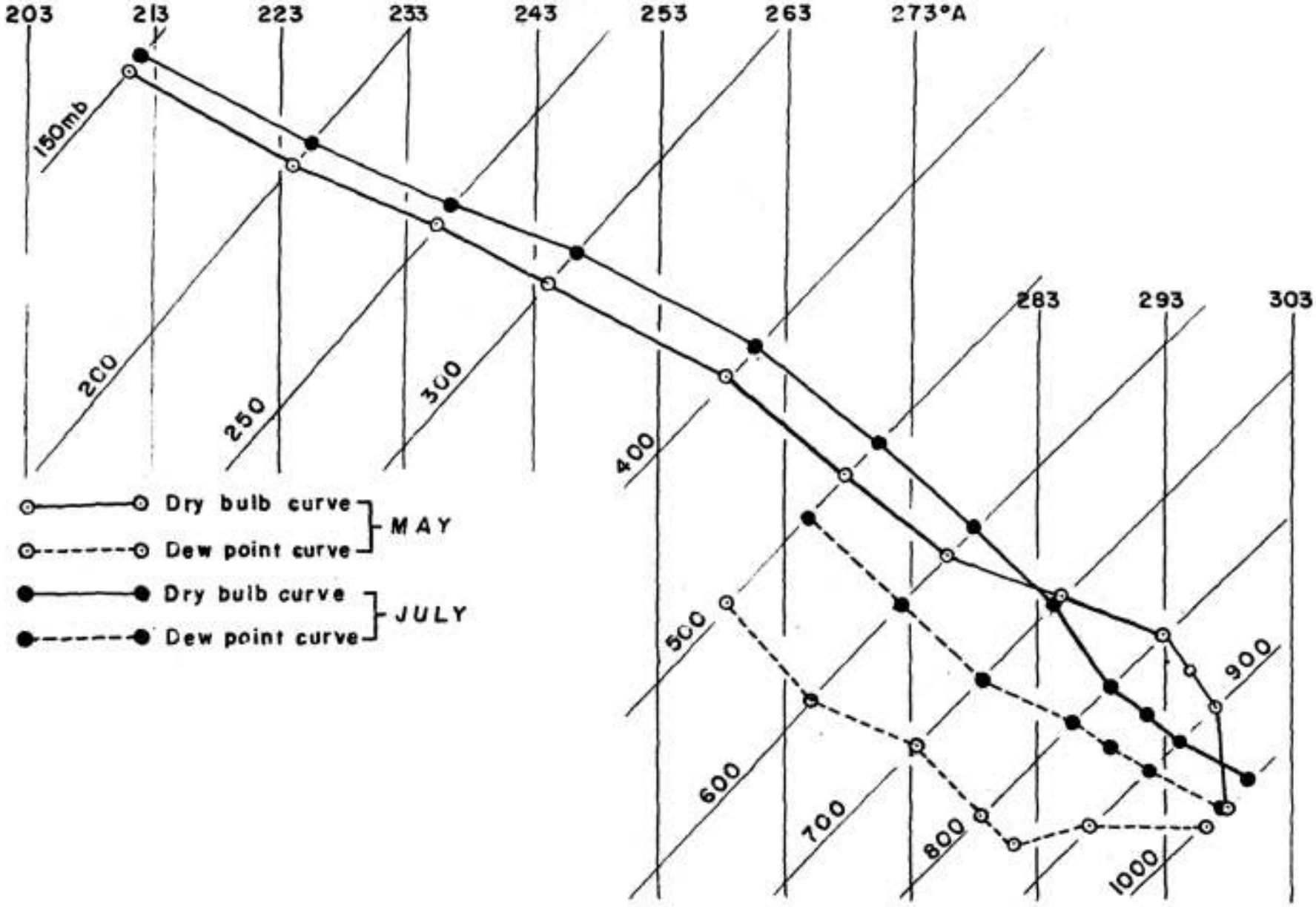


FIG. 2·5 MEAN TEPHIGRAMS FOR BOMBAY (JUL & AUG : 68-70)

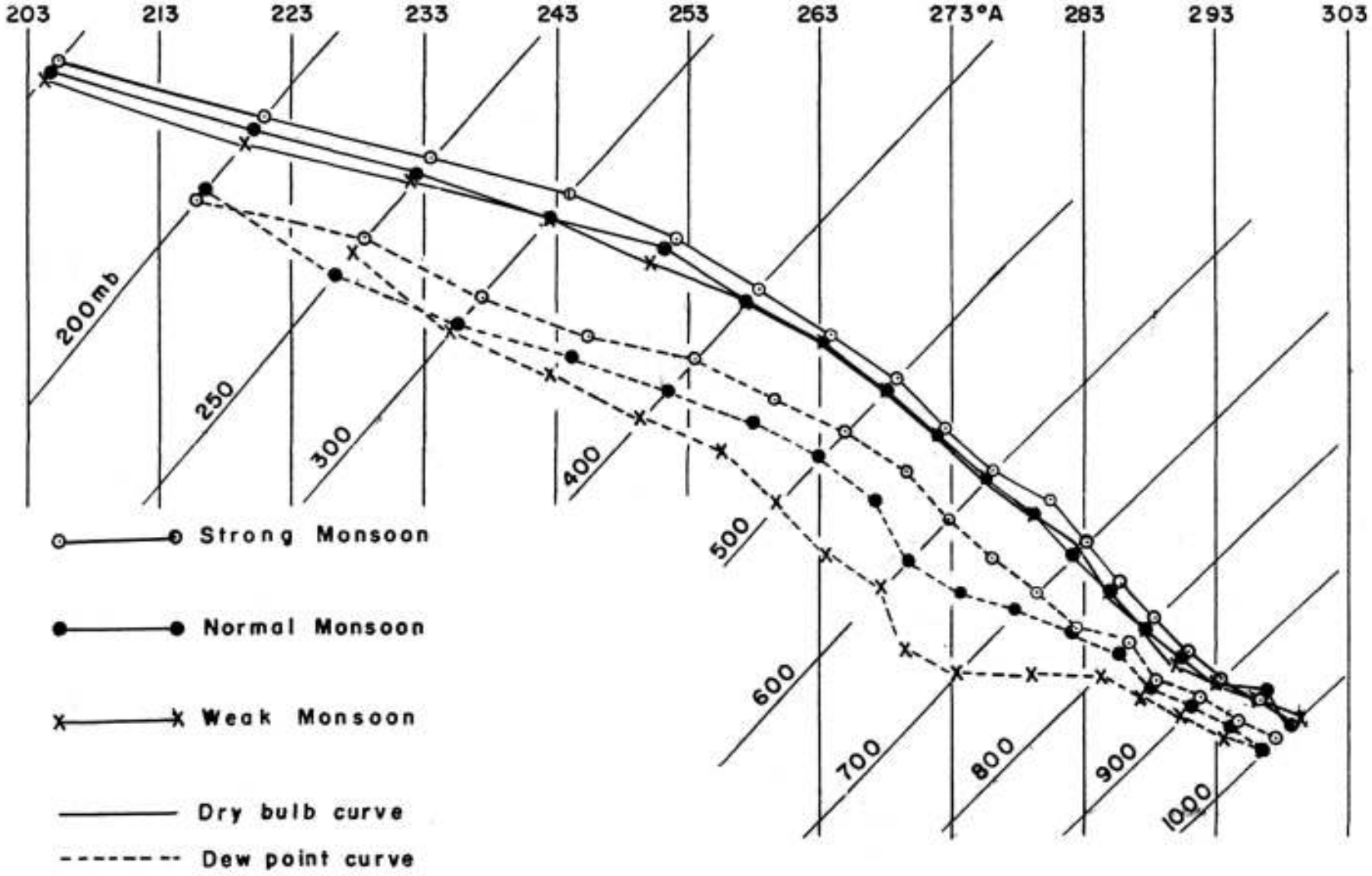


FIG. 2·6 TYPICAL TEPHIGRAM FOR BOMBAY

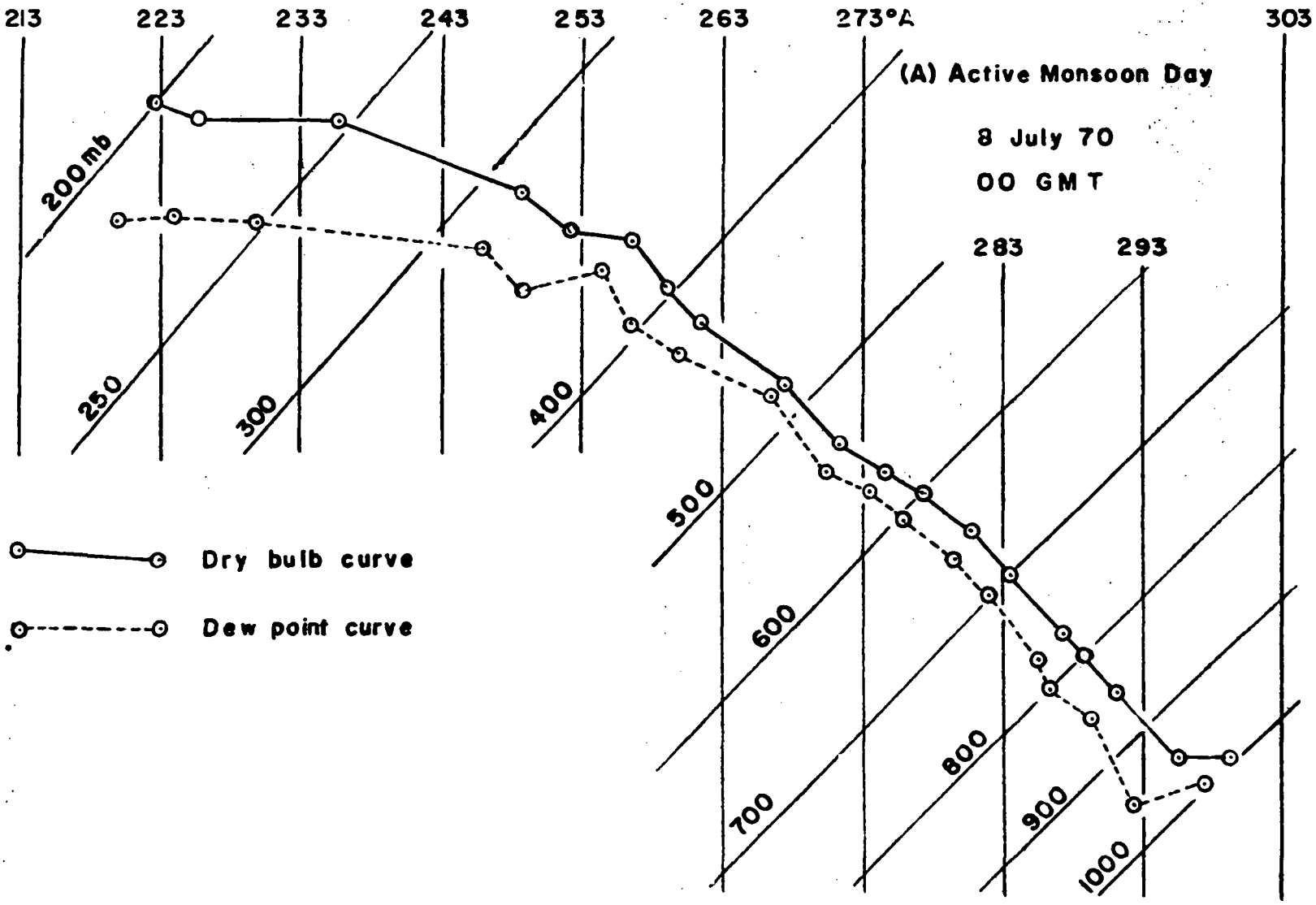


FIG. 2·6 TYPICAL TEPHIGRAM FOR BOMBAY

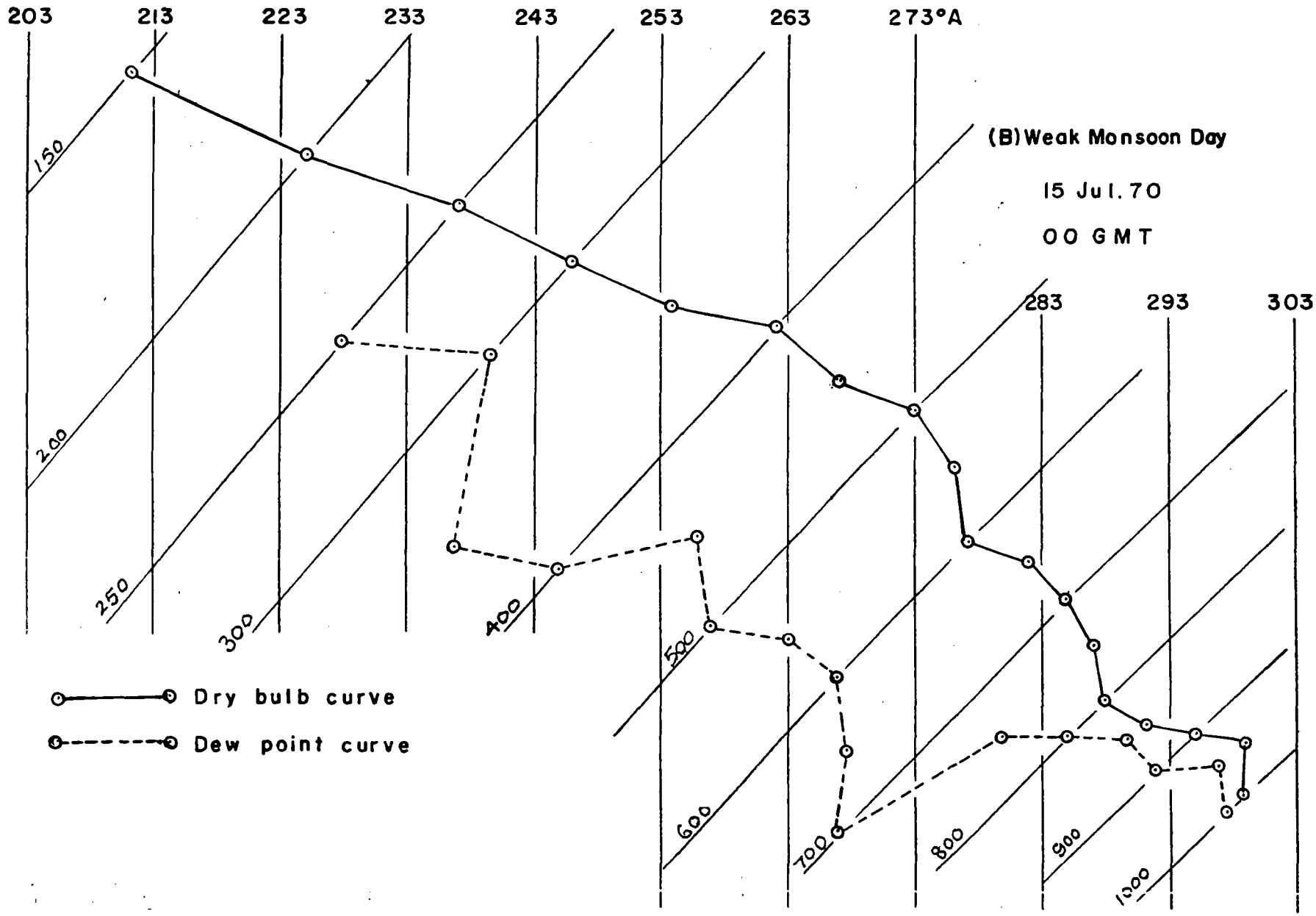
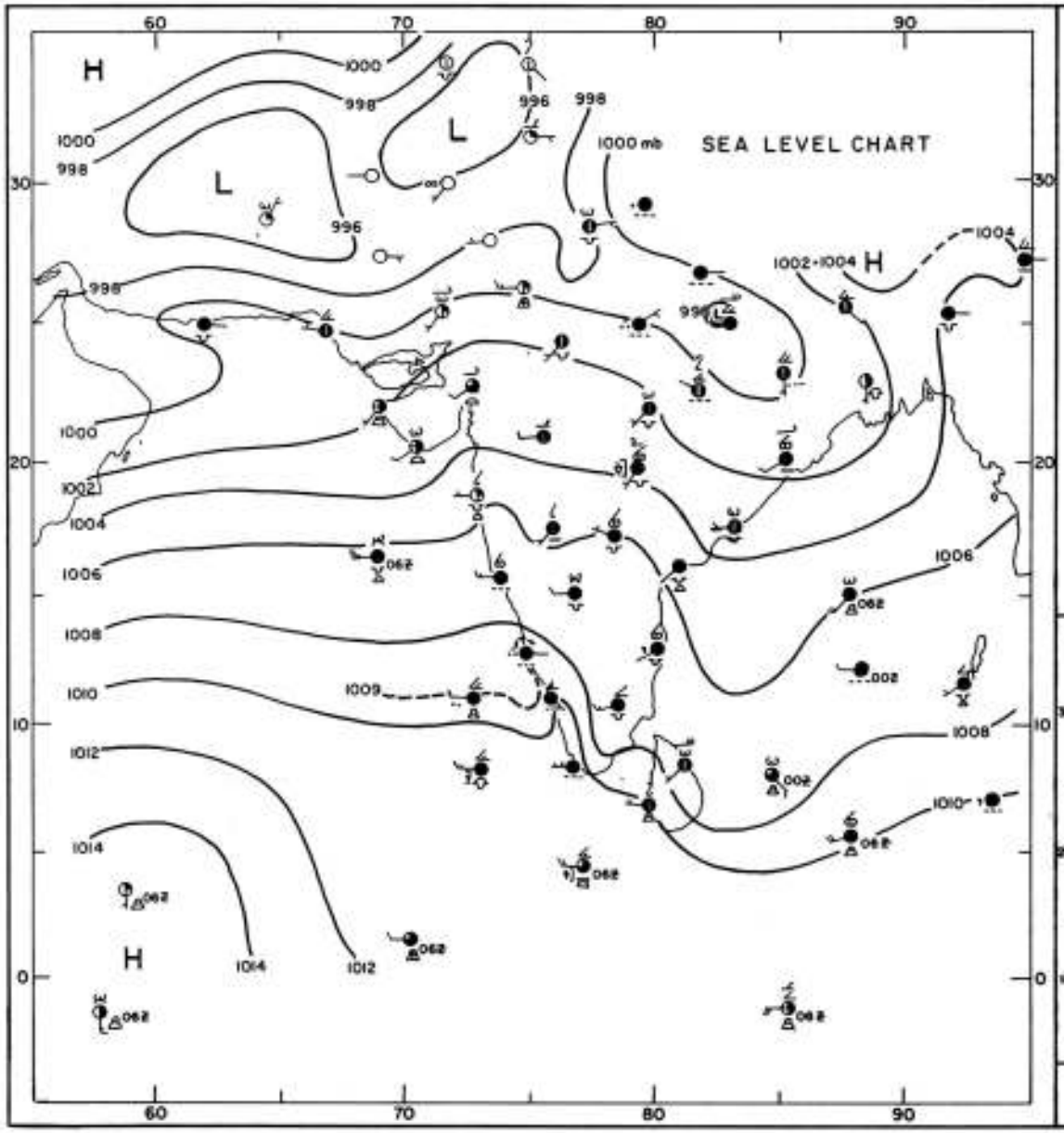
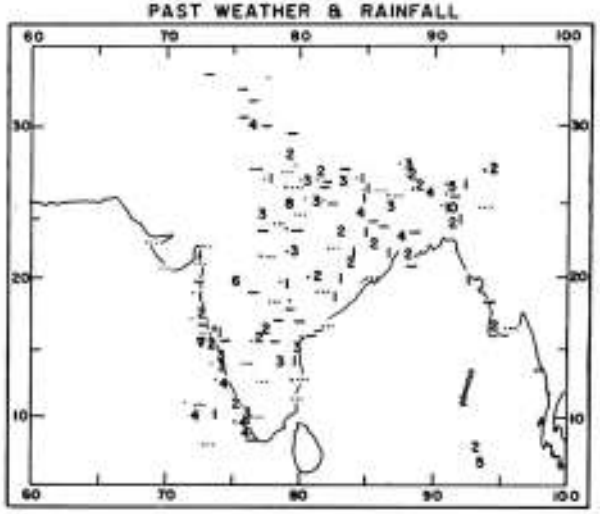
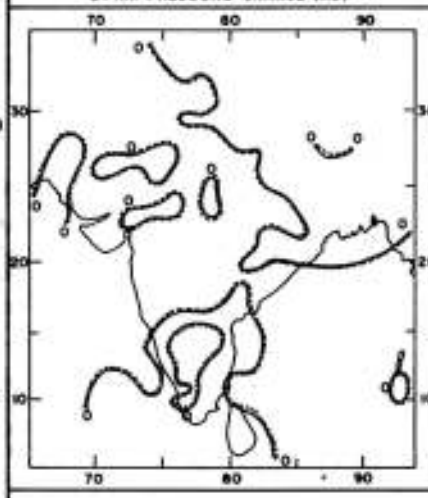


FIG. 5·1 SYNOPTIC CHARTS 0300 GMT 11 JUL 69







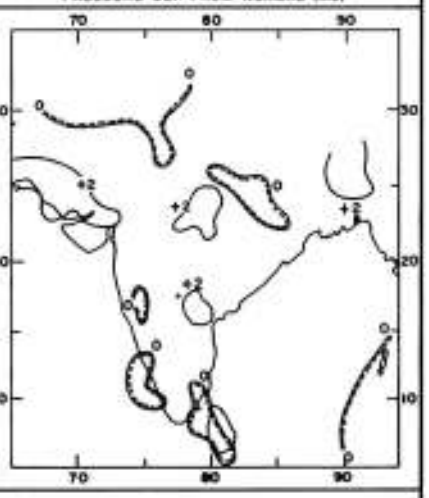


FIG. 5·2 UPPER WINDS 11 JUL. 69 00 GMT

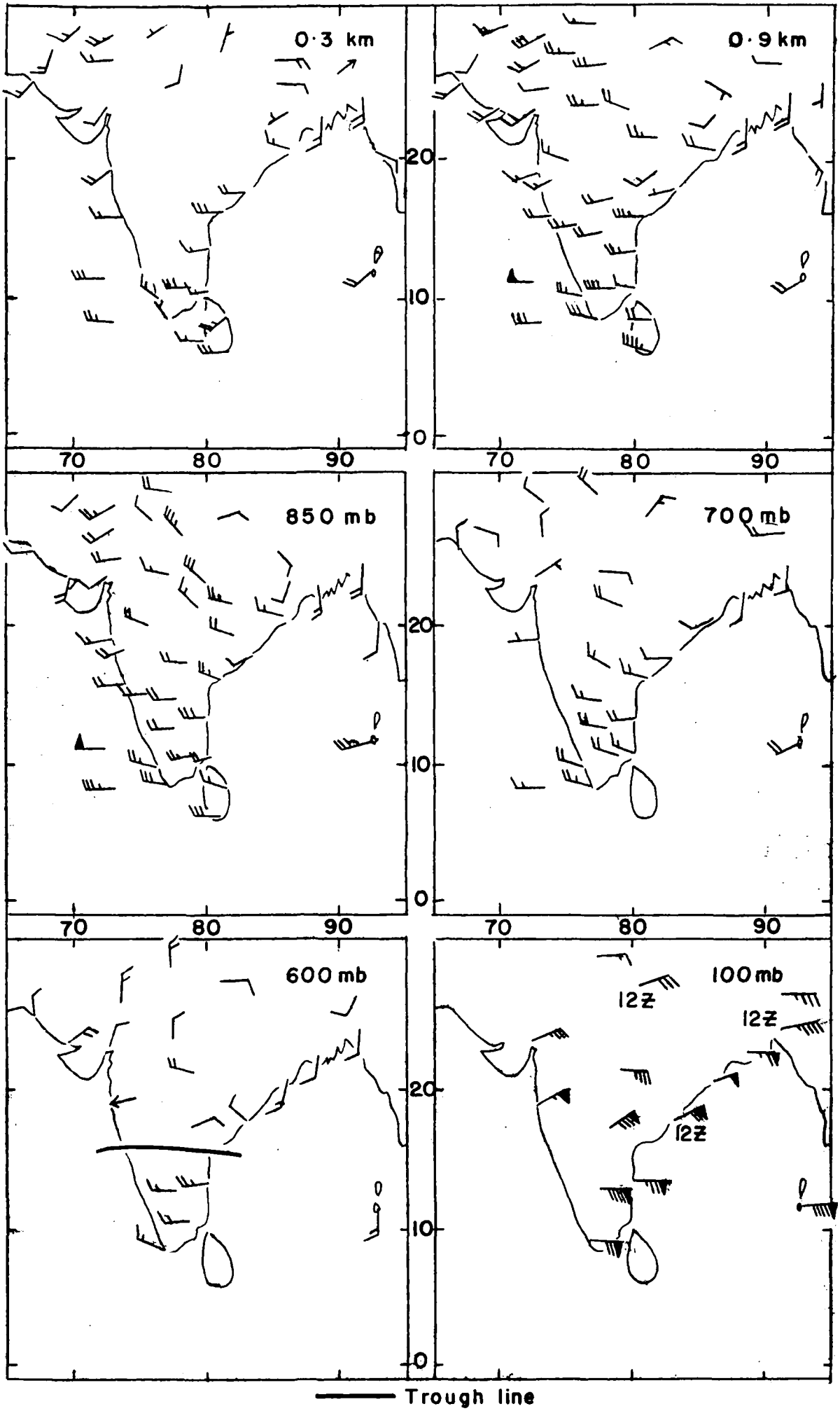


FIG. 5·3 SYNOPTIC CHARTS 0300 GMT 12 JUL. 69

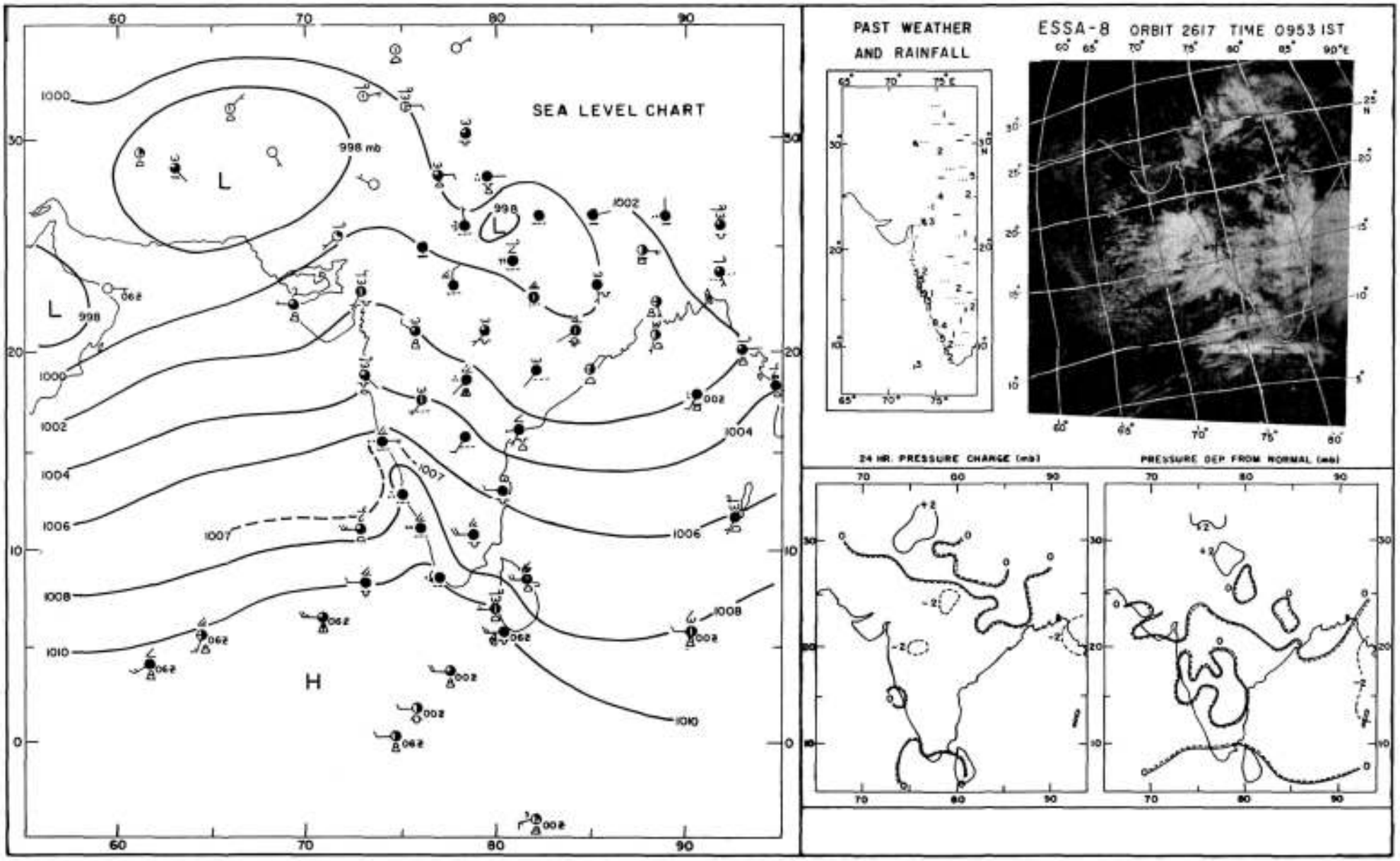


FIG. 5·4 UPPER WINDS 12 JUL. 69 00 GMT

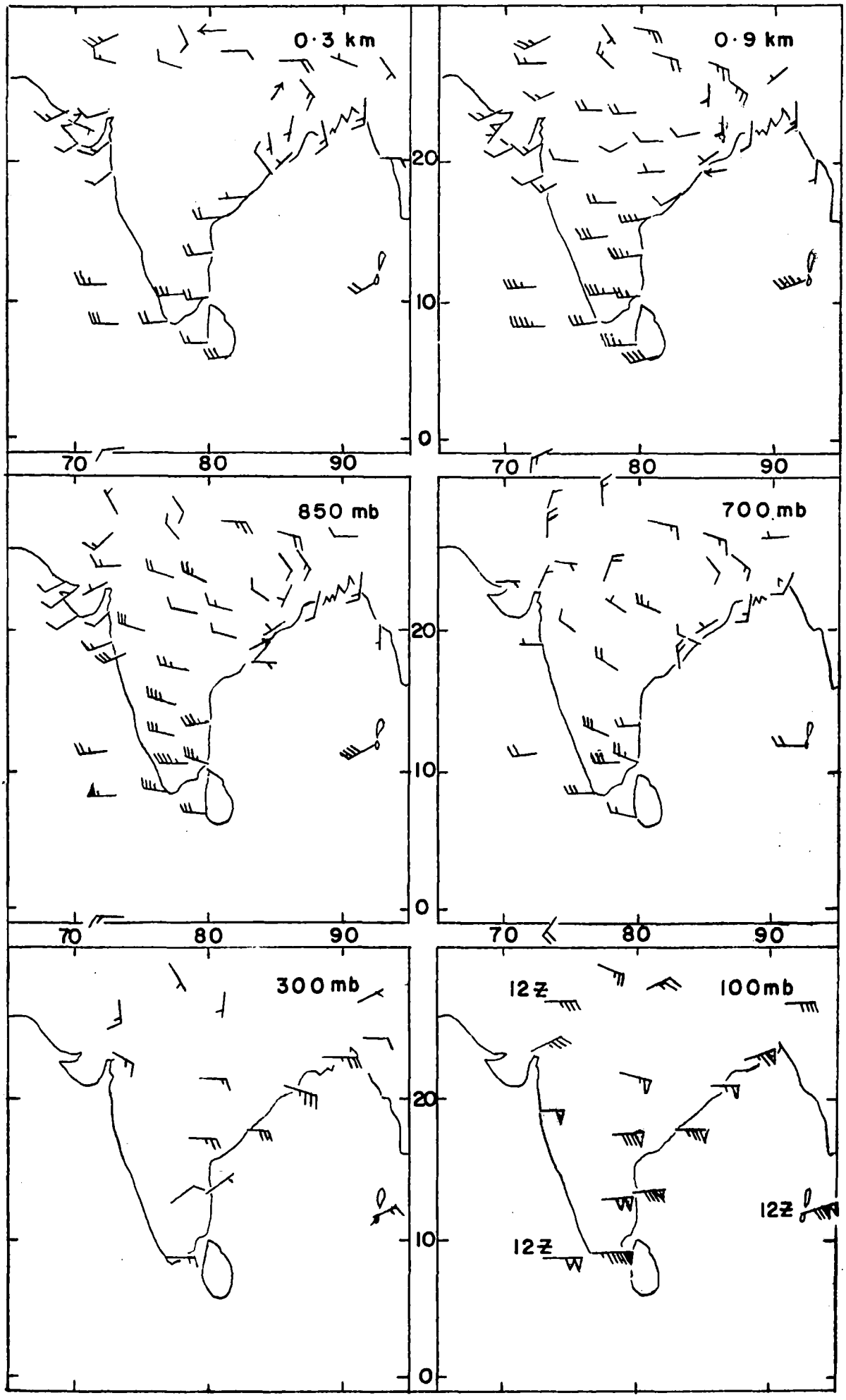


FIG. 5·5 UPPER WINDS 13 JUL. 69 00 GMT

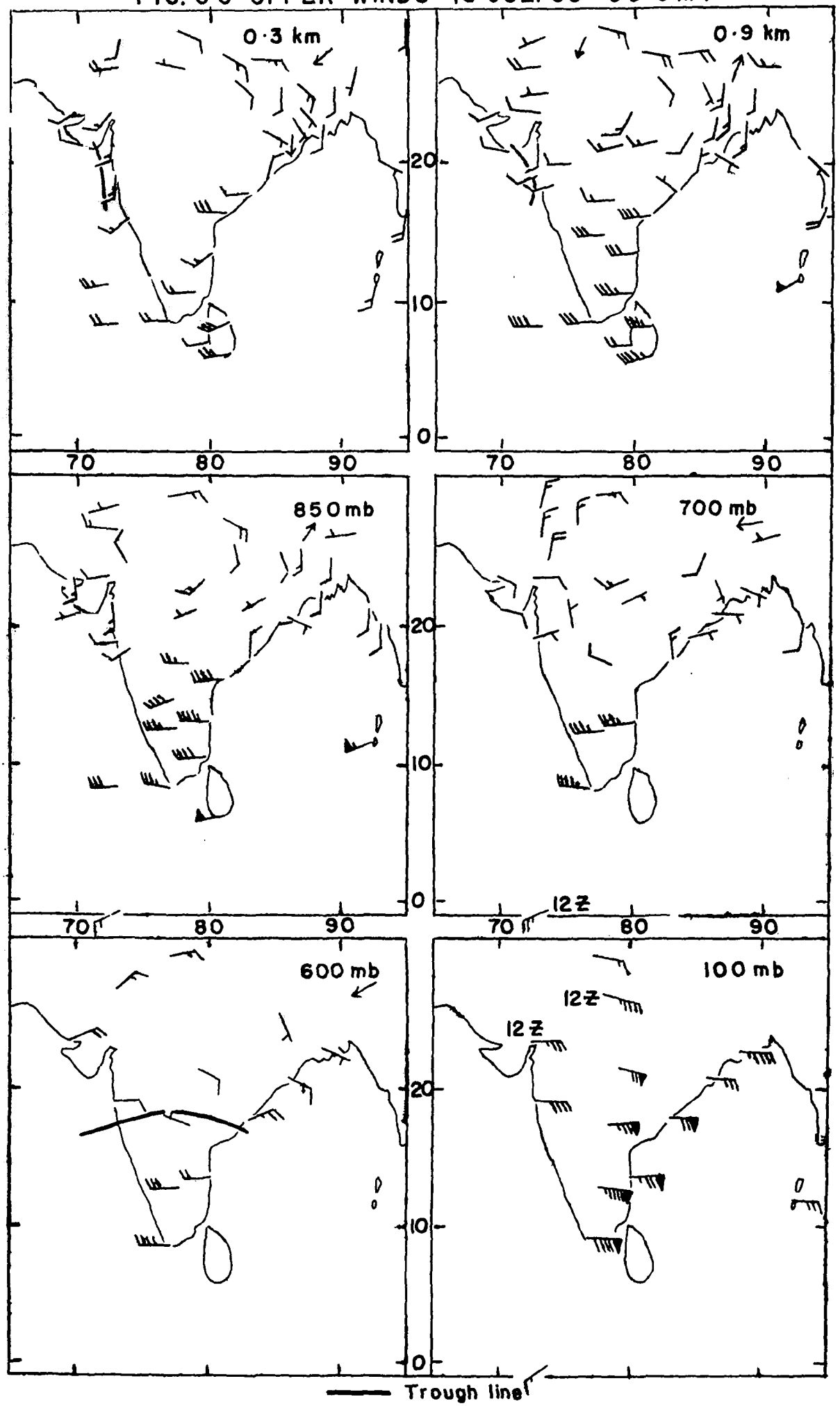


FIG. 5·6

NIMBUS – 3

ORBIT 1206

DATE 13 JUL. 69

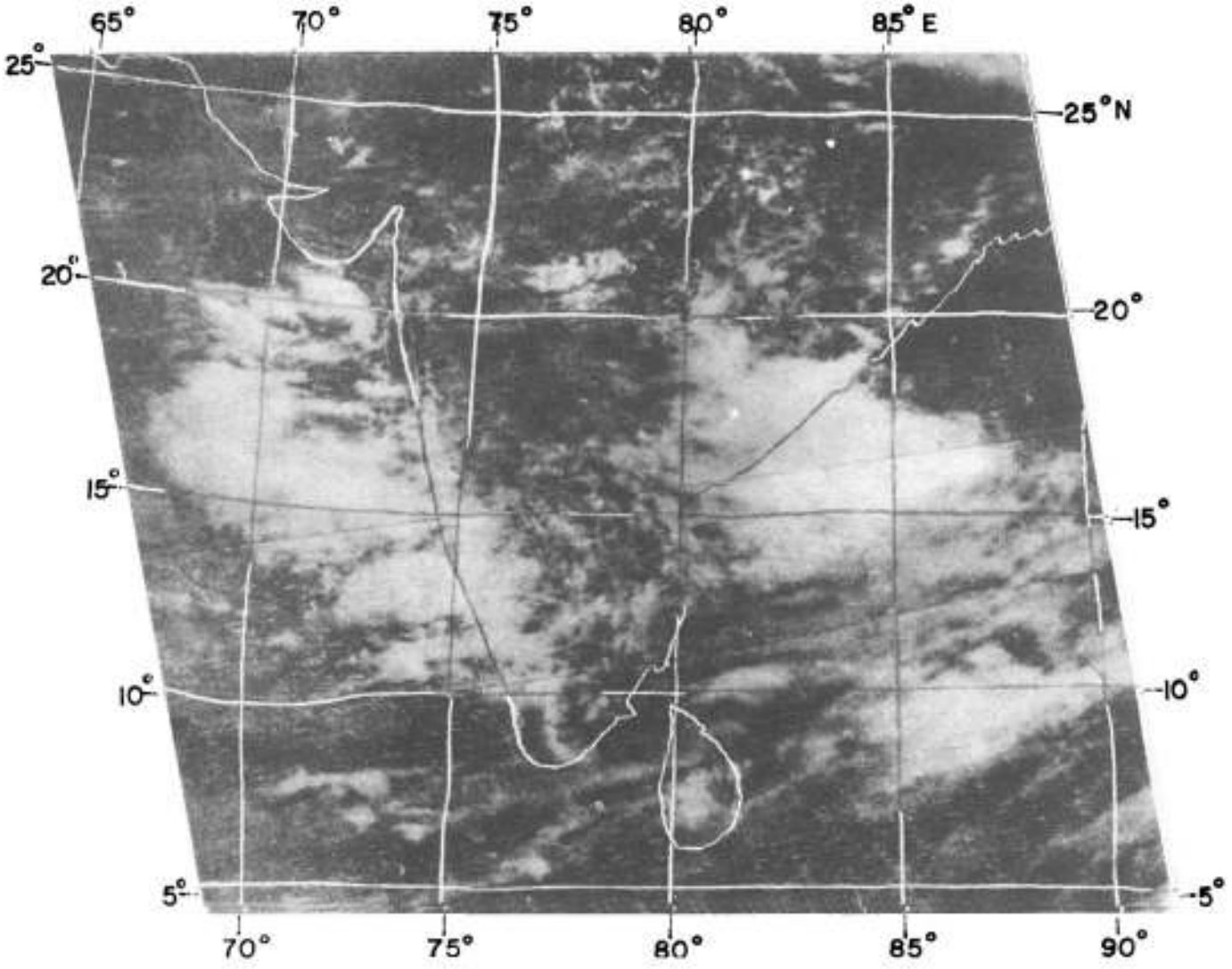
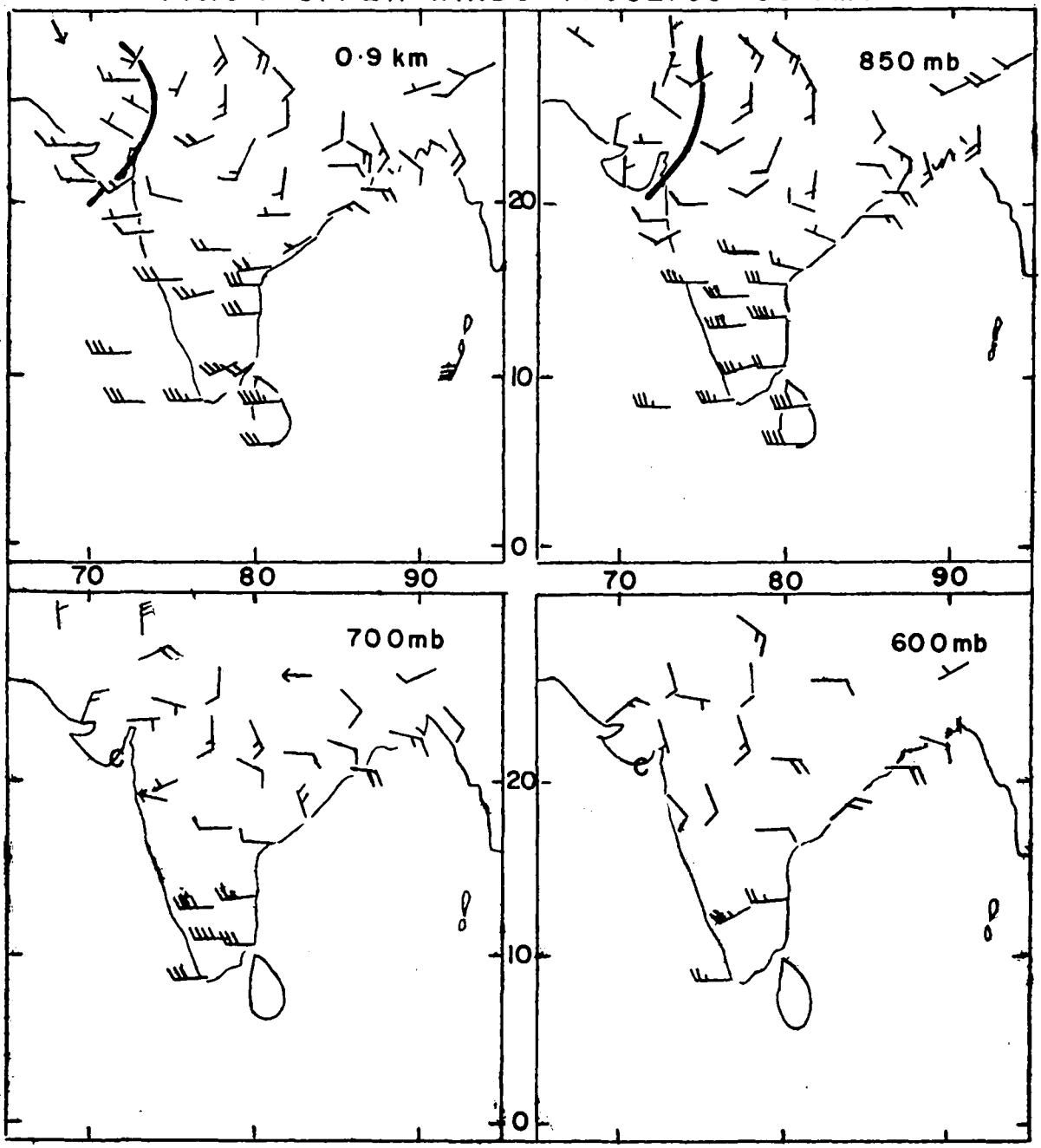
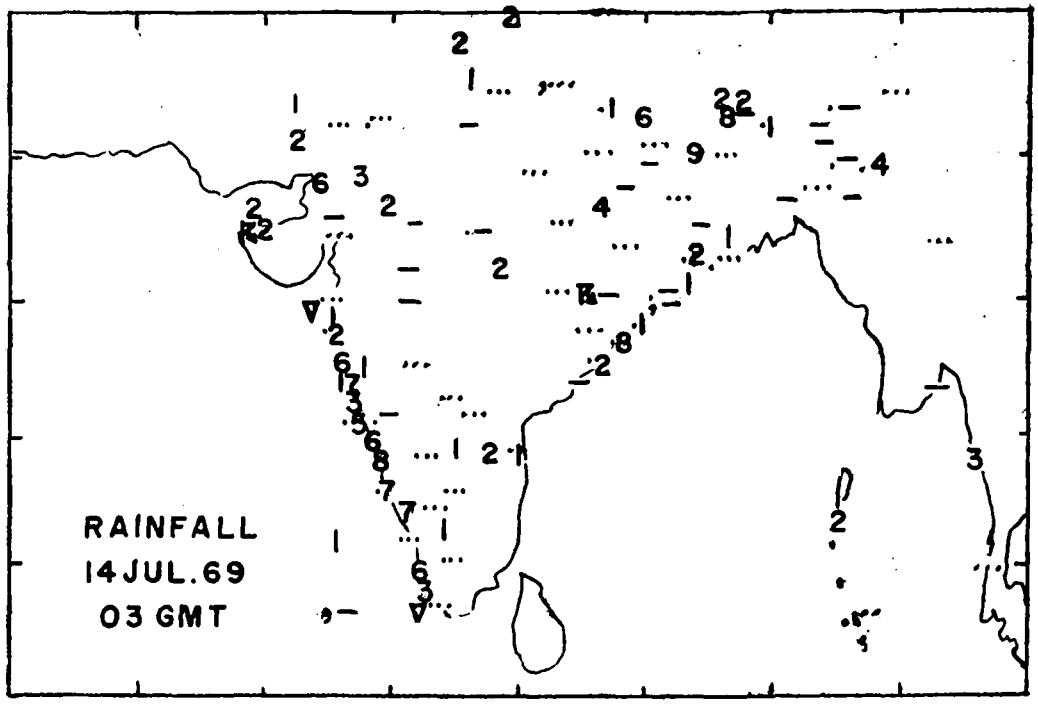


FIG. 5·7 UPPER WINDS 14 JUL. 69 00 GMT





C - Centre of cyclonic circulation —— Trough line

FIG. 5·8 SYNOPTIC CHARTS 0300 GMT 15 JUL. 69

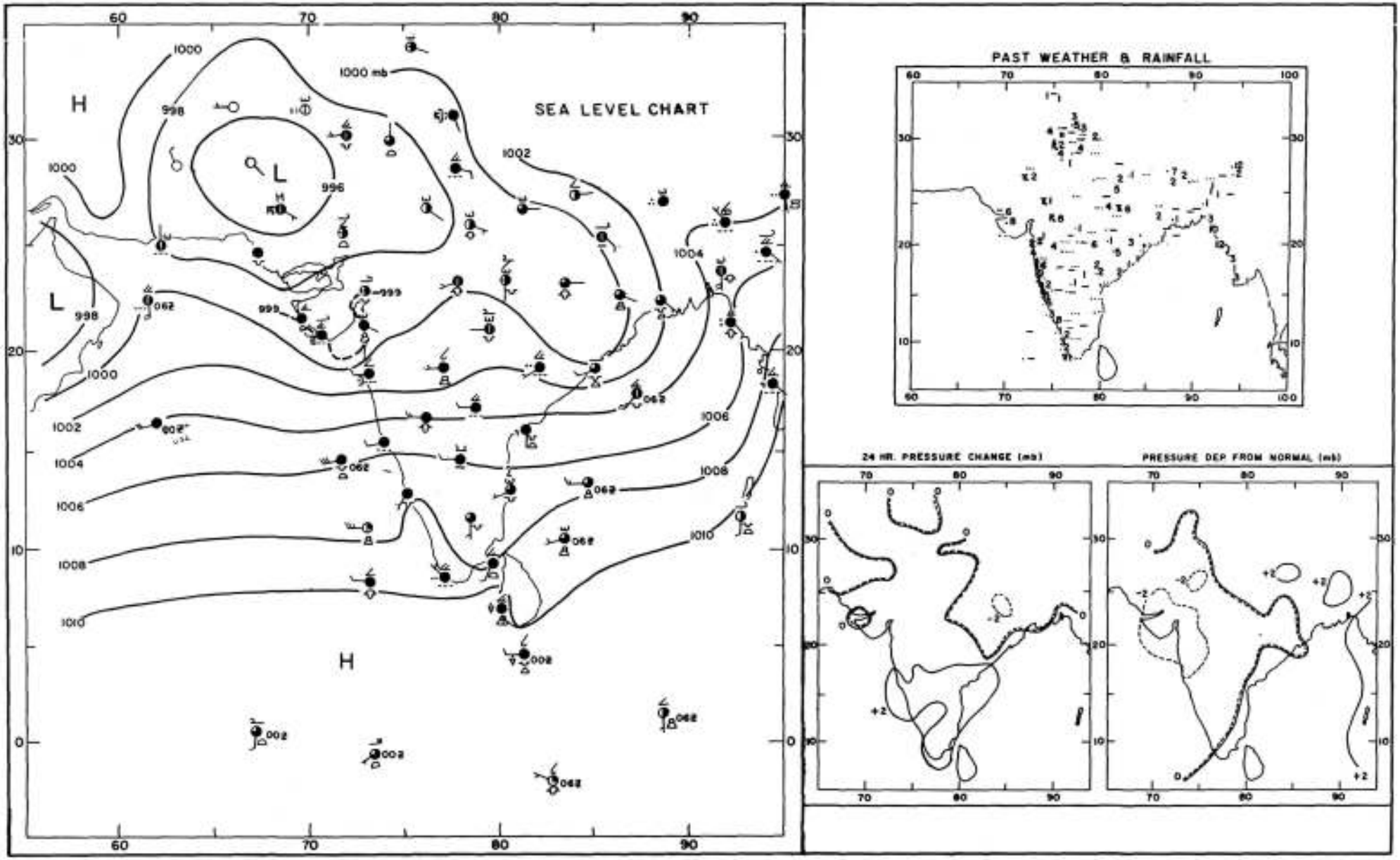


FIG. 5·9 UPPER WINDS 15 JUL. 69 00 GMT

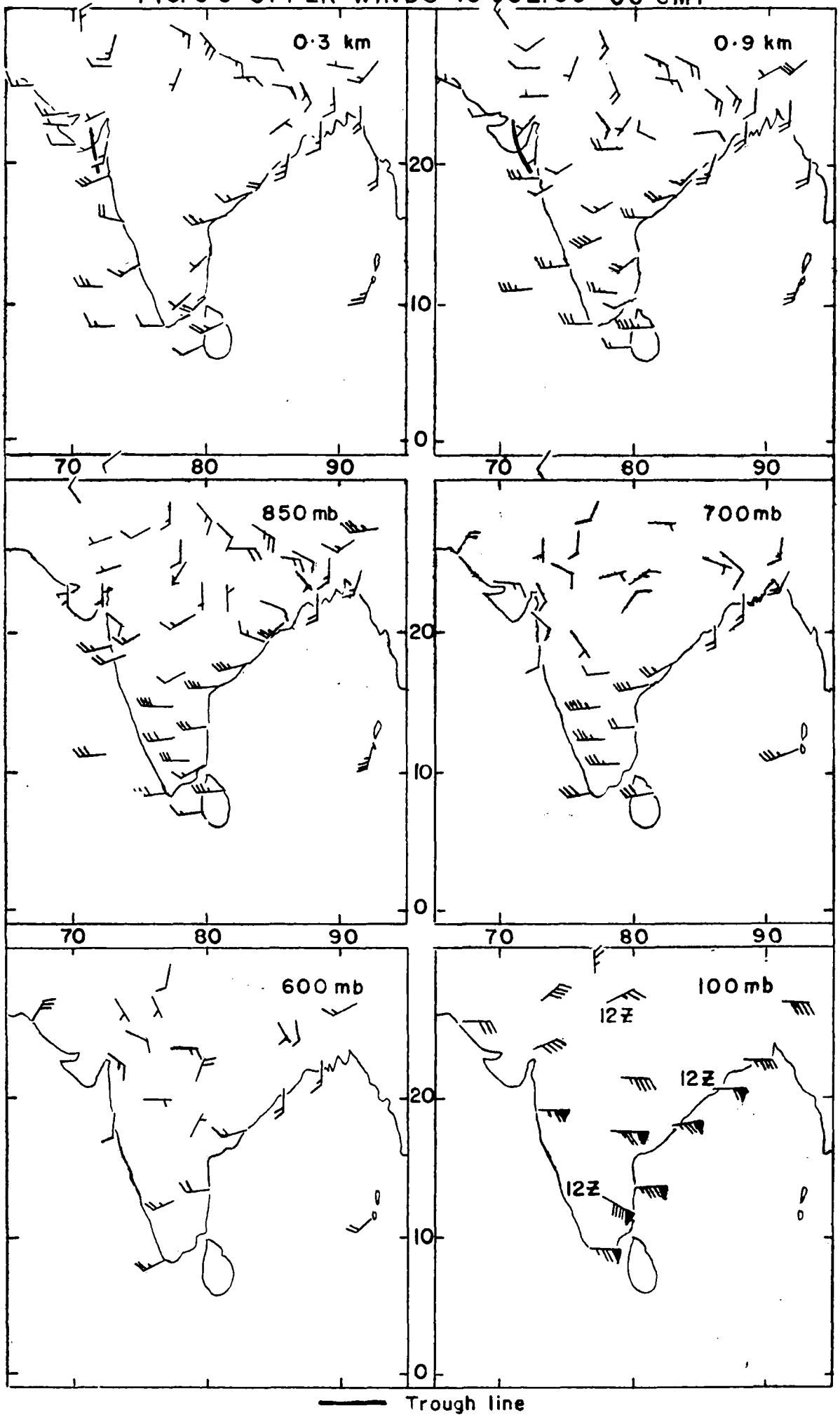


FIG. 5·10
NIMBUS – 3
ORBIT 1233
DATE 15 JUL. 69

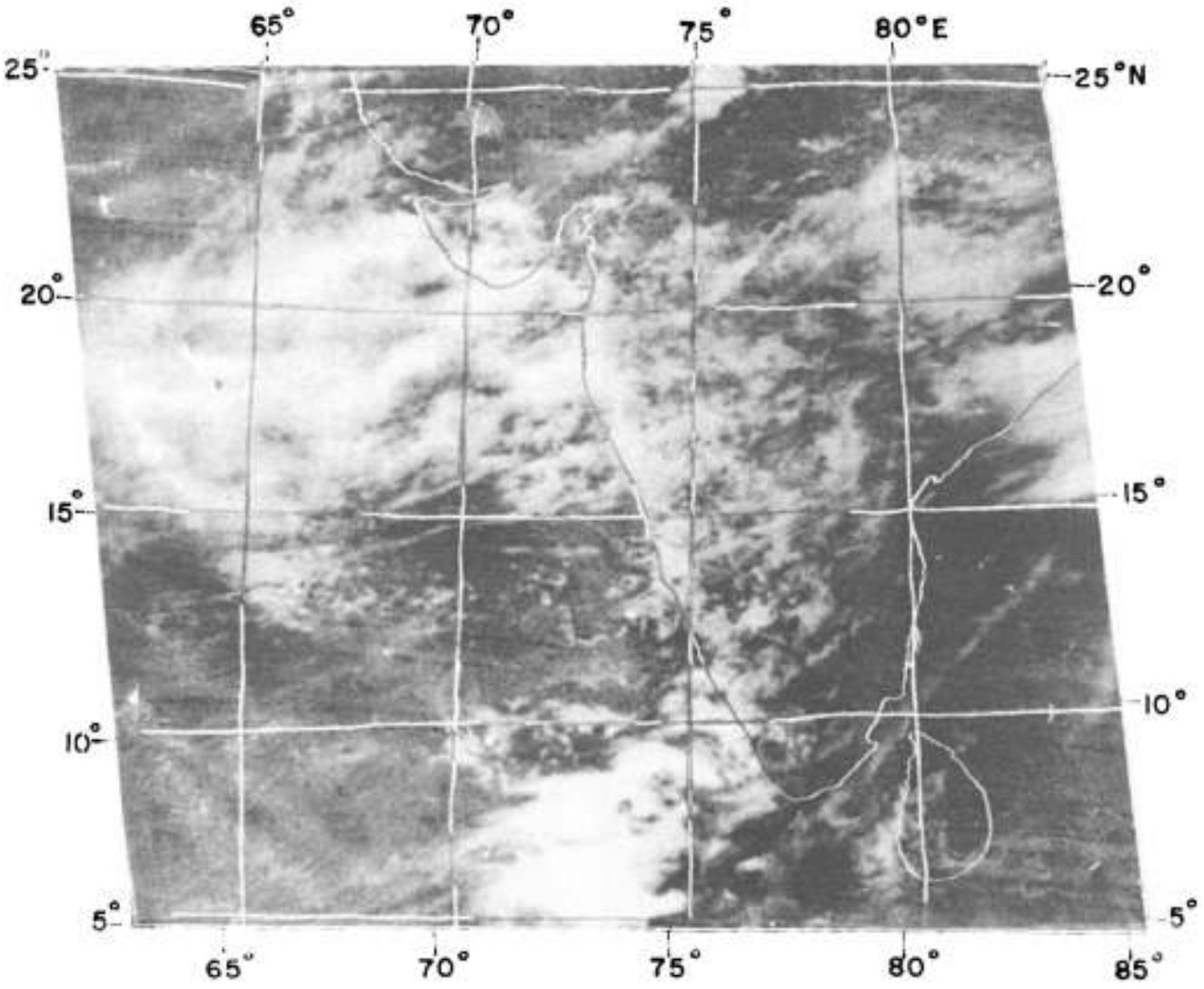


FIG. 5·11 UPPER WINDS 16 JUL. 69 00 GMT

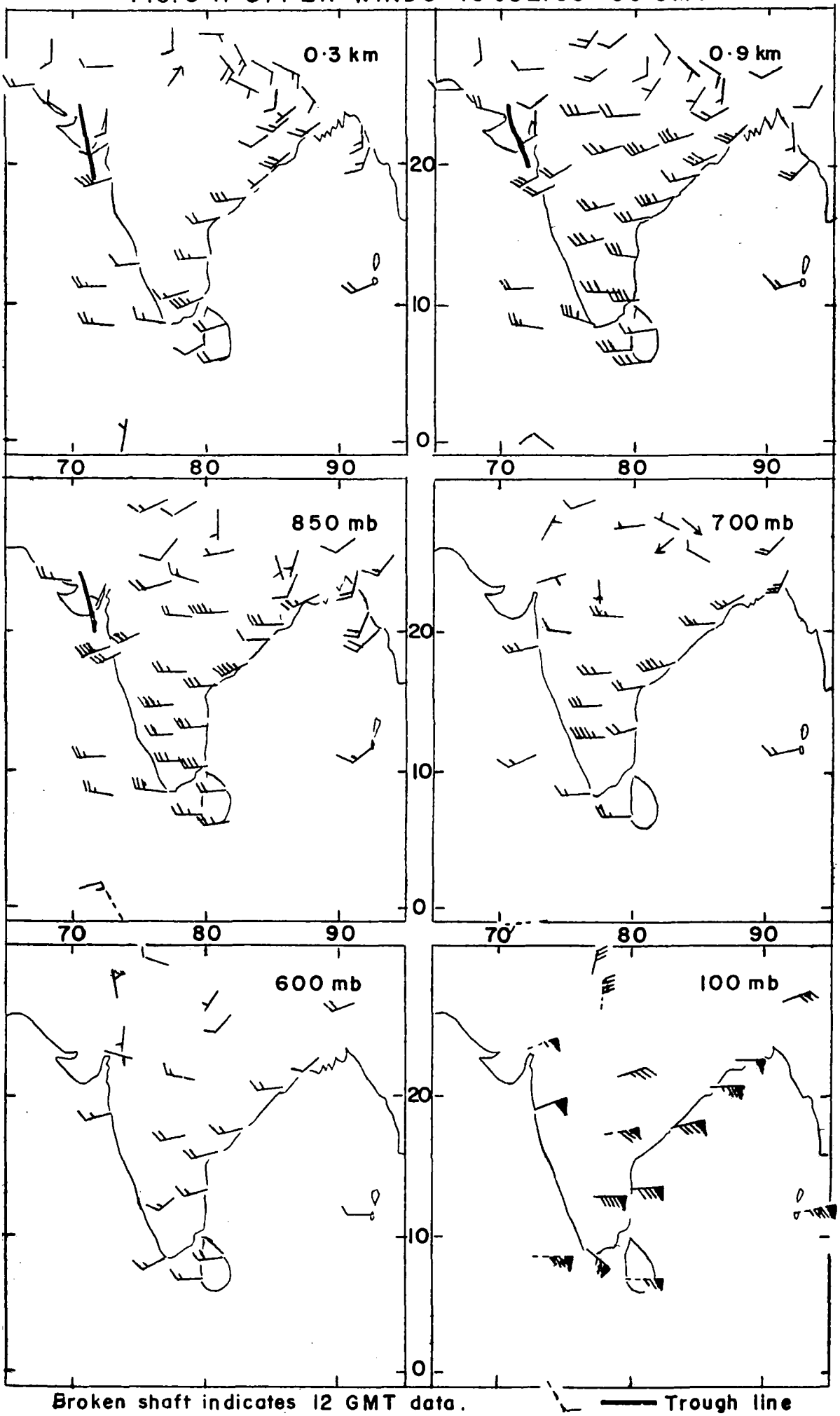


FIG. 6·1·1

SYNOPTIC CHARTS 0300 GMT 26 JUL 67

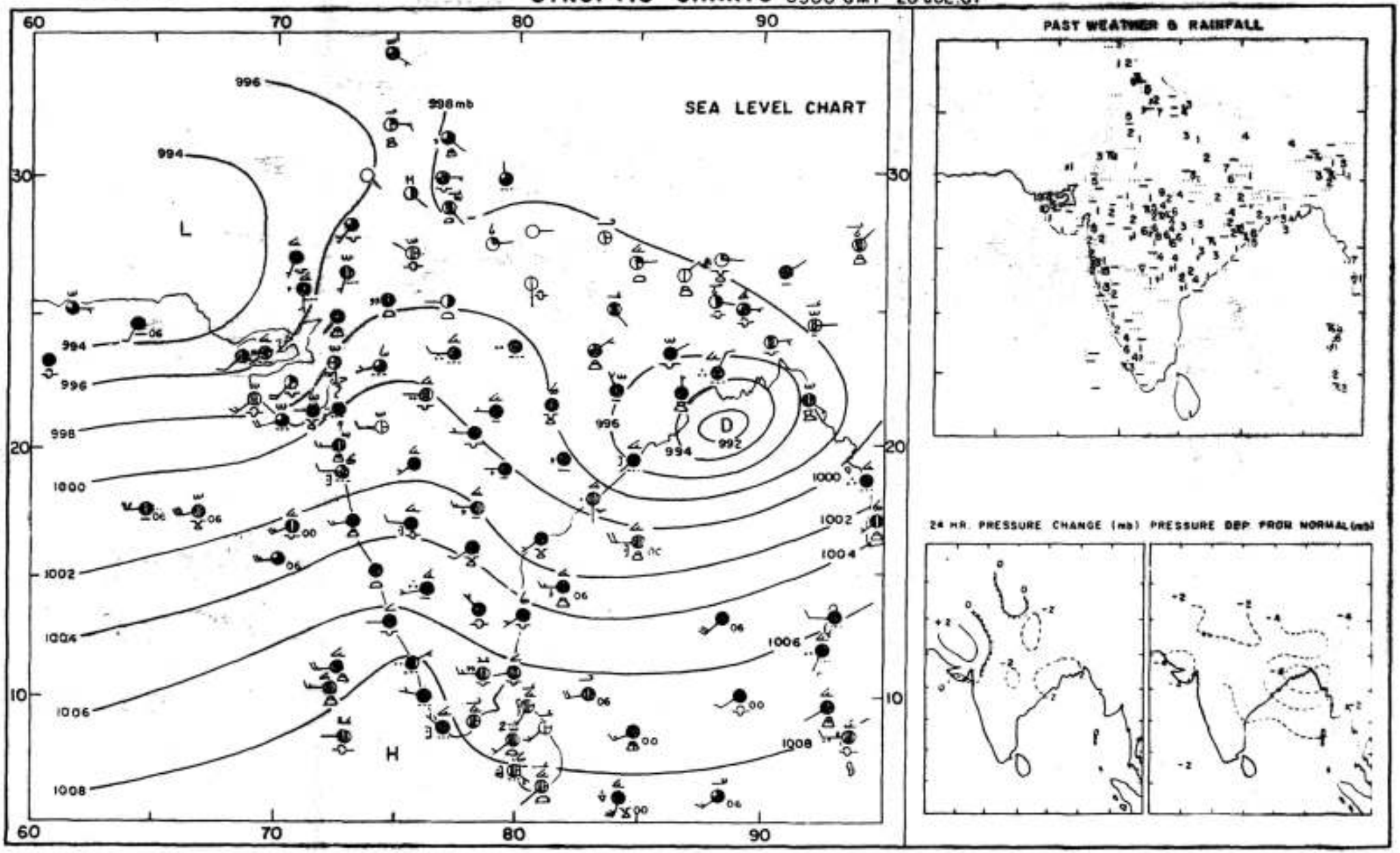
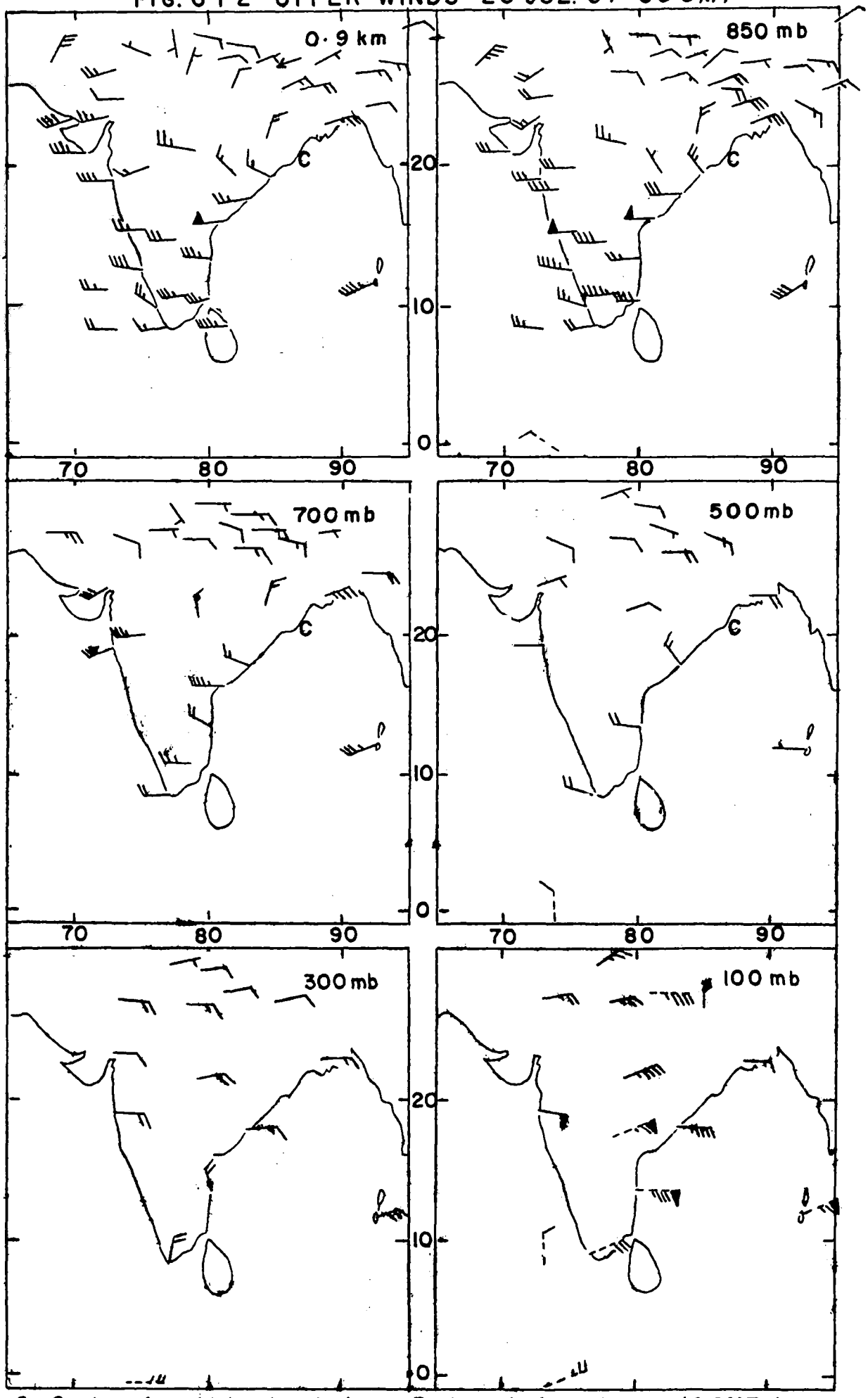


FIG. 6·1·2 UPPER WINDS 26 JUL. 67 00 GMT



C- Centre of cyclonic circulation Broken shaft indicates 12 GMT data.

FIG. 6·1·3

ESSA - 2

26 JULY 67

ORBIT 6501

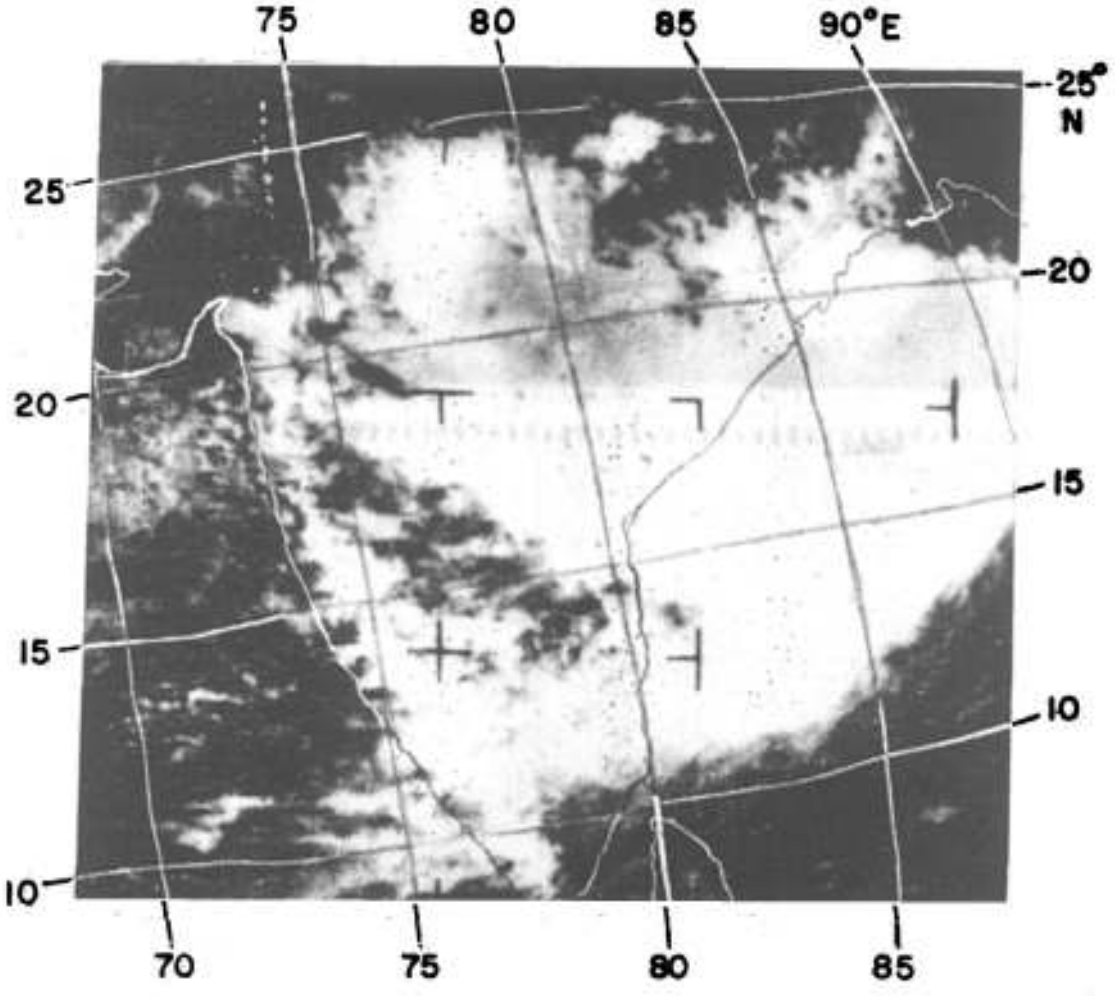
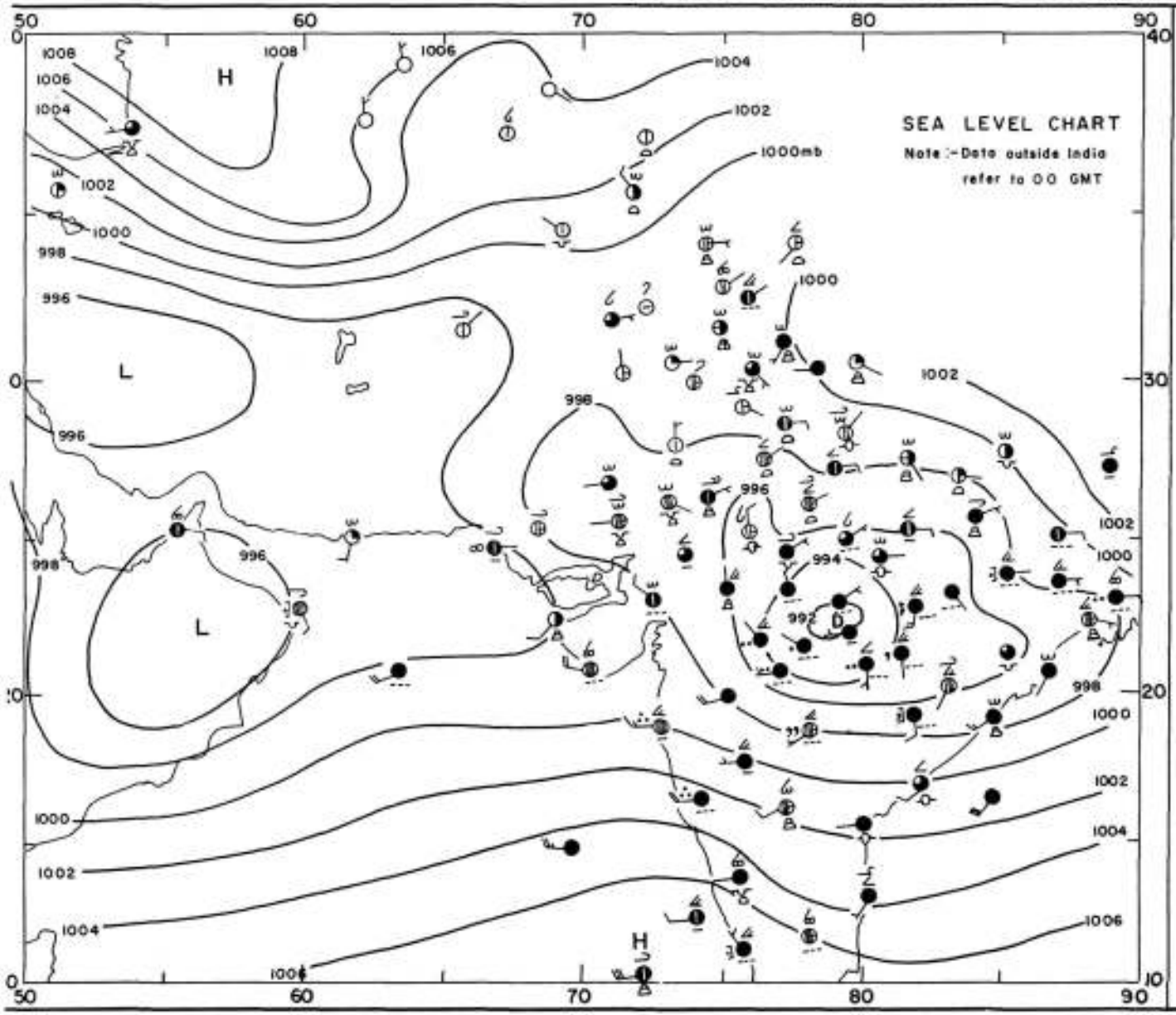
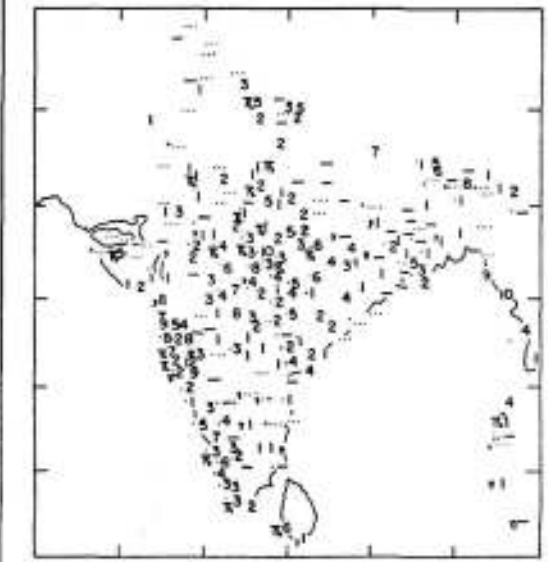


FIG. 6·1·4

SYNOPTIC CHARTS 0300 GMT 28 JUL. 67





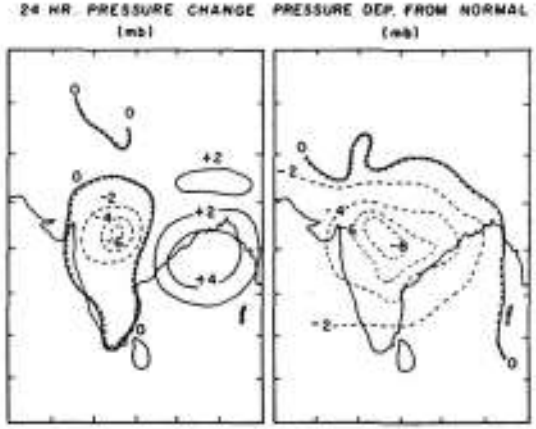
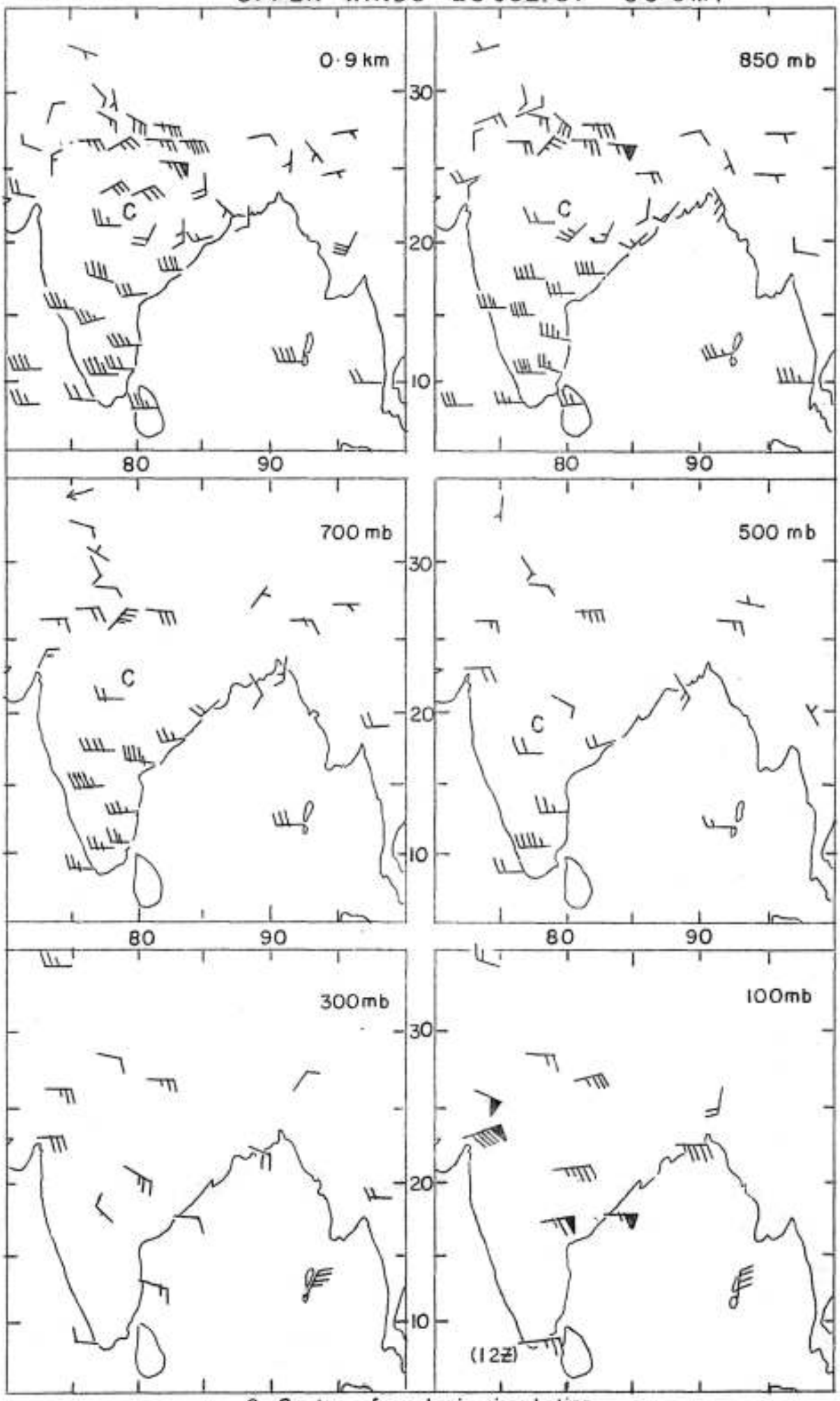


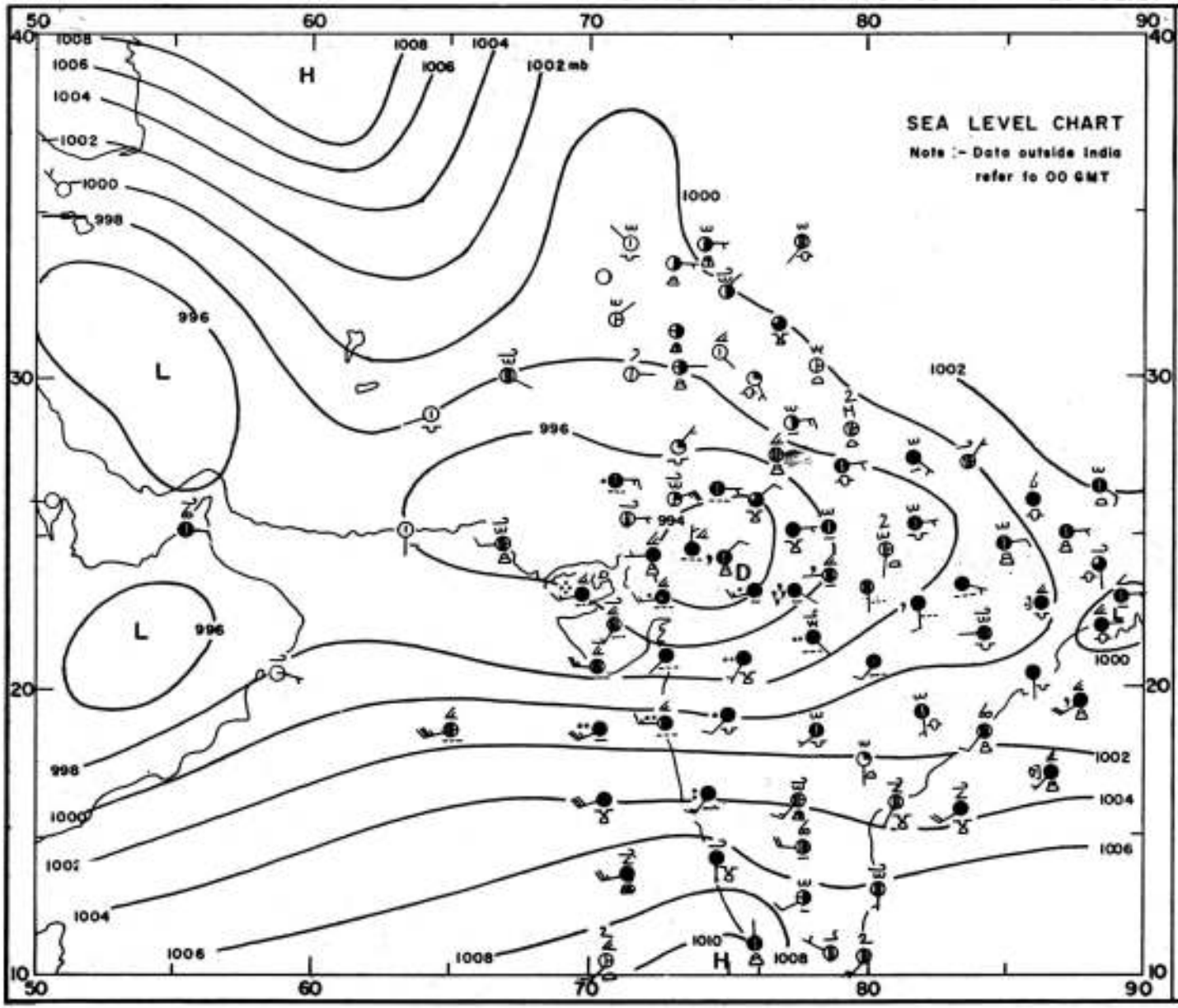
FIG. 6·1·5



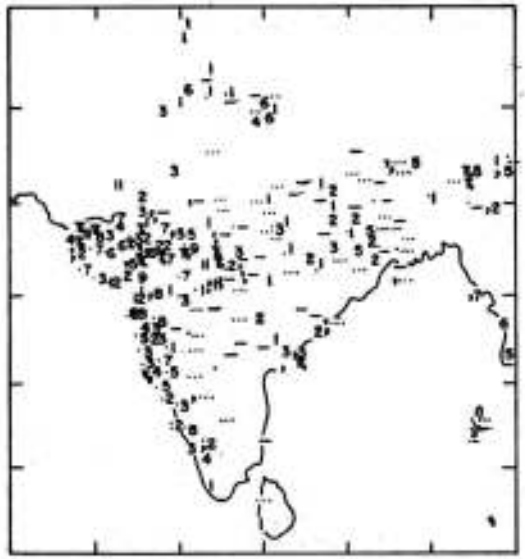
C - Centre of cyclonic circulation

FIG. 6·1·6

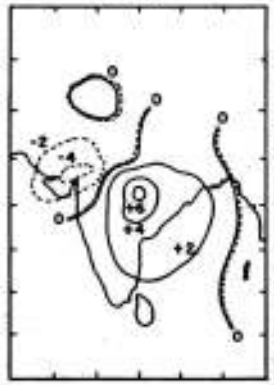
SYNOPTIC CHARTS 0300 GMT 29 JUL. 67



PAST WEATHER & RAINFALL



24 HR. PRESSURE CHANGE (mb)



PRESSURE DEP. FROM NORMAL (mb)

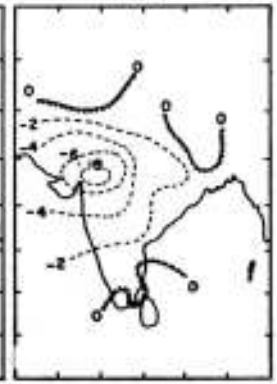
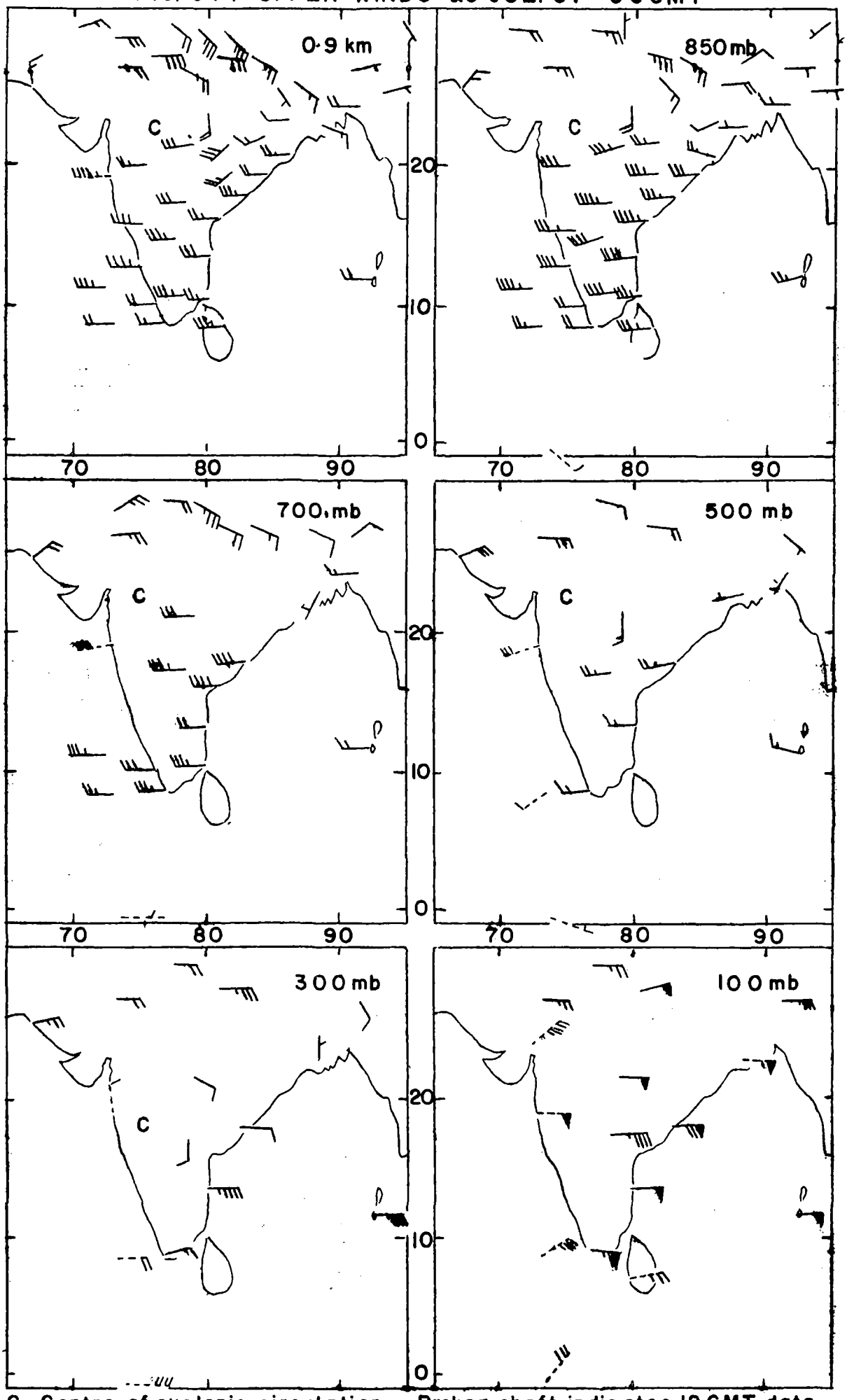


FIG. 6·1·7 UPPER WINDS 29 JUL. 67 00GMT



C - Centre of cyclonic circulation Broken shaft indicates 12 GMT data.

FIG.6·2·1 SYNOPTIC CHARTS 0300 GMT 8 SEPT. 62

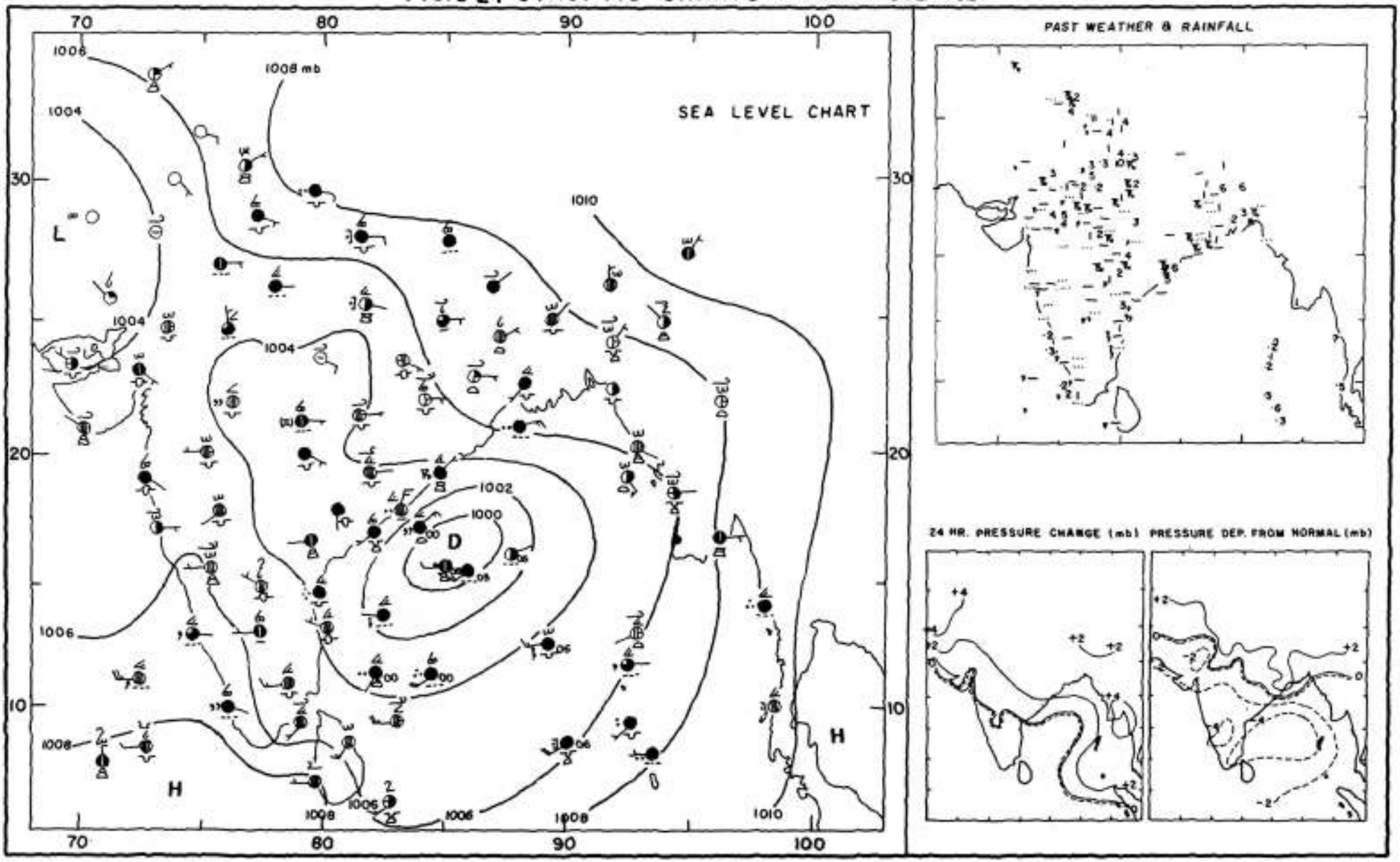
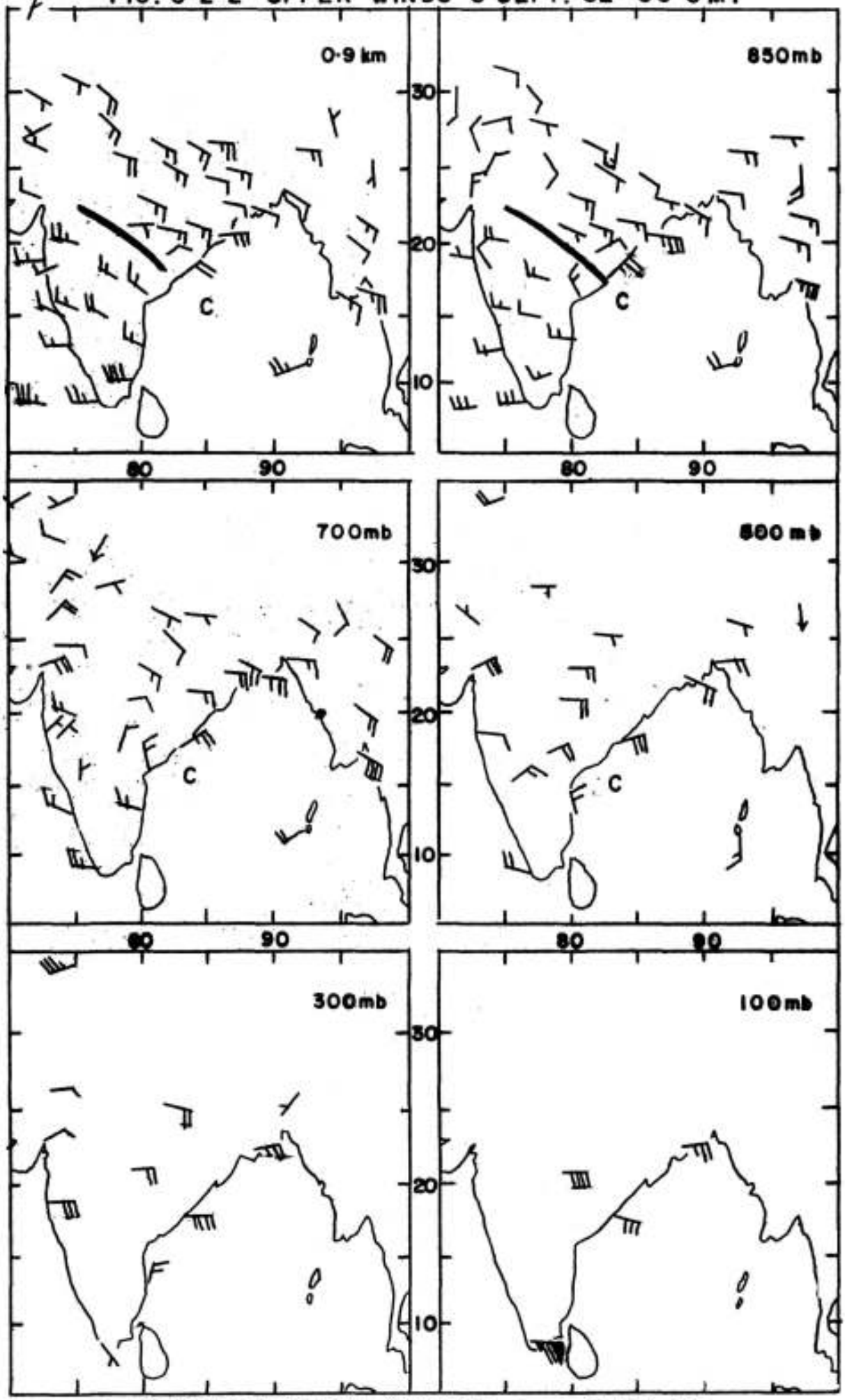


FIG. 6·2·2 UPPER WINDS 8 SEPT. 62 - 00 GMT



C- Centre of cyclonic circulation —— Trough line

FIG.6·2·3 SYNOPTIC CHARTS 0300 GMT 9 SEPT. 62

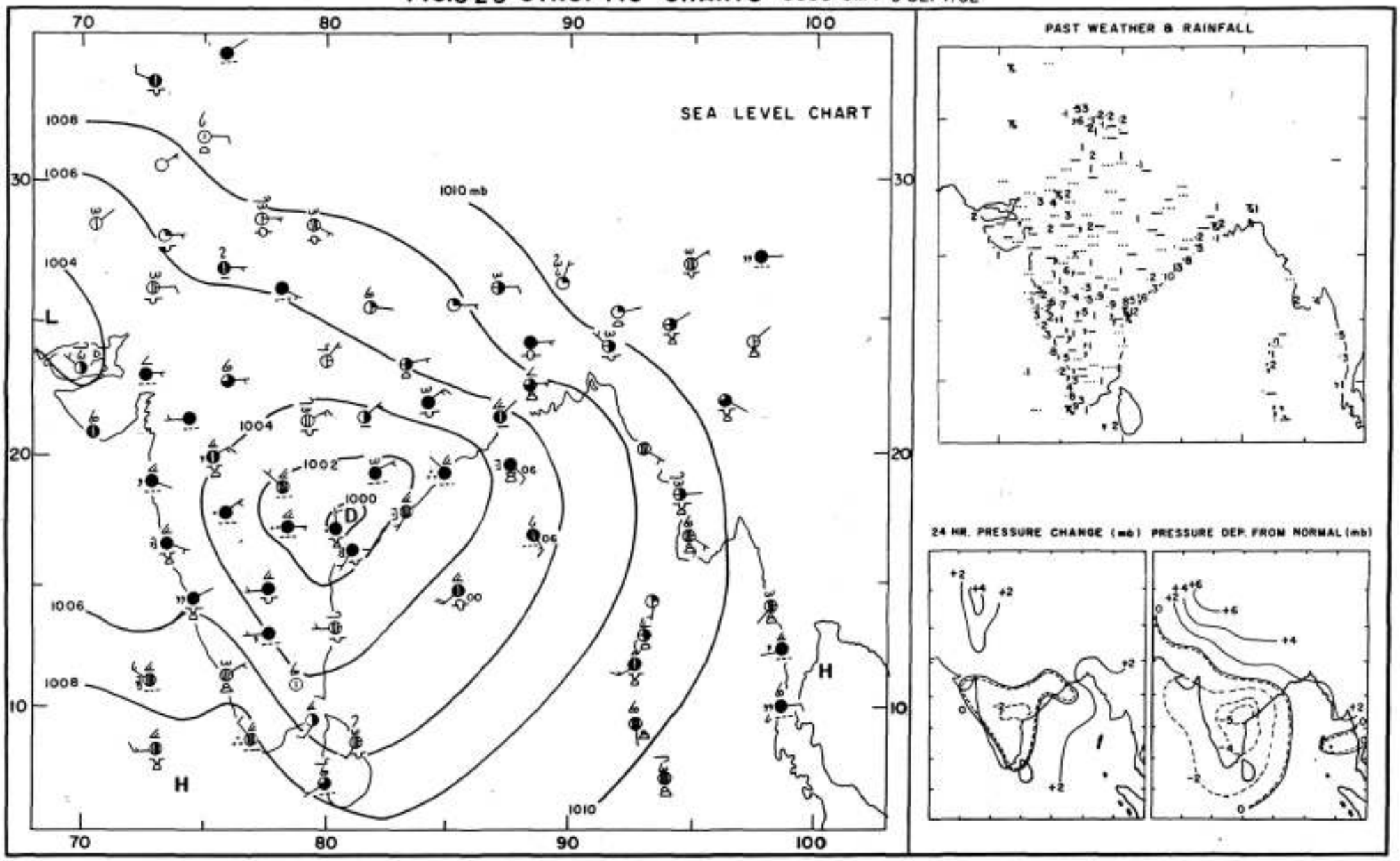


FIG. 6·2·4

SYNOPTIC CHARTS 0300 GMT 10 SEPT. 62

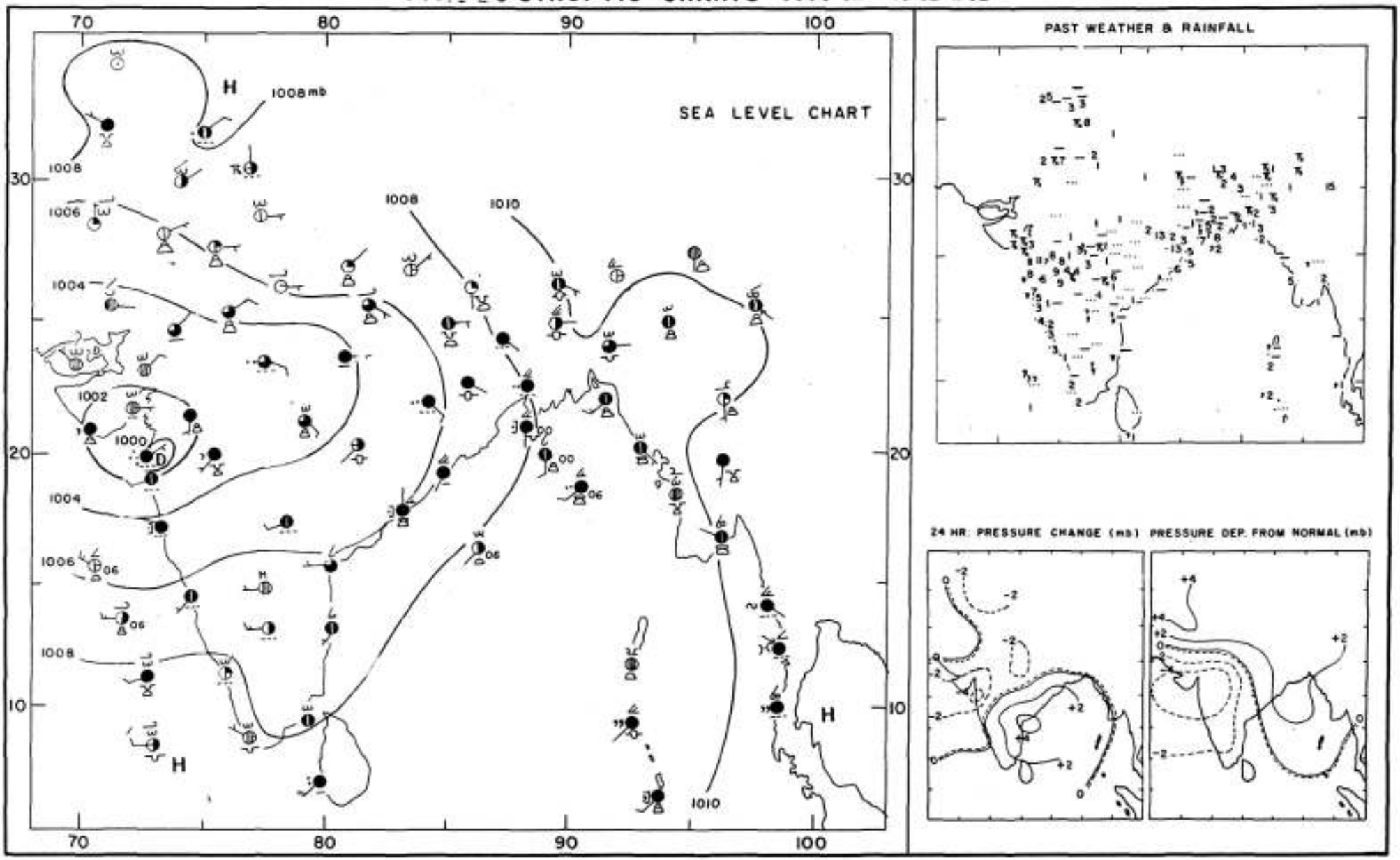
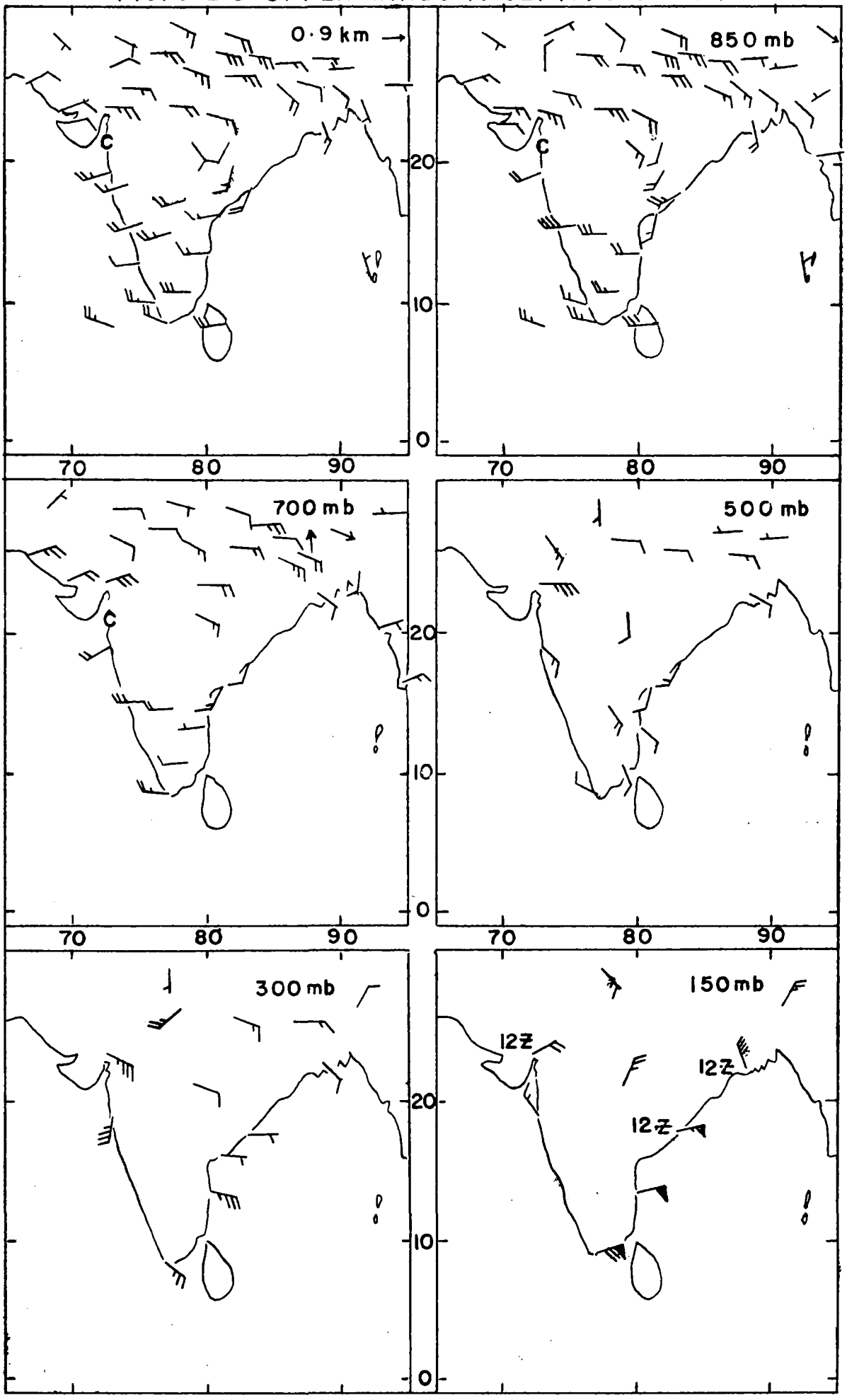


FIG. 6·2·5 UPPER WINDS 10 SEPT. 62 00 GMT



C-Centre of cyclonic circulation

FIG. 7·1 SYNOPTIC CHARTS 0300 GMT 11 JUN 70

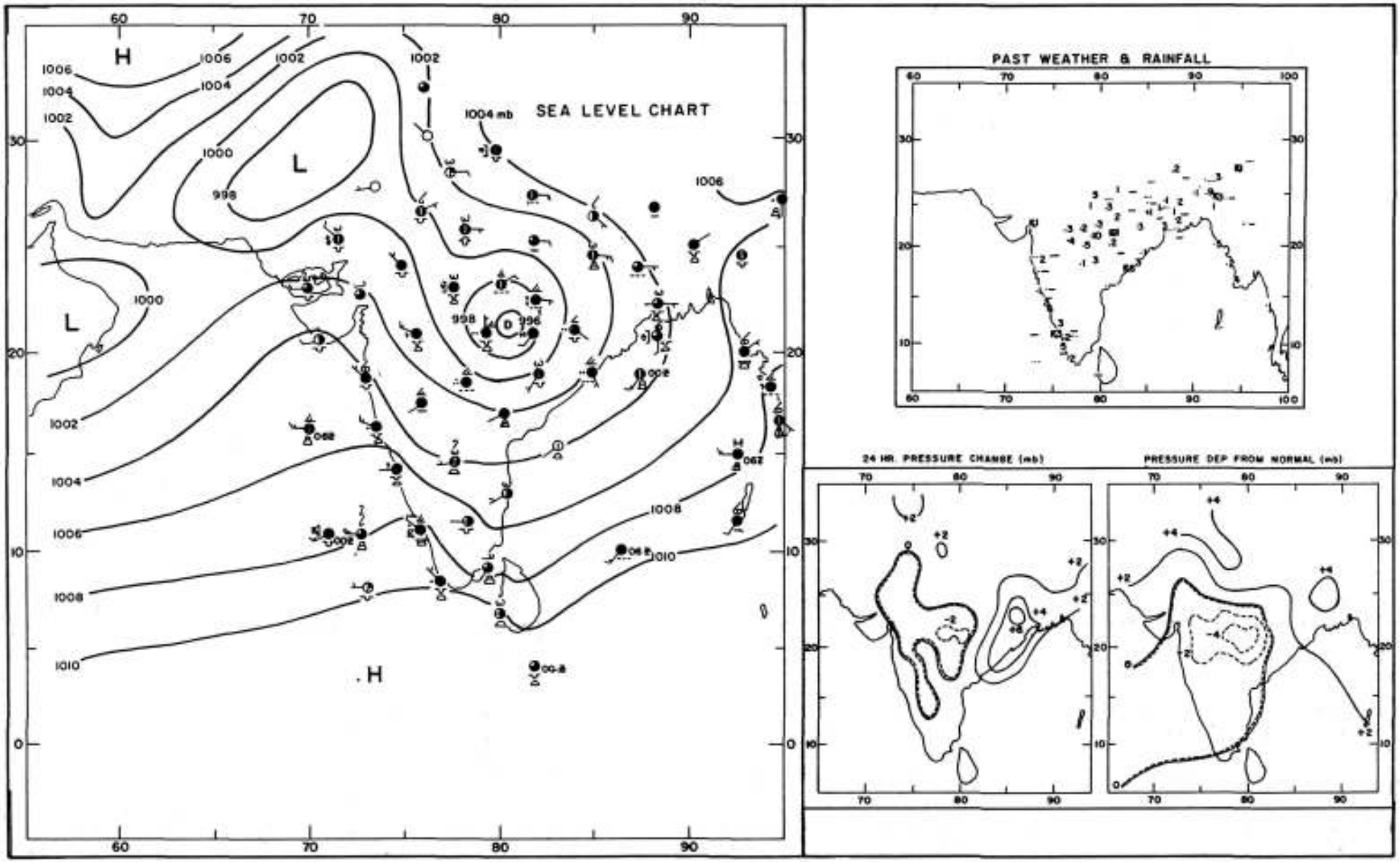
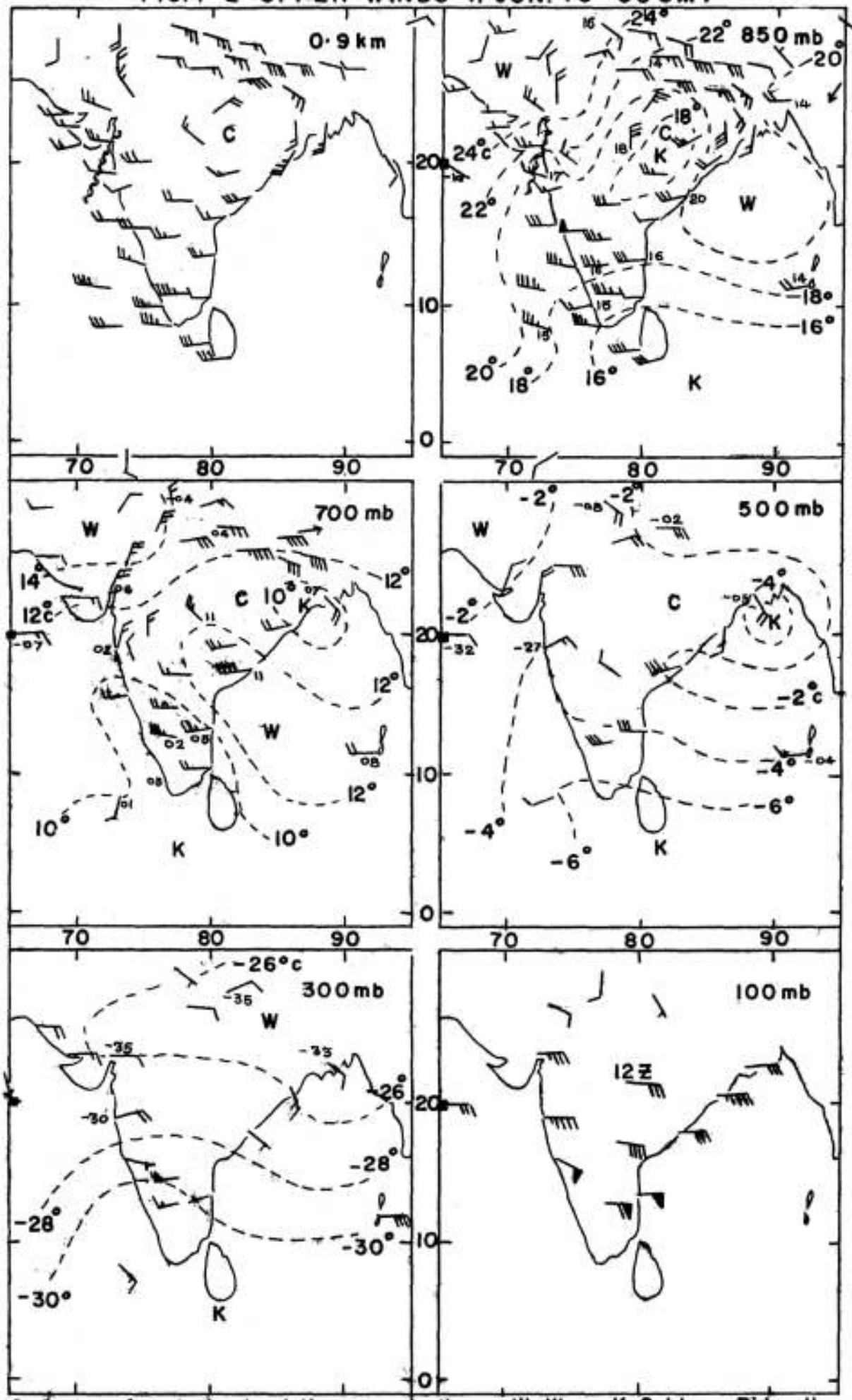
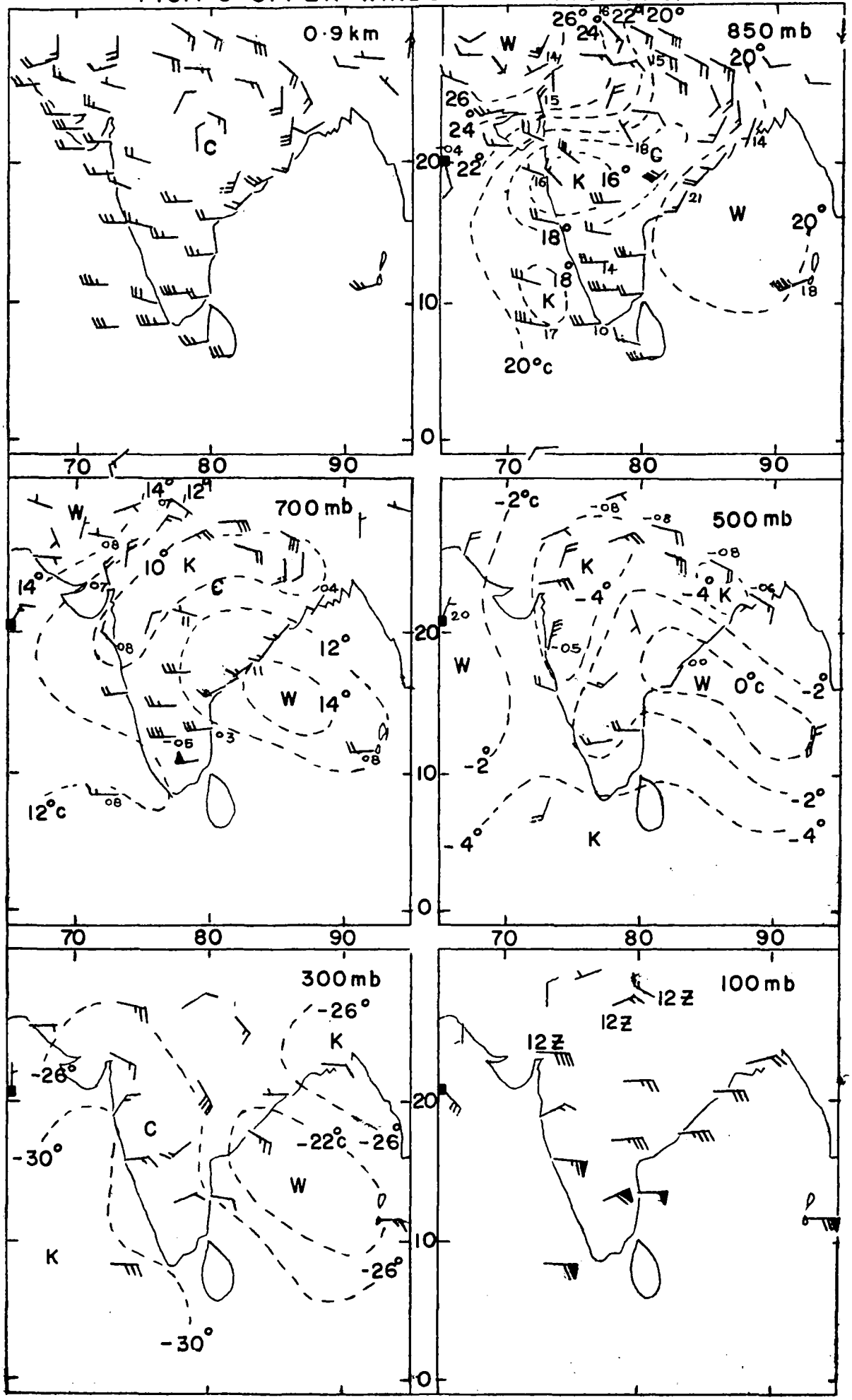


FIG. 7·2 UPPER WINDS 11 JUN. 70 00 GMT



C-Centre of cyclonic circulation ----- Isotherm W-Warm K-Cold ~~Ridge line
Plotted figures $T_d T_d$ ■ Refers to Masirah lat. 20°41'N long. 58°54'E

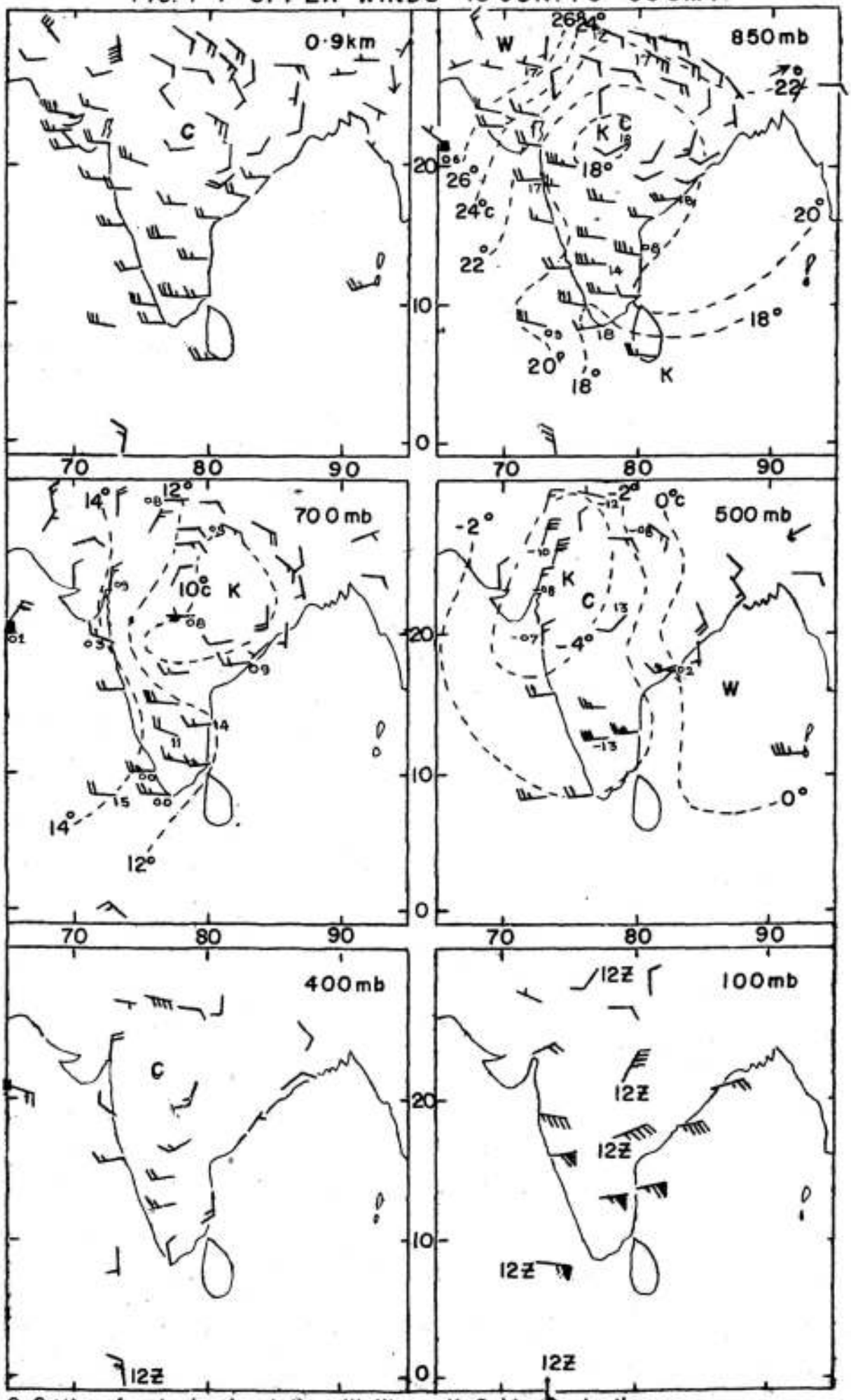
FIG. 7·3 UPPER WINDS 12 JUN. 70 00 GMT



C- Centre of cyclonic circulation ----- Isotherm W- Warm K- Cold

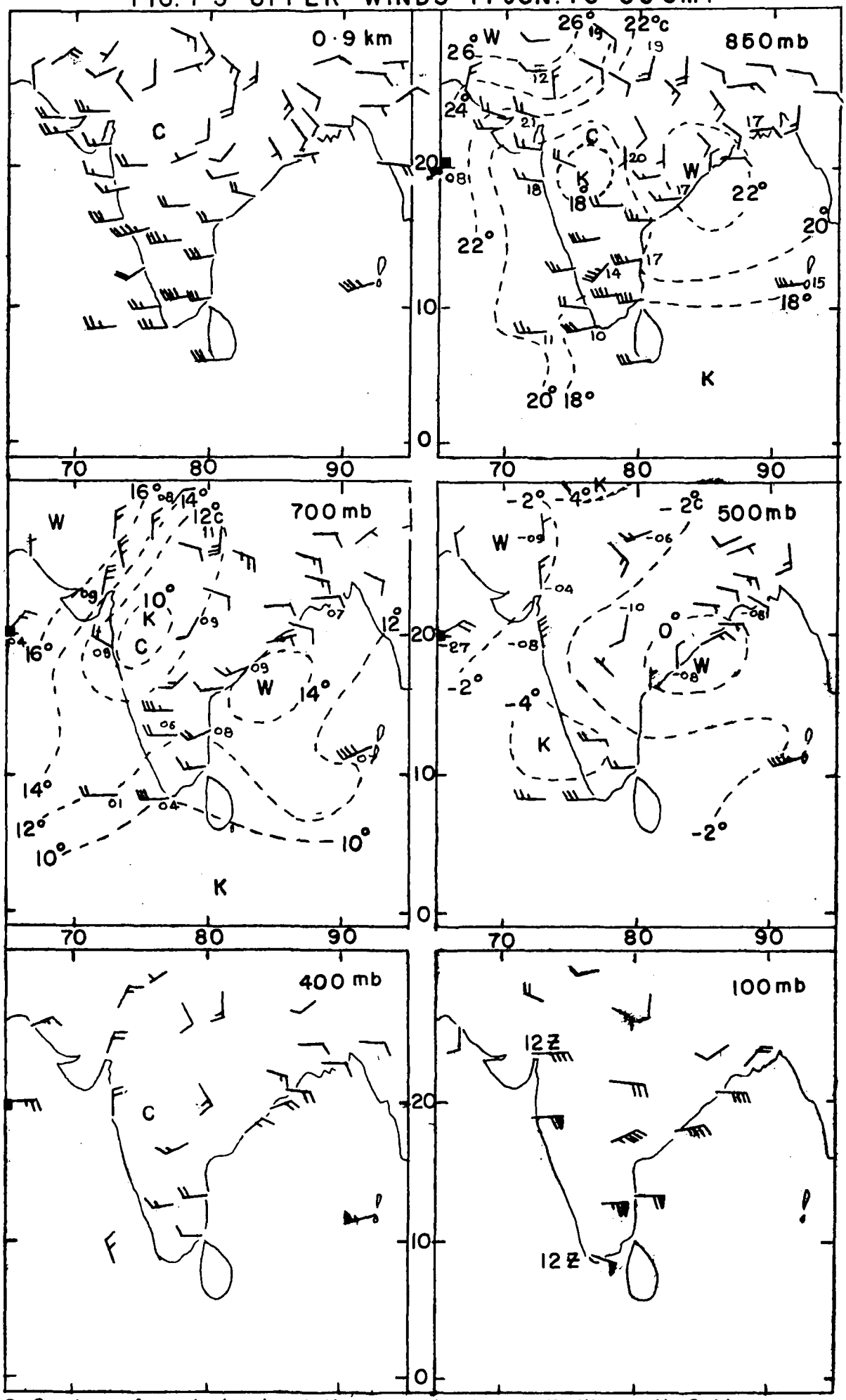
Plotted figures $T_d T_d$ ■ Refers to Masirah lat. 20°41'N long. 58°54'E

FIG. 7·4 UPPER WINDS 13 JUN. 70 00GMT



C-Centre of cyclonic circulation W-Warm K-Cold ----- Isotherm
Plotted figures T_d T_d ■ Refers to Masirah lat. 20°41'N long. 58°54'E

FIG. 7·5 UPPER WINDS 14 JUN. 70 00 GMT



C-Centre of cyclonic circulation ------ Isotherm W-Warm K-Cold
Plotted figures T_dT_d ■ Refers to Masirah lat. 20°41'N long. 58°54'E

FIG.7·6 UPPER AIR CHART 14 JUN. 70 1200 GMT 500 mb.

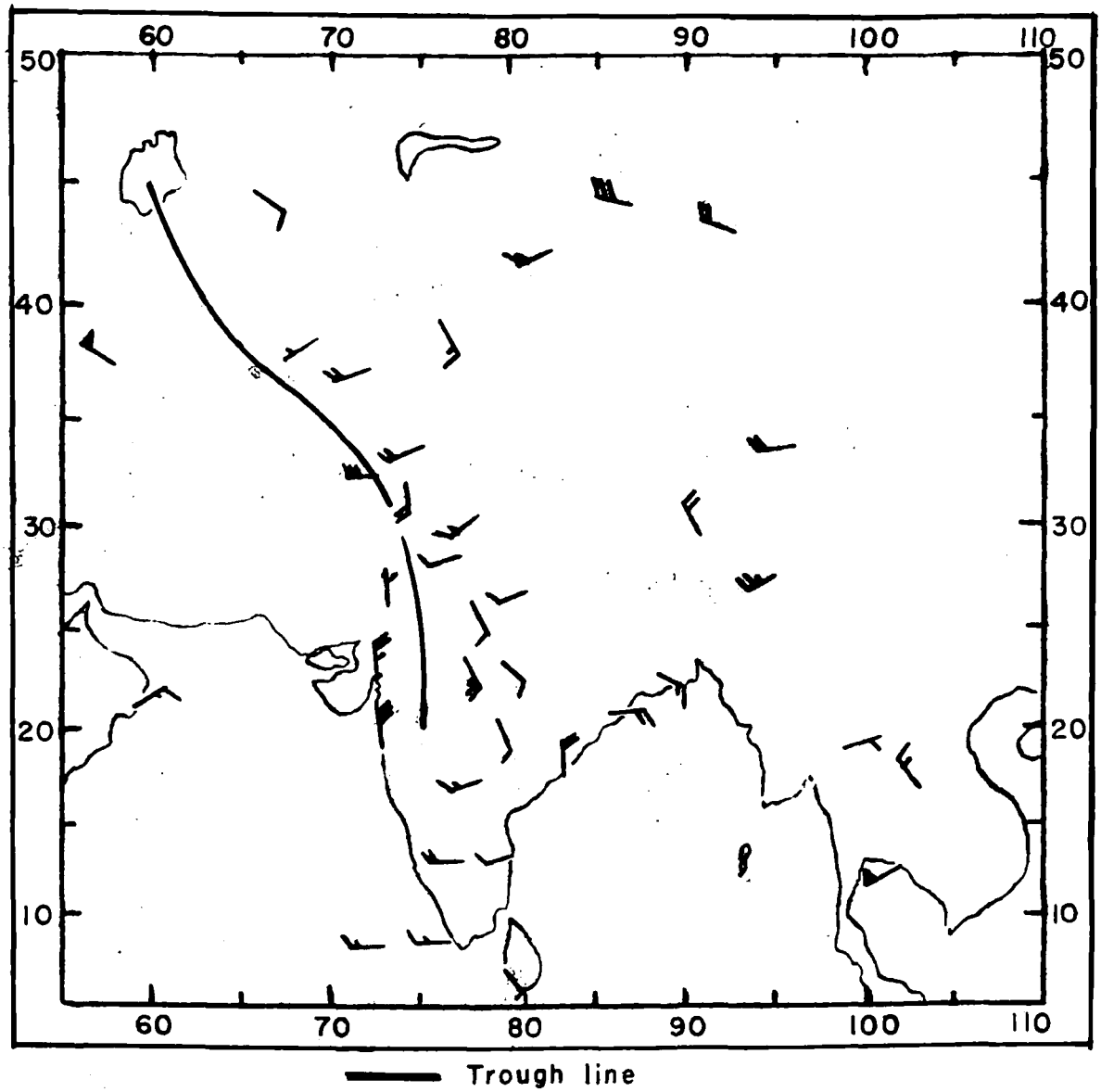


FIG. 7·7 UPPER WINDS 15 JUN. 70 00GMT

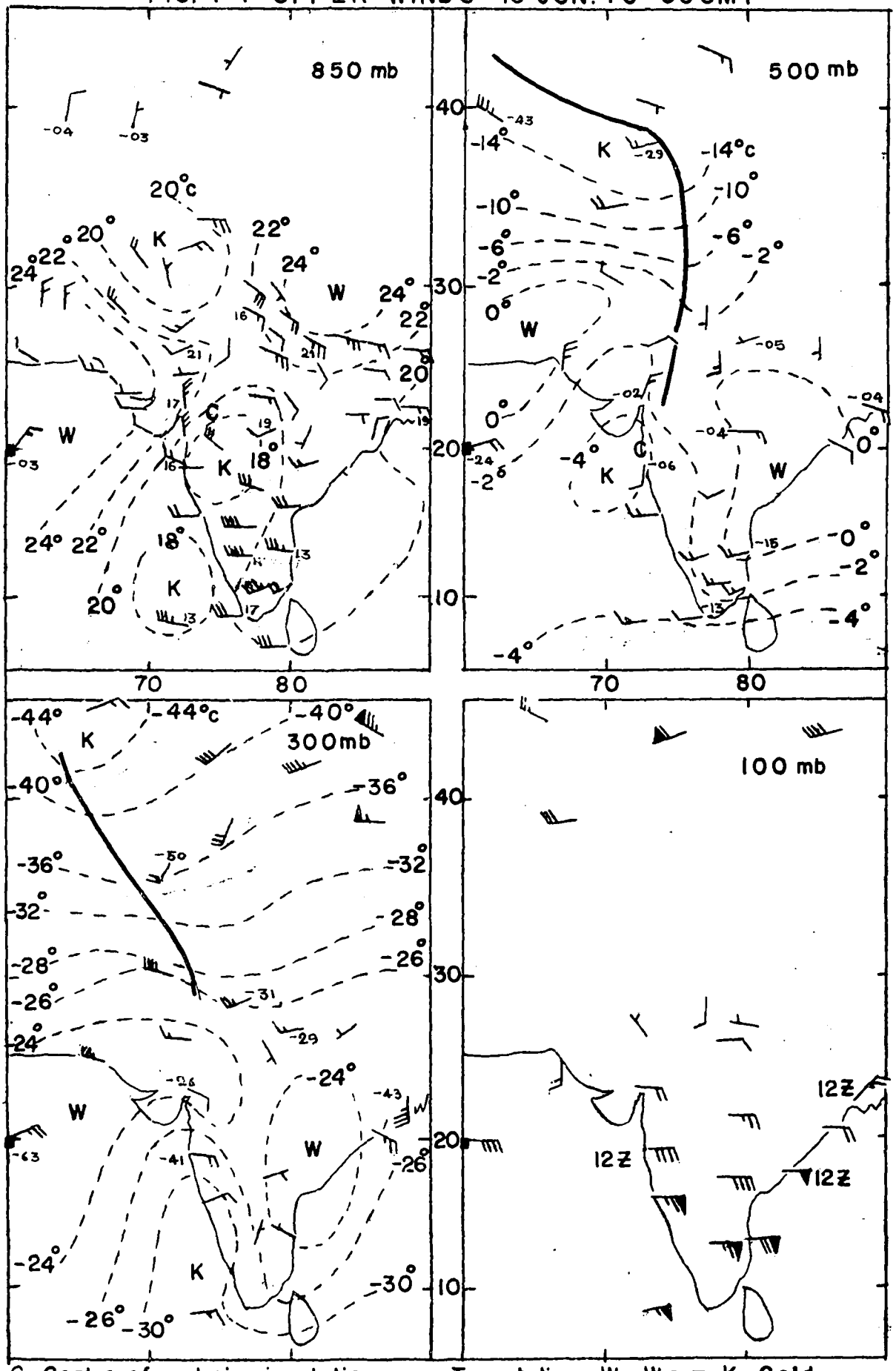
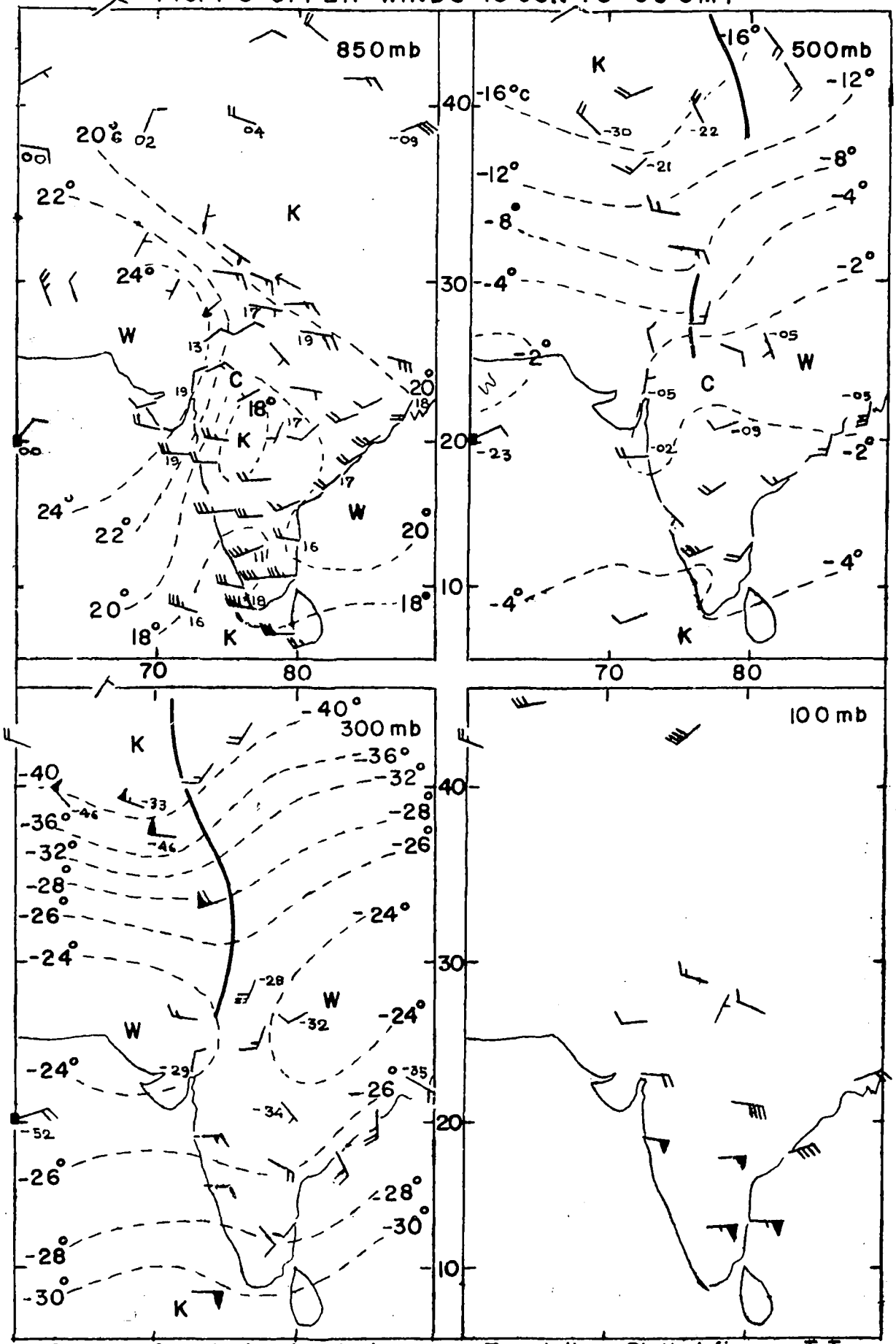


FIG. 7·8 UPPER WINDS 16 JUN 70 00 GMT



C- Centre of cyclonic circulation —— Trough line. Plotted figures T_d T_d
W- Warm K- Cold ■ Refers to Masirah lat. 20°41'N long. 58°54'E
------ Isotherm

FIG. 7·9 UPPER WINDS 17 JUN. 70 00 GMT

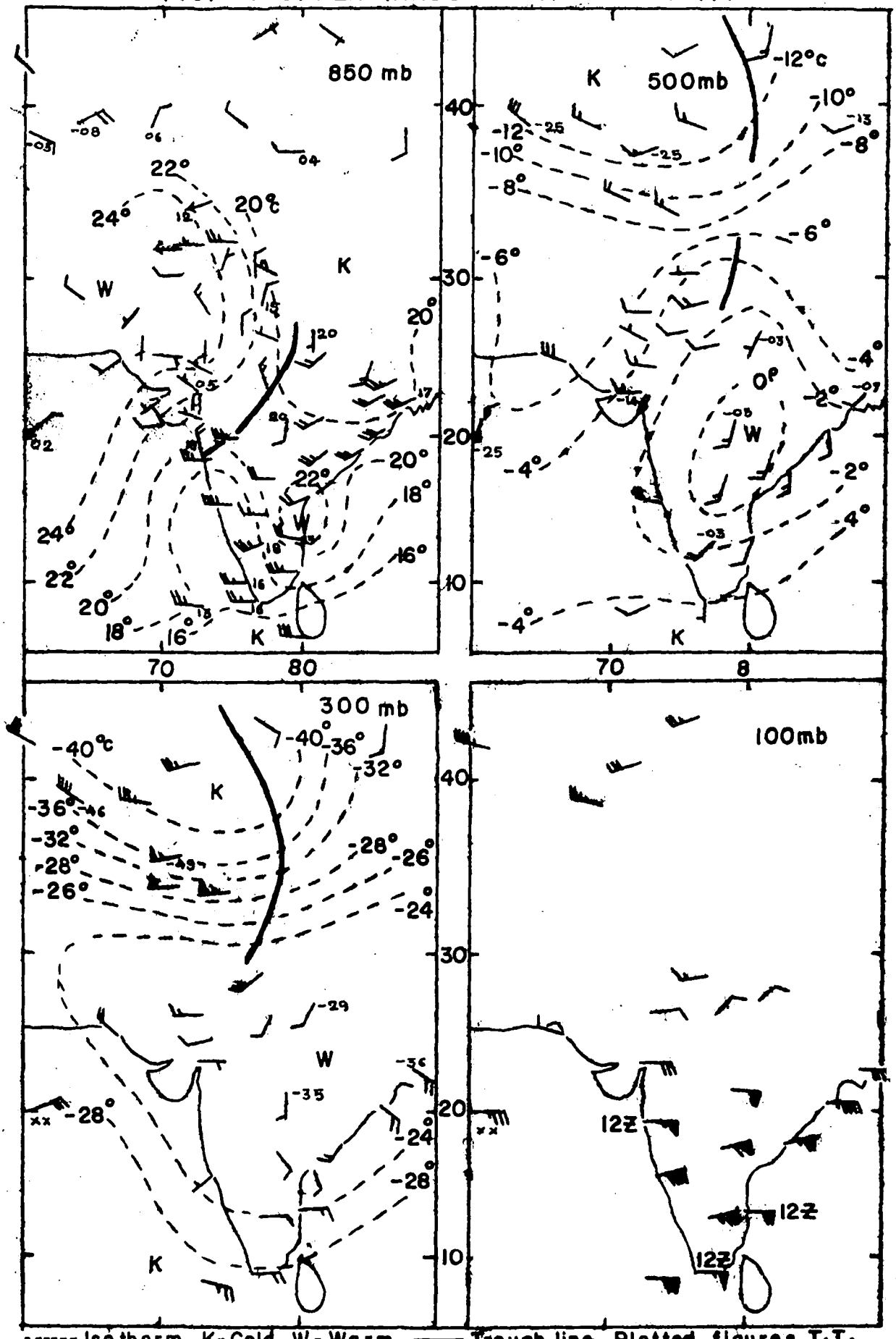
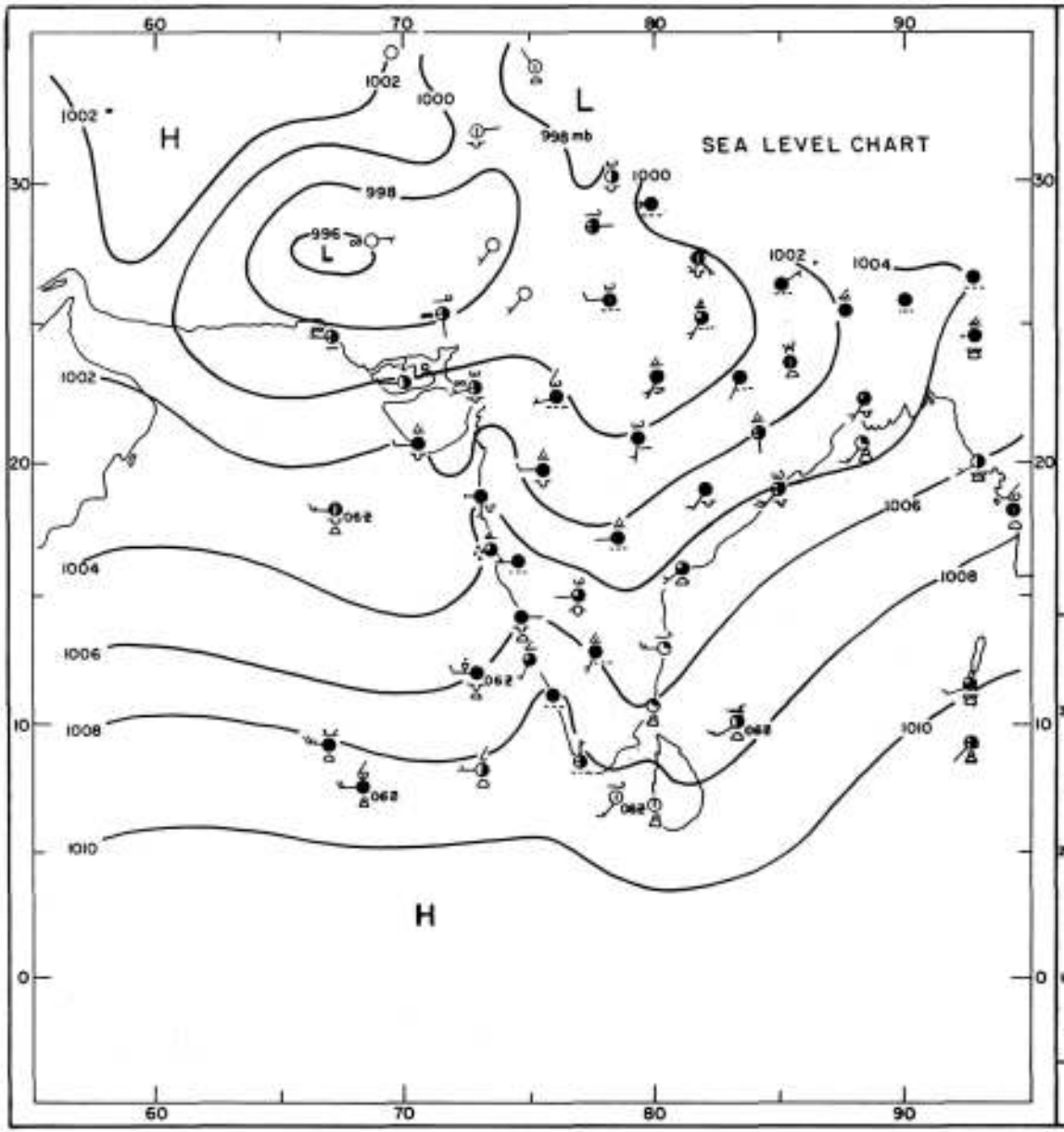
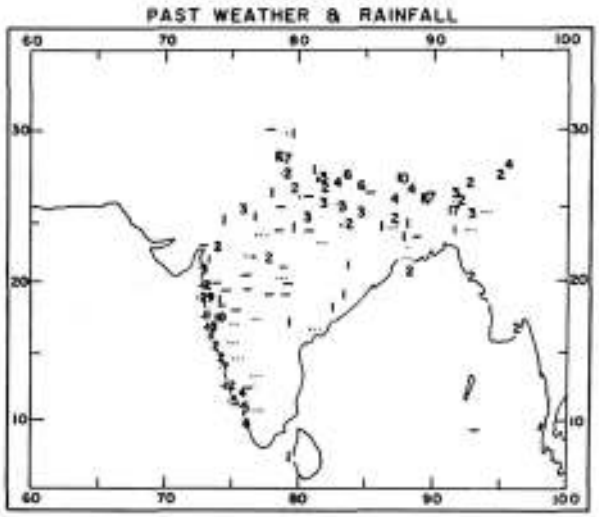
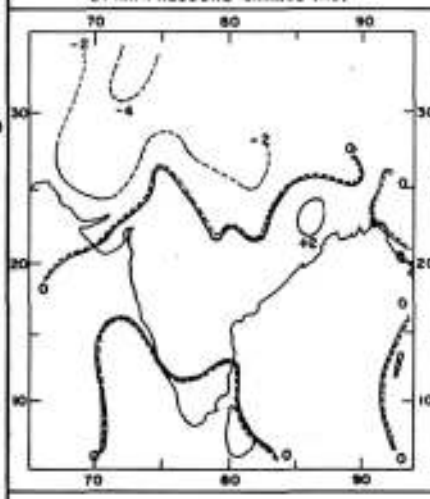


FIG. 7·10 SYNOPTIC CHARTS 0300 GMT 17 JUN. 70







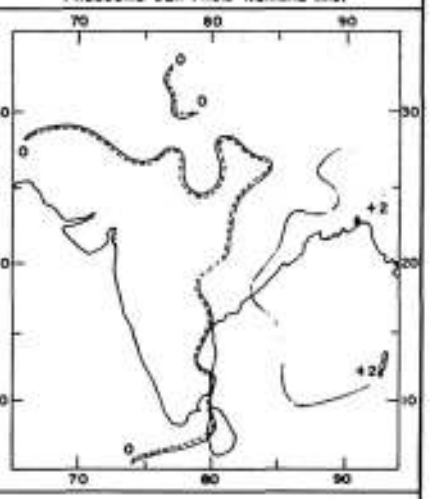


FIG. 7·11 TIME SECTION CHART FOR BOMBAY : 12 - 18 Jun. 70

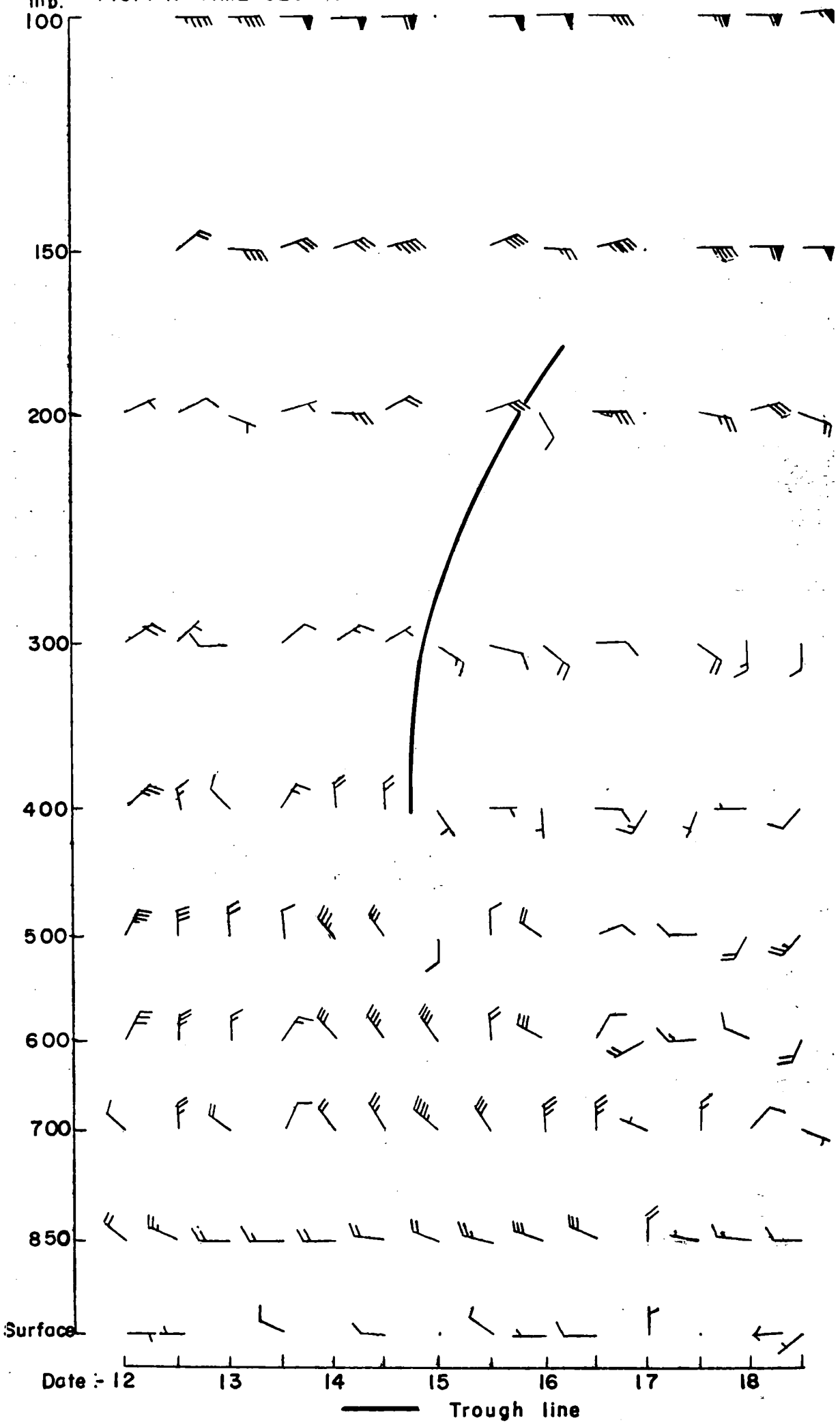
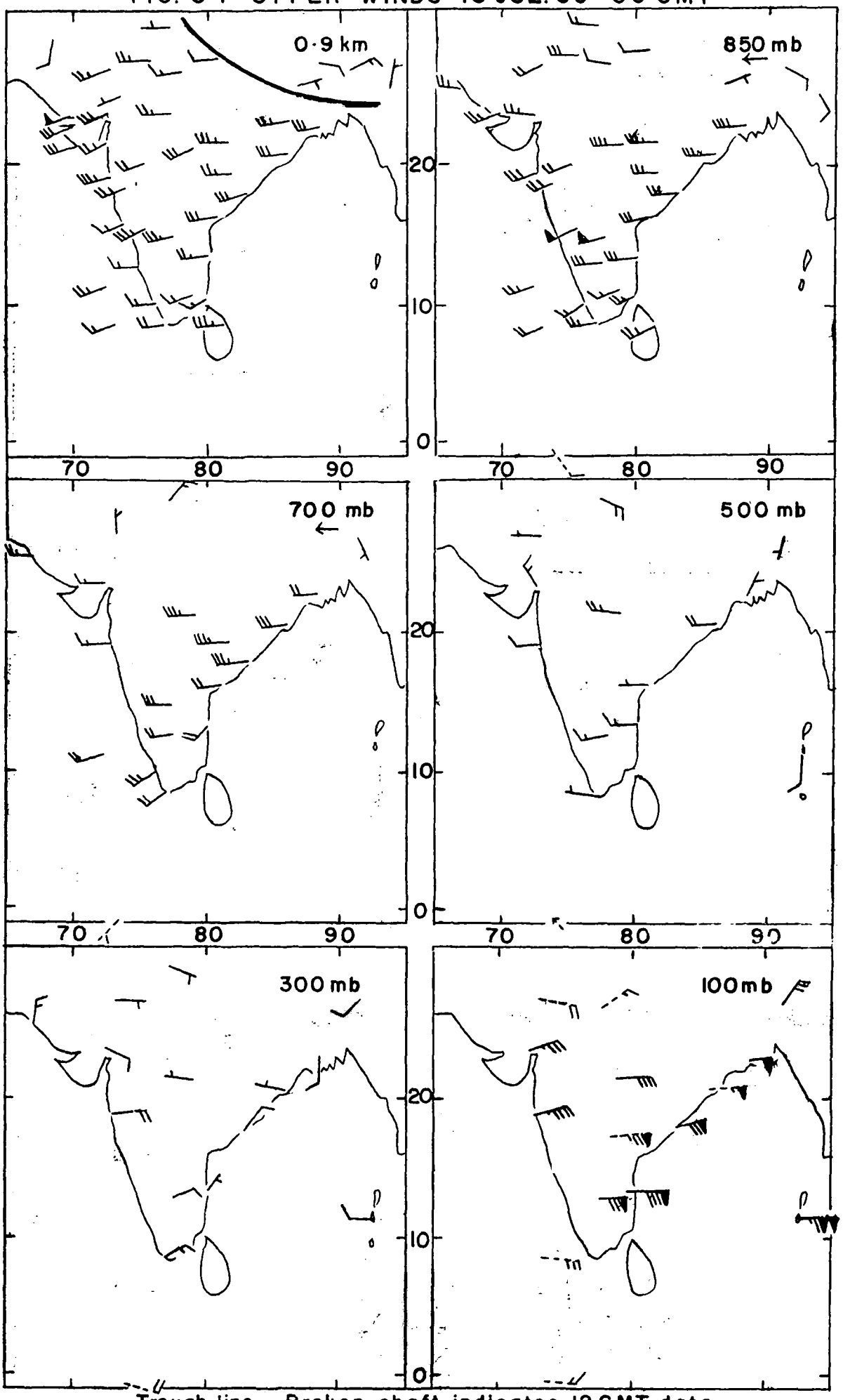


FIG. 8·1 UPPER WINDS 18 JUL. 69 00 GMT



—— Trough line . Broken shaft indicates 12 GMT data.

FIG. 8-2 SYNOPTIC CHARTS 0300 GMT 18 JUL. 69