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INDIA METEOROLOGICAL DEPARTMENT

FORECASTING MANUAL

PART III

DISCUSSION OF TYPICAL SYNOPTIC WEATHER SITUATIONS

2·1 LOW PRESSURE AREAS, DEPRESSIONS AND CYCLONIC STORMS IN THE INDIAN SEA AREAS DURING THE PRE-MONSOON SEASON

BY

N. M. PHILIP, V. SRINIVASAN AND K. RAMAMURTHY.

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FORECASTING MANUAL

Part III - Discussion of Typical Synoptic Weather Situations

2.1 Low Pressure Areas, Depressions and Cyclonic Storms in the Indian Sea Areas during the Pre-Monsoon Season

by

N.M. Philip, V. Srinivasan and K. Ramamurthy

Contents:

1. Introduction

1.1 According to the Departmental classification of the year into various seasons, the Pre-Monsoon season, also known as 'Hot Weather Period' covers the months March, April and May. The weather over the Indian Sea areas (i.e. Arabian Sea and Bay of Bengal) is relatively quiescent in March; disturbed weather is mostly in the second half of the season. Depressions and cyclonic storms of the pre-monsoon type may continue to form in the early part of June also till the southwest monsoon establishes over the sea areas. The general features of storms and depressions in the Indian sea areas have already been dealt with in FMU Rep. No. III-4.1 on "Weather over the Indian Seas during the Post-Monsoon Season"; hence, this aspect will be touched upon in the present report, when necessary, only with reference to the special characteristics of the pre-monsoon disturbances. The present report may, therefore, be usefully read along with FMU Rep. No. III-4.1.

1.2 The common synoptic situations causing disturbed weather over the sea areas during this season are

i) cyclonic storms and depressions; and

ii) low pressure areas and troughs of low pressure.

Apart from tropical cyclones, an important feature of the weather during the season is the advance of the southwest monsoon which occurs towards the second half of May and the beginning of June. This subject has been dealt with earlier in FMU Rep. No. IV-18.2 "Synoptic Features associated with onset of southwest monsoon over Kerala" and hence will be discussed only briefly in this report. Another type of severe weather is when the nor'westers* that occur over Orissa, Bihar and West Bengal occasionally drift east or southeast into north Bay of Bengal.

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* This subject is discussed in FMU Rep. No. III-2.2.

2. Storms and Depressions – Some climatological aspects

2.1 Leaving apart the cyclonic disturbances of the southwest monsoon season, there are two peak periods of tropical cyclone activity in the Indian sea areas – one in the pre-monsoon and the other in the post-monsoon season. October and November are the months of maximum storm activity; next comes May and the early part of June. Climatological information of storms and depressions are already available in the departmental storm track atlas as well as the papers by Rai Sircar (1955) and Rai Choudhary et. al. (1959). A few additional points regarding the climatological aspects will be discussed below.

2.2 Frequency distribution

2.2.1 The statistics of storms and depressions in the Bay of Bengal and Arabian Sea month by month for the pre-monsoon season are given in Table I. The statistics have been split into 3 periods – 1877 to 1890, 1891-1960 and 1961-1972 (the last one is a period when satellite data became available). Each month has been sub-divided into two parts.

TABLE – I

Statistics* of cyclonic disturbances that formed in the Bay of Bengal and the Arabian Sea during the months of March–May

Month	Period	Depression			Storm			Severe Storm			
		1–15	16–31	Total	1–15	16–31	Total	1–15	16–31	Total	Total for the period
	I–Bay of Bengal										
March	1877–1890	–	–	–	–	–	–	–	–	–	–
	1891–1960	–	1	1	1	1	2	2	–	2	5
	1961–1972	–	–	–	–	–	–	–	–	–	–
	Total	–	1	1	1	1	2	2	–	2	5
April	1877–1890	–	–	–	–	–	–	–	–	–	–
	1891–1960	3	5	8	3	8	11	2	5	7	26
	1961–1972	–	–	–	–	–	–	1	1	2	2
	Total	3	5	8	3	8	11	3	6	9	28
May	1877–1890	–	3	3	2	–	2	2	2	4	9
	1891–1960	6	11	17	5	5	10	9	9	18	45
	1961–1972	–	3	3	4	1	5	5	3	8	16
	Total	6	17	23	11	6	17	16	14	30	70
	II–Arabian Sea										
March	1877–1890	–	–	–	–	–	–	–	–	–	–
	1891–1960	–	–	–	–	–	–	–	–	–	–
	1961–1972	–	–	–	–	–	–	–	–	–	–
	Total	–	–	–	–	–	–	–	–	–	–
April	1877–1890	–	–	–	–	–	–	–	–	–	–
	1891–1960	–	2	2	1	–	1	1	3	4	7
	1961–1972	–	–	–	–	–	–	–	–	–	–
	Total	–	2	2	1	–	1	1	3	4	7
May	1877–1890	–	–	–	–	–	–	–	4	4	4
	1891–1960	–	4	4	–	2	2	3	8	11	17
	1961–1972	–	1	1	–	–	–	1	1	2	3
	Total	–	5	5	–	2	2	4	13	17	24

* From "Tracks of Storms and Depressions in the Bay of Bengal and Arabian Sea (1877–1960)" – 1964 and "Tracks of Storms and Depressions in the Bay of Bengal and Arabian Sea"(1961–1970)" (Addendum) 1972.

2.2.2 The Table brings out the following features:-

i) As in the post-monsoon season, Bay of Bengal is more prone to cyclonic storms and depressions than Arabian Sea in the premonsoon season also. As against 114* storms and depressions in the Bay in the months of March-May during the period 1877-1972, there were only 35 in the Arabian Sea.

ii) The storm season begins only by April; storms and depressions occur rarely earlier. The number is more in the second half than in the first half of April.

iii) May constitutes the main storm month; the storm season may continue into June also till the southwest monsoon is established over the sea areas.

iv) Stronger systems like cyclonic and severe cyclonic storms, are more in number than weaker systems like depressions. In May, severe storms are also more numerous than storms. It can, therefore, be antitipated that storms developing in May have a good chance of reaching the severe stage.

2.3 Place of origin

2.3.1 The locations where depressions were first spotted on the synoptic charts and where they intensified into cyclonic storms and subsequently into severe cyclonic storms are given in Figs. 2.1(a) to 2.1(i). Since storm formation is practically nil in March, no chart is given for this month. The mean monthly sea surface temperature isopleths** are also superposed on these diagrams. Some of the climatological features brought out by these diagrams are:-

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* Taking into account the statistics for 1891-1960 as per Table III (b) of "Tracks of Storms and Depressions in the Bay of Bengal and Arabian Sea 1877-1960" IMD 1964.

** From "Monthly charts of Mean, Min. and Max. sea surface temperature of the Indian Ocean", Special Publication, SP-99, 1967 (reprinted 1968), published by U.S. Naval Oceanographic Office, Washington, D.C.

(a) April:

Depressions form and also intensify over Bay of Bengal south of 15°N. Laccadives-Maldives and the adjoining areas are the places of formation of depressions and storms in the Arabian Sea. Over the areas of formation of depressions and their intensification, both in the Bay of Bengal and Arabian Sea, the sea surface temperature is about 29 to 29.5°C (84-85°F) in the mean. This temperature is even higher than the threshold value of 26-27°C considered favourable for storm formation.

(b) May:

The whole of the Bay of Bengal to the north of 10°N is susceptible to depression formation; intensification also occurs over the area north of 12°N. In the Arabian Sea, depressions form over Southeast and adjoining East Central Arabian Sea; intensification is, however, spread out westwards also over West Arabian Sea. Over these areas, sea is quite warm as in April, with a temperature of 29-29.5°C (84-85°F).

(c) June:

While depressions form over the Bay of Bengal north of Lat. 15°N, their intensification into cyclonic storms/severe cyclonic storms is confined to the area north of Lat. 18°N. In the Arabian Sea, depressions form in East Central Arabian Sea while their intensification is spread out into northeast Arabian Sea also. These areas have a sea surface temperature of 29°-29.5°C (84-85°F).

2.3.2 Storms and depressions practically cease formation once the southwest monsoon has advanced into the sea areas and is established. However, in the Bay even after the advance of the southwest monsoon, depressions and on rare occasions cyclonic storms form over the north Bay of Bengal, but these disturbances are entirely of a different character from the tropical disturbances of the pre-monsoon season.

2.3.3 The storms and depressions that form late in the season towards second half of May or beginning of June usually usher in the southwest monsoon.

2.4 Movement

2.4.1 A large majority (nearly 60%) of cyclonic storms in the Bay move towards Bangla Desh or Burma; only about 30% of them cross the Indian coast, such cases being more in May than in April. A few also dissipate over the sea. A general northward movement which may ultimately result in recurvature is characteristic of the Bay cyclones during the season.

2.4.2 In the Arabian Sea also, a good percentage of storms either move towards Arabia coast or dissipate over the sea. Only about 25% cross Indian coast – mainly north Maharashtra – Gujarat coasts.

2.4.3 The details of the statistics of storms and depressions crossing the coast or coming within 2 degrees of the coast are given in Table II.

TABLE – II

Statistics of depressions and storms in Bay of Bengal and Arabian Sea crossing the Indian coast or coming within 2 degrees of the coast during the months March to May (period 1891–1970)

	March		April		May		Total	
	Bay	Arabian Sea	Bay	Arabian Sea	Bay	Arabian Sea	Bay	Arabian Sea
No. of depressions	–	–	2	–	6	–	8	–
No. of storms	–	–	2	–	6	–	8	–
No. of severe storms	1	–	1	2	9	5	11	7
Total No. of disturbances formed	5	–	27	8	57	22	89	30
Percentage that crossed/approached Indian coast	20	–	19	25	37	23	30	23

2.5 Development, intensity and other details

2.5.1 In Sec. 3 of FMU Rep. No. III-4.1 the different stages of the life history of a typical disturbance have been given. In Table II of the same Section, the time intervals between formation and intensification have been indicated in the case of cyclonic storms of post-monsoon season. A similar statistics for the pre-monsoon is given below in Table III.

TABLE - III

(a) Percentage frequency of depressions intensifying into storms (in Bay of Bengal and Arabian Sea) within different time intervals

(Period of data 1891-1970)

Month	0-12 hrs	12-24 hrs	24-36 hrs	36-48 hrs	48-72 hrs	72-96 hrs	96-120 hrs
April	-	33	33	-	-	17	17
May	22	34	9	13	-	22	-
Average percentage	11	33	21	7	-	20	9

(b) Percentage frequency of storms intensifying into severe storms (in the Bay of Bengal and Arabian Sea) within different time intervals (Period of Data 1891-1970)

Month	0-12 hrs	12-24 hrs	24-36 hrs	36-48 hrs	48-72 hrs	72-96 hrs	96-120 hrs
April	-	80	-	20	-	-	-
May	30	44	7	4	-	11	4
Average percentage	15	62	3	12	-	5	2

The table shows that during the pre-monsoon months, depressions intensify into cyclonic storms within 36 hrs, in 65% of the cases; in 44% of the cases it is within 24 hrs; 12-24 hrs is the most common interval (33% cases). Similarly, they further intensify into severe cyclonic storm within 48 hrs in over 92% of the cases and in 24 hrs in 77% of the cases. The statistics brings out the rapid intensification, characteristic of the immature stage of the cyclonic storms. The time interval taken for intensification into cyclonic storms in the case of pre-monsoon disturbances does not differ very much from that of post-monsoon cases. However, intensification of cyclonic storms into severe storms appear to be quicker during pre-monsoon season as compared to the post-monsoon season.

2.6 The frequency distribution of the lowest pressures observed in the case of severe cyclonic storms has been given in Table IV of FMU Rep. No. III-4.1. From this Table it will be seen that May is a month of intense storms during the pre-monsoon season.

2.7 As explained in para 4.1.1.8 of FMU Report No. III-4.1, an analysis of the size of the storms in the Bay of Bengal during the pre-monsoon season was made by measuring the average diameter of the outermost closed isobar. The results are given in Table IV below:

TABLE - IV

Percentage frequency of mean diameter (in degrees) of cyclonic storms in the Bay of Bengal during March to May (based on data of 1951—1970)

	Mean Diameter (in degrees) Lat/Long								
	2-3	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11
Percentage frequency	5	3	21	15	16	19	12	7	2

(Total No. of observations: 61)

It is seen that the cyclonic storms of the pre-monsoon season are slightly less in size than those of the post-monsoon season (see Table III of FMU Rep. No. III-4.1). Nearly 70% of the pre-monsoon storms have a diameter of 4 to 8° of lat/long. The maximum diameter has been only 11 deg. in contrast to 14.5 degrees in the case of post-monsoon storms. The outermost closed isobar in the pre-monsoon storms has generally a value ranging between 1002 and 1006 mb.

2.8 Table V gives some details of the tropical disturbances during the pre-monsoon season, (based on data for the period 1968-1972) as seen in satellite pictures. The table indicates* that storms of Cat.2 or 3 are the most frequent and the most common size of the overcast area of these systems ranges upto 3 degrees in diameter. The smallest diameter was 1.5°. When we derive the maximum winds from the satellite pictures, we find that according to this table, the storms in this season have winds of the order of 50-75 kt. Higher intensity storms are almost nil. When we compare these storms with those of the post-monsoon season (vide para 10.9 and 10.10 of FMU Rep. No. III-4.1) we find that

i) pre-monsoon storms are slightly smaller in size than post-monsoon storms and

ii) very intense storms are more likely in the post-monsoon season than in the pre-monsoon season.

TABLE - V

(a) Frequency distribution of various types of disturbances as seen from satellite pictures

Sea Area	A	B	C	C-	Type of disturbance C+	Cat.1	Cat.2	Cat.3	Cat. 4	Total No. of Obsns.
Arabian Sea	1	9	3	0	0	0	1	0	0	14
Bay of Bengal	1	6	4	0	1	0	3	2	1	18

(b) Frequency distribution of size of overcast (in degrees)

	1.1 to 2.0	2.1 to 3.0	3.1 to 4.0	4.1 to 5.0	Total No. of Observations
Arabian Sea	0	1	0	0	1
Bay of Bengal	3	2	0	1	6

* In view of the small number of samples the conclusions in this paragraph may be treated only as tentative.

2.9 The rainfall associated with the depressions and cyclonic storms of the pre-monsoon season when they cross the coast, is also heavy to very heavy as in the case of post-monsoon storms. Very heavy falls of the order of 30-40 cm have occurred on such occasions.

3. Synoptic conditions favourable for formation of cyclonic storms and depressions

3.1 The synoptic factors favourable for formation of storms have been discussed in detail in Sec.8 of FMU Rep. No. III-4.1. Here we will briefly discuss a few points peculiar to the pre-monsoon months.

3.2 Depressions and storms of the pre-monsoon season generally form in situ in the Indian sea areas. Unlike in the post-monsoon season, those that develop out of disturbances moving westwards into the Bay from the east are not common. The disturbance initially forms in the east-west oriented trough over the extreme south Bay and south Arabian Sea. The trough may not be well-delineated on the surface chart; but it is more marked in the upper air - 850 to 700 mb levels. In view of this, the disturbances that develop during this season may be more easily detected in the upper air first. On the surface chart and in the very low levels it may be initially seen only as a region of weak pressure gradient or light winds. This is particularly true in May. This east-west oriented trough is usually to the south of Lat.10°N in April; and it shifts northwards across the Bay and the Arabian Sea in May. The first signs of the intensification of the trough are:

i) Strengthening of the westerlies to the south in the low latitudes over the extreme south Arabian Sea and south Bay of Bengal. A strengthening of the lower tropospheric westerlies over Gan in the earlier part of the season and over Arabian Sea Islands, Sri Lanka, south Peninsula and Bay Islands later in the season is usually noticed prior to the formation of low pressure systems in the Arabian Sea and the Bay of Bengal; they may reach 30–40 kts in speed. Ships in this area also report on such occasions strong winds of the order of 20–30 kts.

ii) Reports of widespread convective activity over the sea areas, as reported by ships, is another significant sign to anticipate development. Satellite pictures also show heavy overcast clouding. Generally, the heavy cloud belt is broad and extends east–west over a long distance (some authors refer to this clouding as the ITCZ).

3.3 As may be seen from Figs. 2.1(a) to 2.1(i) large portions of Arabian Sea and Bay during this season are warmer than the threshold value of 26–27°C considered favourable for development. As in the post monsoon season

i) warm sea surface

ii) intensification of the east–west trough in the lower tropospheric wind field and

iii) heavy convective activity associated with the trough are precursors of formation of depressions and storms in the season.

4. Low Pressure Area and Troughs of Low Pressure

4.1 In March and April, an anticyclonic circulation predominates over the Arabian Sea and Bay of Bengal and weather is generally quiescent over these seas. The charts for two typical quiescent days (20 March 1968 – 12 Z and 4 April 1969 – 03Z) are given in Figs. 4.1(a) and 4.1(b). Satellite pictures for 20 March 1968 showed broken Cb, Ci over the extreme south Bay of Bengal and South Arabian Sea. Otherwise, the Bay as well as the Arabian Sea was free of clouds. On 4th April 1969, there was only a very small patch of broken to over cast Cb over the south Bay islands. The Arabian Sea and rest of the Bay were devoid of clouds.

4.2 In March and early April, the anticyclone over the sea areas is pronounced and it gradually becomes less marked as the season progresses. By the beginning of May, the high over the Bay of Bengal collapses. A similar oceani high also exists over the Arabian Sea and weakens much later (almost by the end of May). During these two months (March and April) low pressure areas form only over the extreme southern portions of the sea areas. Their movement also cannot be easily followed on account of the lack of data in the near equatorial areas. Low pressure areas with sequential east-west movement are generally noticed only in the month of May. Satellite pictures give valuable help in following the movement of the cloud systems associated with these low pressure areas. In March and April low pressure areas are seen on the charts, mainly close to the coasts of Sri Lanka and south Peninsula. Sometimes, the low pressure areas may be seen only in the upper air charts.

4.3 In addition to low pressure areas, we have also troughs of low pressure and they usually form along and off the coast, those appearing over Comorin, Laccadives, Maldives and off Mysore coast being more common. The trough of low pressure generally forms and dissipates in situ and may not show any appreciable movement. But those that develop later in the season may move northwards and bring in the monsoon to the country.

4.4 The statistics of these feeble low pressure systems, monthwise, are given below in Table VI.

TABLE-VI

Statistics of low pressure areas which formed in the Indian seas during the months March to May

Period of Data 1953-1972

		March	April	May
I. Bay				
Surface lows		20	19	8
Upper Air Lows		3	3	1
	Total	23	22	9
II. Arabian Sea				
Surface lows		4	10	9
Upper Air Lows		1	4	1
	Total	5	14	10

Table VI shows that these low pressure systems are more common in March and Apri in the Bay of Bengal and decrease considerably in May.

5. The Near Equatorial Trough

5.1? One of the synoptic features of the charts over the Indian sea areas during the pre-monsoon season is an east-west oriented trough with marked wind shift, in the near equatorial region, with westerlies prevailing to the south of the trough line. The westerlies are first noticed between equator and 5°N by about the middle of April and thereafter they gradually become a persistent feature by the end of April, as the season advances. In view of availability of more ships observations in the south Bay, the westerlies can be better document in the Bay of Bengal. The westerlies are weak in the beginning and as the season advances they become moderate or even strong.

5.2 Westerlies are present practically throughout the year in the near equatorial region as may be seen from the lower troposphere mean winds over Gan. In the beginning of the season (i.e. in March) northeasterlies prevail over the south Bay and south Arabian Sea, so that the trough line is close to the equat Subsequently in April, the westerlies penetrate slowly northwards into south Arabian Sea and south Bay.

5.3 The monthwise frequency distribution of wind directions (from ship reports) at some selected locations in the near equatorial region is given below:-

TABLE-VII

Mean percentage frequencies of wind direction – March to May

(From US Navy Marine Climatic Atlas of the World – Vol.III : Indian Ocean, September 1957)

Location	Wind direction							
	N	NE	E	SE	S	SW	W	NW
I. 5°N, 90°E								
March	15	31	9	3	2	3	3	4
April	5	11	8	6	8	15	8	3
May	—	—	1	1	14	59	12	1
II. 0°, 80°E								
March	12	6	4	4	11	12	11	5
April	2	1	4	4	13	24	23	4
May	0	0	0	2	12	56	16	1
III. 0°, 65°E								
March	25	9	4	3	2	6	4	12
April	2	2	2	2	6	15	18	27
May	1	–	1	3	17	25	27	4

The table brings out –

i) the appearance of westerlies in extreme south Bay and south Arabian Sea by April and their greater persistence as the season advances

ii) the appearance of westerlies at corresponding latitudes in the Bay earlier than in Arabian Sea.

5.4 Thunderstorms and shower activity are found along the trough line as well as in the westerly regime to the south of it. Satellite pictures often show heavy blobs of clouds in these areas and sometimes bands stretching over long distances of the sea. Frequently, the westerly stream in the near equatorial region freshens and winds may reach 20/30 kt; and such strengthening of the westerlies is associated with increased convective activity. Often such strengthening may be in association with low pressure systems in the near equatorial region to the south of the equator. With strong westerlies in the equatorial region, low pressure systems may develop in the low latitudes on either side of equator in the two troughs; some of them intensify into depressions and cyclonic storms as these lows move away from the equator.

6. Advance of the Southwest Monsoon

6.1 While we have well-defined normal dates of onset of southwest monsoon over the land areas, there are no similar dates for the sea areas. The charts published so far contain the dates, only for the Bay of Bengal and that too perhaps in a tentative way only. The advance normally occurs earlier into Andaman sea and the southeast Bay than into any other part of the Indian sea. The advance of the monsoon over the sea area is usually heralded by

i) ships and island stations reporting moderate to strong winds from southwest/west

ii) upper winds over island stations showing fairly deep westerlies upto at least 3 km; (radiosonde ascents at these stations may also show the incursion of the moist monsoon current).

iii) reports of squalls, rainfall and convective weather by ships and heavy rains over island stations

iv) satellite pictures showing heavy clouding which may be in the form of a long broad band or large blobs.

6.2 The northern limit or the advancing edge of the monsoon current over the sea area may be fixed by the above mentioned criteria. On the synoptic charts in the area of the monsoon current, the pressure gradient is fairly steep and the lower tropospheric winds (surface and upper air) strong. In contrast, winds and pressure gradient to the north of the northern limit of the monsoon current are weaker, so that significant cyclonic vorticity is present at the advancing edge of the monsoon current.

6.3 A typical day's charts (28 May 1969 0300Z) where the monsoon had advanced over parts of the Bay and the Arabian Sea are given in Fig. 6.1 a and b. On this day, the southwest monsoon had advanced upto nearly 12–15°N in the Arabian Sea and the Bay of Bengal; along the Arakan coast it had reached upto Akyab. The ships observations in the monsoon field reported moderate to strong southwest/westerly reaching upto 30/35 kts in speed. Along and near the advancing edge of the current, thunderstorms and showers have been reported, and judging by the 24 hrs amounts at island and coastal stations (see 29-03Z rainfall) the rainfall had been heavy. On the surface chart, along the northern edge of monsoon current a discontinuity in pressure gradient was noticed with much stronger gradient to the south. In upper air also, the monsoon current is seen to be one of moderate to strong westerlies extending upto atleast 700 mb. The contrast in moisture distribution may be seen by a reference to relative humidity distribution (composite of 27, 28 and 29 May 1969) at 850 and 700 mb levels (Figs. 6.2 a and 6.2 b). The tephigrams (Port Blair and Calcutta for 27 May 1969 00Z) representing respectively the monsoon and non-monsoon areas are given in Fig. 6.3.

6.4 The satellite pictures for 28 and 29 May also show extensive heavy clouding over the sea areas from West Arabian Sea to Arakan coast associated with the advancing monsoon current.

6.5 We will now discuss a few case histories of typical synoptic situations over the sea areas during this season. Two typical days of quiescent weather in the earlier part of the season have been illustrated in Figs. 4.1 and 4.2. A case of advancing monsoon current has also been discussed in this section (para 6.3). In the following sections, therefore, we will discuss a few other tyes of situations viz. storm, depression and low pressure area.

7. Severe Cyclonic Storm in the Bay of Bengal moving towards Bangla Desh - 1 to 7 May 1970

7.1 Cyclonic storms which develop in the Bay of Bengal during the pre-monsoon months of April and May have a tendency to move more often in a north/northnortheasterly direction than towards the west or westnorthwest which is more common in the post-monsoon season. During the pre-monsoon season even those cyclonic storms which move initially in a west/northwesterly direction may recurve later. While the cyclonic storms and depressions late in the pre-monsoon season may serve to bring in the monsoon, those in the earlier part of the season do not.

7.2 In this section we will deal with a case of a severe cyclonic storm in the Bay of Bengal which moved in a northerly and later northeasterly direction towards Bangla Desh and struck coast south of Coxs' Bazar. It was one of small areal extent; the satellite also reported a diameter of about 2 to 3 degrees of overcast only (which is almost a minimum limit for storms). The winds in the lower troposphere below (1.0 km) along the east coast of India did not come under the grip of circulation at any stage.

7.3 A low pressure area which formed in the south Andaman Sea on 30 April 1970 moved westwards into southeast Bay on 1st May (Fig. 7.1). The circulation was extending upto 500 mb but was better noticed between 700 and 500 mb levels than lower down (Fig. 7.2). On 1st May, the APT picture showed a comma shaped (❟) heavy clouding to the south and southeast of the low pressure area and this band of heavy convective activity extended further southwestwards upto 65°E Rather heavy rain of about 4 cm had occurred in the south Bay Islands. Although pressure change and departure charts did not reveal any significant feature, the organization of the clouding and the intense convection in the area of the low were favourable indications for development. The low was also over an area climatologically favourable for development.

7.4 During the next 24 hrs, upper winds over Port Blair veered from southeasterly to southerly and strengthened from 10 kts to 25/30 kts in the lower troposphere. This together with a rotational field in the cloudmass seen in the satellite pictures indicated that the low pressure area had concentrated into at least a depression (Figs. 7.3 and 7.4); its centre was within a degree of 11°N 88°E on the morning of 2nd. As on the previous day, the clouds in West Central Bay extended southwestwards to the near equatorial region (upto 65°E) as a broad band. The pressure changes and departures over the mainland and Bay Islands did not give any significant information. Because of lack of ships data, the sea surface temperature data was not available. However, climatologically the depression was moving into an area favourable for further development. In the upper troposphere also the system was close to a ridge line. From these factors, it could be expected that the depression would deepen. Climatology was in favour of a northward movement.

7.5 The depression moved almost due north and rapidly intensified into a cyclonic storm by 3rd morning with centre near 15°N 88°E (Fig. 7.5). Neither the scanty ships observations in south Bay nor the observations from the Bay Islands or the east coast gave any clue to the intensification. The lower tropospheric winds (below 850 mb) along the east coast did not even indicate clearly any cyclonic circulation over the Bay (Fig. 7.6). The only evidence for intensification was the satellite data. Nimbus 3 at 0527 Z gave Stage X Cat. 2, diameter about 3 degrees, while ESSA 8 (0320Z) gave a diameter of 2 to 3 degrees only. This will correspond to maximum winds of about 55 kts in the circulation. In view of the limitations of nomogram used for estimating wind speed, it was perhaps only a border case between a cyclonic storm and a severe cyclonic storm. On this day also there was hardly any ship observation in the Bay to the north of 9°N. Climatology, upper tropospheric ridge pattern as well as the broad "feeder band" extending south (as seen in the satellite pictures) were indications favourable for further intensification. The surface position of the storm was very close to or even slightly to the north of the sub-tropical ridge line at 200 and 150 mb levels which was indicative of north/northeasterly movement for the cyclonic storm.*

7.6 The cyclonic storm moved in a northeasterly direction and was centred near 18°N 90°E, on 4th morning (Fig. 7.7). There were hardly two ships observations in the north and central Bay and they were also at the outer periphery of the circulation. Observations from the east coast of the country were not useful to locate the storm. The centre and the intensity of the storm had to be based almost exclusively on the satellite pictures which gave the intensity of the system as Stage X Cat.2 diameter 2°. The system appeared better organised and more typical of Stage X Cat.2 on 4th than on the previous day. In the absence of complete observations from Bangla Desh and Burma coasts, no conclusion could be drawn from the change and departure charts.

7.7 The satellite pictures showed the 'feeder band' extending into the storm area from 8°N. The cyclonic storm was also in an area climatologically favourable for further development. These were the only basis on which one could expect further intensification of the system.

7.8 During the next 24 hrs, the storm moved rather slowly northeastwards and apparently intensified as revealed by satellite pictures (ESSA 8 - Orbit 6345 at 0314Z of 5th May which showed development of an 'eye' Fig. 7.8). Since the eye was visible, the position of the centre may be considered quite accurate and it was near 19.5°N 91°E at 0808Z when the storm was categorized as Stage X Cat. 3.5 with diameter 2°. This gives a maximum wind of about 75 kt. The inference from this would, therefore, be that the storm had reached severe intensity and had hurricane winds in its circulation. Available ships observations did not indicate more than 25/35 kts within 1 to 2 degrees of the centre. Apparentl the storm was in early "immature" stage and strong winds were confined to a

* In this connection vide para 9.5.4 of FMU Rep. No. III-4.1.

very narrow core. The very small diameter of 2° for the circular overcast shown by the satellites is consistent with a small core. The satellite pictures also showed "feeder bands" extending into the storm area from the Bay Islands. The pressure change and departure patterns took a well-defined shape on this day and they indicated a northeast movement towards Akyab, where the pressure fall was 3.7 mb. Other factors - climatology, persistence and upper tropospheric flow pattern - were also favourable for a northeasterly movement.

7.9 Moving in a northeasterly direction, the severe cyclonic storm was off Bangla Desh - north Burma coast centred near 20°N 91.5°E on 6th morning (Fig. 7.9). Akyab winds (below 1.0 km) become southeast 35 kt. Even on this day, the upper winds along Orissa coast were not affected by the severe cyclonic storm (Fig. 7.10). The surface winds along the Bangla Desh and Burma coasts were not helpful to fix the centre. Satellite picture gave the centre of the storm near 20.5°N 91.5°E at 0359Z. Though the storm was close to coast, in view of its small dimension, no other station except Akyab was affected and satellite picture was very helpful to determine the centre and the intensity. The storm was more or less of the same intensity as on 5th.

7.10 The pressure changes showed heavy falls towards Assam. Climatology and persistence gave a northeasterly track. The severe storm moved northeast, crossed coast south of Cox's Bazar by the early morning of 7th.

7.11 The some of the points to be noted in this discussion are:

i) The circulation associated with the severe cyclonic storm covered a very small area; even at the stage of maximum intensity, the outermost closed isobar did not exceed 4-5° in diameter. Consequently Indian coastal and island stations were not affected. In view of the lack of ships' data and the small extent of the storm, the forecaster had to depend mainly on the satellite pictures for determining the centre and the intensity. On a few charts where some ships' data were available, we could fix the centre using them; but the intensity could not be judged from these observations.

ii) Even when an 'eye' was seen in satellite pictures and the estimates of maximum winds from the satellite pictures were about 70 kts, conventional observations as close as 1-2 degrees from the centre did not report more than 25/35 kts.

iii) The centre of the storm was on most charts either close to or slightly to the north of the 200-150 mb ridge line. As a result there was no westerly component of motion at any stage.

iv) The cyclonic storm apparently developed from a low in a region of slack pressure gradient over the south Bay. There was hardly a mb pressure difference between the Tamil Nadu coast and the Bay Islands on 1 May. There was no clear evidence of any disturbance from the east moving into Andaman Sea and the Bay. On the other hand, the sequence of satellite pictures from 25th April onwards showed a broad cloud band over the equatorial region extending over 30° degrees of longitude and shifting northwards and a disturbance developing out of the band (Fig. 7.11). Unlike the post-monsoon season, in the pre-monsoon season, disturbances rarely move into the Andaman sea or the Bay from the east.

v) From the beginning, the satellite pictures showed a 'feeder band' extending from very low latitudes into the storm area. This was one of the indications of the progressive intensification. The feeder band which was well-marked earlier, began to dissipate from 5th onwards and a north-eastward extension of clouding from the storm area developed from this day.

8. Severe Cyclonic Storm in the Arabian Sea — 9 to 13 June 1964

8.1 In this section we will discuss the case of a severe cyclonic storm which formed in East Central Arabian Sea off Maharashtra coast and moved in a northnorthwesterly/northerly direction and crossed Kathiawar coast near Naliya. It served to take the southwest monsoon rapidly northwards along the entire west coast. Although the number of storms and depressions that develop in the Arabian Sea in June are only a few in number, most of them travel northwest or north. While the disturbances that form earlier in the month of May (just like the one in May 1970 discussed in Sec. 7) may not usher in the monsoon, those that form in the later part of May or in the beginning of June usually bring the monsoon also along with them.

8.2 The disturbance was seen initially as a trough of low pressure off Coastal Mysore on 7th June 1964 and it shifted slightly northward to south Maharashtra—Mysore coasts, by 8th (Fig. 8.1). In June, East Central Arabian Sea to the east of 67°E and the adjoining northeast Arabian Sea are climatologically favourable areas for formation of depressions and their further intensification. In this particular case, ships in the area reported sea surface temperatures of 29°–30°C (nearly normal for the area), which is also favourable for development of cyclonic storms. The strong cyclonic shear in the area as evidenced by the stronger westerlies to the south was a third factor favourable for development (Fig. 8.2). With these features the forecaster would only be watching for the first signs of actual intensification.
A depression developed in East Central Arabian Sea off Maharashtra coast on the morning of 9th, with its centre near 17°N 71°E (Fig. 8.3). The intensification into a depression was indicated by

i) a ship reporting southerly wind of speed 25 kts and squally weather, and
ii) two closed isobars (at 2 mb interval) around the centre

Although the pressure changes were only about 1 mb along Maharashtra coast, the departures were about 2 to 3 mb. The depression was very much more marked in the upper air particularly at 700–600 mb levels, where winds of speed about 30/35 kts were observed (Fig. 8.4).

8.3 Climatology gave a northwesterly/northerly movement for the depression. Though the 03Z pressure changes were not very useful, pressure falls at 12Z were more along west Saurashtra coast, (see Fig. 8.3) indicating a northnorthwesterly track.

8.4 Conditions being favourable as discussed in para 8.2, the depression intensified into a cyclonic storm during the night of 9th and it was centred on 10th morning near 18.5°N 70.5°E (Fig. 8.5). The cyclonic storm stage was indicated by ships reporting 30/35 kts within a degree or two from the centre. The stronger winds extended over larger areas to the south than to the north of the centre. The lower tropospheric winds over Bombay also strengthened to 30/35 kts from the mid-night of 9th. From a southeasterly 15/20 kt at 12Z of 9th it became southsoutheasterly 30/35 kt at 00Z of 10th. The circulation apparently became small in extent above 500 mb level and could not be detected with the available network of observations (Fig. 8.6). Climatology and upper tropospheric flow pattern indicated a northwest/northerly track. Pressure changes along the coast were also favourable for a northwest/northerly movement.

8.5 The cyclonic storm moved in a nearly northwesterly direction, further intensified into a severe storm and was centred on the morning of 11th near 21°N 69°E (Fig. 8.7). Coastal stations along Kathiawar coast about a degree from the centre reported surface winds of speed 40/45 kt. At Veraval the surface wind veered from easterly 20 kt at 1200Z of 10th to southsoutheasterly 45 kt at 0000Z of 11th. It is, therefore, likely that winds exceeded 50 kts close to the centre. This was the only basis on which the storm could be declared "severe". There was no satellite data for the storm. The pressure at Veraval was 995 mbs with a departure of about -7 mb. Pressure changes and the upper tropospheric flow pattern suggested a continued movement towards northwest/north. Climatology and persistence were also favourable for such a movement. The inference of strong winds of 50 kts or more near the centre was borne out by the hourly observations received from ship "Dumra". On the evening of 11th, when the ship was within half a degree of the centre, it reported winds of strength 60 kt and a pressure of 979 mb which was about 22 mb below normal.

8.6 The severe cyclonic storm which till now moved parallel to the coast, slightly curved to the right and after the evening of 11th moved in a northerly direction. This change in direction was consistent with the general upper air flow over Gujarat and northwest India as well as the centre of the storm reaching close to the sub-tropical ridge line in the upper troposphere (Fig.8.8). The severe cyclonic storm was centred close to Naliya on 12th morning when the station reported a surface wind speed of about 75 kt and a pressure of 973 mb (Figs. 8.9 and 8.10) which fell further to 969.5 (32.5 mb below normal) at 0400Z. The storm had, therefore, developed a core of hurricane winds on this day, which perhaps was not present on the previous day, as could be judged from the hourly reports of Dumra. The severe cyclonic storm crossed Kutch and moved in a northeasterly direction towards lower Sind and southwest Rajasthan where it weakened.

8.7 The main features to be noted in this case are:-

i) In June 1964 we did not have satellite coverage over this storm. Hence, the forecaster had to depend only on conventional data - viz. ships and coastal observations. As the track of the storm was within a degree or so of the coast, the coastal observations were very helpful to locate the centre and judge the intensity and movement, though the storm was not one of large extent. Had the storm been further out at sea, it would have been more difficult to locate it accurately and judge its intensity without ships observations sufficiently close to the centre.

ii) The depression formed and further intensification took place over an area climatologically favourable for development and where sea surface temperatures were 29°–30°C.

iii) The movement of the storm appears to have been influenced by a deep upper air westerly trough extending from central USSR southwards to north Arabian Sea across Iran, Afghanistan and Pakistan (Fig. 8.8). The track of the storm showed a recurvature and there was a slight retardation at the recurvature stage. The change in the track after 11th morning was also consistent with the position of the upper tropospheric sub-tropical ridge line (200 mb). The track of the storm was also in general agreement with the climatological track over the area.

iv) On 11th when the coastal observations reported winds of speed about 40 kt/ 45 kt, the storm was at a distance of about a degree away from the coast; it was inferred on the basis of the model distribution of winds in the storm area that the maximum winds nearer the centre might be about 20 kt more than the coastal wind (i.e.) at least 60 kt/65 kt. This was borne out by the later observations received from ship Dumra. We do not have any evidence to say whether it could have been more than 60 kt (reported by Dumra) and touched hurricane strength on 11th itself.

9. Cyclonic Storm in the Arabian Sea moving westwards and crossing Arabia Coast – 15 May 1970 to 3 June 1970

9.1 A trough of low pressure developed off Kerala-Mysore-Goa coasts on 25th May 1970 and persisted till 28th, with a slight northward movement (Fig. 9.1 and 9.2). The system was better marked in the upper air, extending upto 500 mb. A feature noticed during this season is that the southwest/westerlies to the south of the low pressure systems are fairly strong, while east/southeasterlies to the north are relatively much weaker. In the upper air, the low pressure system could be clearly seen moving northwards parallel to the coast from off south Kerala to off north Mysore coast between 24th and 28th (Fig. 9.3). As it moved north, the winds to the south became southwest/westerlies and they were also fairly strong, about 35/40 kt.

9.2 The strengthening of the winds over the Laccadives area on 27th implied an increase in the cyclonic vorticity in the area to the north. The sea surface temperatures in Southeast and East Central Arabian Sea were between 29°C and 31°C, which was well above the threshold value for storm formation and which was also slightly more than the normal mean sea surface temperature of 29–29.5°C over the area for May and June. The area is also climatologically favourable for development. On 28th, the pressure fall over the area was about 2 mb in a general field of 1–1.5 mb fall over the Peninsula. The departure over Southeast and adjoining East Central Arabian Sea was about –4 to –5 mb. The satellite pictures showed continued heavy convective activity in the South and adjoining Central Arabian Sea for the previous 3 days or so. All these features pointed towards an intensification of the trough of low pressure. By 28th evening a depression formed with centre near 14.5°N 71.5°E, as indicated by the lower tropospheric winds (easterly/southeasterly) to the north of the system reaching a speed of 20/25 kt for the first time. The depression was centred within half-a-degree of 16°N 71.5°E on 29th morning with an associated pressure departure of –6 mb (Fig. 9.4). Climatology, pressure changes and upper air flow were all indicative of a northwesterly/northerly movement for the depression (Fig. 9.5). All factors as discussed earlier in this para, were also favourable for further development.

9.3 During the next 24 hrs, the depression intensified into a cyclonic storm, and it was centred near 17.5°N 71.5°E on 30th morning (Figs. 9.6 and 9.7). The intensification was indicated by ships' reports of 30 kt winds from northwest as well as southwest and a ship reporting pressure of 994 mb which was nearly 13 mb below normal. The APT picture (ESSA 8 at 0519Z) of the disturbance was classified as Stage X Cat.2 with a diameter of 2° which could put it even as a severe cyclonic storm. But in view of the ships so close to the centre reporting only 30 kts, the system was kept only as a cyclonic storm.

9.4 On account of the absence of observations to the west in the Arabian Sea, it was difficult to get a complete picture of the distribution of pressure changes. Climatology gave a modal direction of movement towards northwest(specially if we take the climatology for June also into account). The upper air pattern at 200 mb over north and central Arabian sea rapidly changed between 29-0000Z and 30-1200Z (Fig. 9.8). By 30th evening, a well-defined anticyclone appeared over north Arabian Sea at 200-150 mb levels and the anticyclone also shifted northwards during the next 24 hrs so that the cyclonic storm came under a field of deep and broad easterlies. Thus the system which was initially moving in a northerly direction, curved to the left (after 30th morning) moved northwest and later almost due west towards Arabia Coast.

9.5 On 31st the system was centred near 19°N 68°E (Figs.9.9 and 9.10). East/southeasterlies of speed 20/30 kts were reported at a distance of about 2 degree from the centre. The APT picture, however, showed a weakening of the system since the previous day, and it was classified as only Stage C + (in contrast to Stage X Cat.2, 24 hours earlier). From the satellite picture we may draw the inference that the cyclonic storm had weakened into a deep depression. But for the APT picture, there was no other evidence for weakening. The heavy rises of pressure over Gujarat and Maharashtra States on this day, were indicative of the storm moving away from the coast. Subsequently, the deep depressior moved due west and crossed Arabia coast near 20°N on the morning of 3rd June. (1st and 2nd the position and intensity have to be based almost exclusively on satellite pictures till the system came close to Arabia coast. Masirah, which was only within half a degree of the track of the disturbance, reported surface winds of only 20 kt and upper winds (850 mb) of 20/30 kt on 2nd (morning), in association with the deep depression (Figs. 9.11 and 9.12). This is in agreeme with the inference drawn earlier (on 31st May) from satellite pictures that the system was not a cyclonic storm. However, in the southern quadrants at distances of 2-4 degrees to the south of the centre of the deep depression, ships reported winds of speed 30 to 40 kts (on the night of 2 June and morning of 3rd). Such a distribution of winds (viz. winds a little away from the centre in some sectors being stronger than winds nearer the centre) was also another indication that the disturbance was not of storm intensity.

9.6 The main points to be noted in the sequence are:-

i) The development of the depression at the leading edge of the advancing monsoon current is typical of the season. An asymmetric distribution of winds with considerably stronger winds (westerlies) to the south extending over larger areas than the easterlies to the north, is a characteristic feature of disturbances of the pre-monsoon season.

ii) So long as the system was to the east of 70°E it could be traced with the help of ships observations and coastal observations, with satellite data to supplement. However, when it moved to the west of 70°E, satellite pictures became the main basis till the disturbance reached Arabia coast.

iii) On the 30th, even though the satellite pictures suggested a maximum wind of about 55 kts in the circulation, it was kept only as a cyclonic storm in view of the ships observations close to the centre reporting winds of speed only 30 kts. In this context, one should note that the satellite derived winds are usually correct within 10/15 kts only. Again, on 31st, winds of speed 20/30 kts were reported in the northern sector of the depression at a distance of about 2° from the centre. Although 30 kts winds from an easterly direction is very significant and one can even infer stronger winds nearer the centre, in view of the weakening of the system to stage C + as seen in the satellite picture, the system was down-graded into a deep depression.

iv) Considerable changes took place in the upper tropospheric flow pattern between 29th and 30th and a well defined anticyclone developed over the north Arabian Sea. Along with this change in the upper tropospheric flow pattern, there was also a change in the track of the deep depression towards the west.

10. Low Pressure Area moving westwards from Andaman Sea to extreme Southeast Arabian Sea – 9 to 16 April, 1970

10.1 A low pressure area was seen over the Andaman Sea on the morning of 9th April 1970. It could be delineated on the surface chart only by an odd isobar.

10.2 The sequence of the cloud area as seen in satellite pictures and weather and rainfall over Tennasserim, Malaysia and Bay Islands suggested that the low pressure area might have moved into Andaman Sea from the east. The satellite pictures indicated that the main heavy clouding associated with the low was to the south of 10°N.

10.3 Moving rather slowly westwards the low pressure area was to the west of Bay Islands over southeast Bay on 11th morning (Fig. 10.1). This was seen by the changes in the wind direction (surface and upper air) over Bay Islands and on the pressure change chart. As the low moved westwards, weather also decreased over south Bay Islands on 11th. In view of the westerly winds to the south, a closed isobar could be drawn on the surface chart, delineating the low pressure area although in the upper air it was not clear (due to lack of data) whether the system extended into the upper air as a closed low or was only a north-south oriented trough (Fig. 10.2).

10.4 Continuing to move westwards, it reached Comorin-Sri Lanka and adjoining south Tamil Nadu on 13th morning (Fig. 10.3 a). It was seen as a closed low on the surface isobaric chart and as a cyclonic circulation in the upper air upto about 2.1 km (Fig. 10.4). Between 11th and 13th, the low pressure system could be traced on the chart mainly by the satellite clouding supplemented by a few ships observations. As far as could be judged from the satellite pictures, there had been a weakening of the system while it was travelling over the south Bay and it once again became active when it reached the Comorin area (Fig.10.3 b). There was no rain over south Tamil Nadu and Sri Lanka on 11th and 12th. However, on 13th there was widespread rainfall over Sri Lanka and scattered rainfall in south Tamil Nadu.

10.5 The low pressure area moved across the Maldives and reached to the west of it by 15th (Fig. 10.5). This could be seen on the sea level isobaric charts, and also by the changes in the lower tropospheric upper winds and satellite observed clouding (Fig. 10.6). On 16th, it was over the extreme south Arabian Sea to the west of Long 70°E and subsequently became unimportant (Fig. 10.7). While it was over the Comorin-Maldives area and south Arabian Sea there were a number of observations in the near equatorial regions to the south of the low with westerly winds showing clearly that the system was not a north-south oriented trough but a closed circulation. Afterwards the low pressure area apparently became unimportant.

10.6 The main features noticed in the case history are:-

i) The low pressure area moved from the Andaman Sea to southeast Arabian Sea. It could be traced on the surface chart as a closed isobar. In the upper air also the system was seen upto about 700 mb level. While the low was over the Bay of Bengal, because of lack of data, it is not clear whether in the upper air it extended as a closed cyclonic circulation or only as a north-south oriented trough. But the changes in the upper winds at Gan (near equator) which became westerlies in the lower troposphere in connection with the movement of the low, suggested that in the upper air also it was a closed cyclonic circulation.

ii) During the passage of the 'low' across the Andaman sea and the south Bay, the seasonal 'high' over the Bay became less marked on the surface chart.

iii) Satellite pictures indicated that the clouding associated with the low extended on either side of the central region of the low. There was no perceptible asymmetric distribution of clouding with reference to the central region of the low pressure area.

iv) The satellite pictures were very helpful in tracing the low pressure area from day-to-day. The time cross sections of stations across the path of the low – viz. Port Blair, Madras, Trivandrum and Minicoy showed the sequential passage of the low pressure area from east to west (Fig. 10.8). From these time-sections it will be seen that the low was mainly in the lower troposphere. The low pressure area travelled at an average speed of about 4-5 degrees (400-500 kms) per day from Bay Islands to southeast Arabian Sea.

v) As seen from the satellite pictures there was a decrease of clouding associated with the low when it moved across the south Bay of Bengal. When it was over Andaman sea and south Bay Islands, and again over Sri Lank Comorin and Maldives area, the low was active as inferred from the heavy clouding and the appreciable rainfall. The rainfall amounts recorded over land stations in association with the low were generally moderate to rather heavy.

vi) The weather associated with the low pressure area over the sea area was heavy Cb, showers and thunderstorms. The convection was heavy over a limited area.

vii) There was a temporary strengthening of the lower and mid-tropospheric winds over the Peninsula in association with the movement of the low pressure area across Comorin-Sri Lanka area.

11. Well-marked Low Pressure area moving westwards from south Andaman Sea to Tamil Nadu coast – 7 to 11 May 1970

11.1 While the severe cyclonic storm (1-7 May 1970) discussed in Section 7 moved towards Bangla Desh and crossed coast, a fresh low pressure area developed over south Andaman Sea on the evening of 6 May 1970 and persisted over the same area next day also. The low could be delineated on the surface chart (on 7th) by an odd-valued closed isobar (Fig. 11.1); in the upper air, the circulation extended to about 2.1 km (and perhaps as a trough at higher levels upto 6.0 kms), with a westward slope with height (Fig. 11.2). The maximum pressure departure associated with the low pressure area was about -2 to -2.5 mb.

The satellite pictures showed a heavy mass of clouding (similar to stage B) to the southwest of the low pressure area. Ci outflow was evident in the western edge of the cloudmass.

11.2 The low pressure area moved westwards into southeast Bay of Bengal on 8th morning and also became well-marked. (Fig. 11.3). The movement could be clearly noticed by the veering and strengthening of the winds over Bay Islands (particularly Port Blair) at the surface and in the lower tropospheric levels (Fig. 11.4). The strengthening of the winds over Port Blair also showed that the system was becoming more marked. Lower tropospheric winds reached 25 kt from southeast over Port Blair. The surface wind at the station was also southeast/20 kt (unusually gusty). Though such a strong southeasterly wind at Port Blair in this season is significant and by itself, may even be indicative of a cyclonic storm at a distance, in the present case, the available ships observations and the satellite pictures did not suggest that the low pressure system was stronger than a well-marked low pressure area or at best a depression. The weaker winds near the centre and stronger winds on the periphery is a feature characteristic of weak tropical cyclonic systems. Ships observations to the south of the low, in the westerly field, showed winds of speed 20/25 kt, implying a considerable cyclonic shear in the region of the low pressure area, immediately to the north of the westerly belt. The satellite picture showed a mass of bright heavy clouding to the southwest of the low pressure area, with its western boundary reaching Sri Lanka and Tamil Nadu coast.

11.3 Continuing the westward movement, the well-marked low pressure area reached West Central Bay off North Tamil Nadu-south Andhra coast on 10th morning (Fig. 11.5). The associated cyclonic circulation extended upto 2.1 km, and above this level, the system was seen as a trough extending into the mid-troposphere also where the system had a southwestward tilt with height (Fig.11.6). The 1200Z upper wind charts of 10th and the time cross-section of Madras clearly brought out the tilt of the disturbance (Fig. 11.7 and 11.8 a).

11.4 Moving westwards across the south Peninsula, the system weakened in the surface and the lower troposphere (below 850 mb level). Above this level, the circulation moved into across East Central and adjoining Southeast Arabian Sea and progressively weakened.

11.5 The main points to be noted in this sequence are:-

i) The well-marked low pressure area discussed in this section developed over the south Andaman sea in a region of slack pressure gradient. In contrast to March-April where there is a high pressure cell over the sea areas (i.e. Arabian sea and Bay of Bengal) on the surface chart, the configuration in May is one of nearly parallel isobars over Arabian Sea and the Bay, around the land low over India. The first signs of formation of any cyclonic disturbance are

(a) the decrease in number of isobars over the sea area and

(b) increase in the distance between two isobars, resulting in the formation of a region of very weak pressure gradient. The isobaric configuration over the Bay, in the present case, was different from the configuration in the previous case discussed in Section 10 which occurred in the earlier part of the season.

ii) Due to lack of sufficient ships observations over the Bay, it was difficult to say definitely whether the well-marked low pressure area attained the depression stage at any time, although moderate to strong lower tropospheric winds from Port Blair on 8th and 9th would lend support to the view that disturbance might have been a depression. Satellite pictures could not throw any light on this point as there is no clear cut difference between a depression and a low pressure area as viewed by a satellite.

iii) Though it was only a well-marked low pressure area, it extended upto the mid-troposphere; there was considerable southwest/westerly slope for the system which could be clearly seen when the low pressure reached the Tamil Nadu coast. The slope was of the order of 1:100. Available temperature observations over the south Peninsula showed that the slope was towards the cold air side (Fig. 11.7). Port Blair time-section also suggested that the system was perhaps extending upto the mid-troposphere with a large southwest/west slope even while far out at sea, from the very formation (Fig. 11.8 b). During the northeast monsoon season also we have come across such westward moving systems which slope towards the west (vide para 16.8 (vii) of FMU Rep. No. IV-18.4).

iv) The heavy clouding and weather associated with the system was mostly to the southwest/west of the low. This asymmetric distribution was clearly brought out by the satellite cloud pictures. This is in contrast to the case discussed in the previous section (Section.10) where there was no asymmetrical distribution in clouding.

v) The winds in the southern sector of the low reached 20/25 kts. Widespread thundershowers, CB development and squalls were associated with this low pressure area while it was over the Bay. Rainfall amounts of the order of 2-3 cm were reported from a number of stations over south Peninsula in association with this system.

...

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which may move eastwards.

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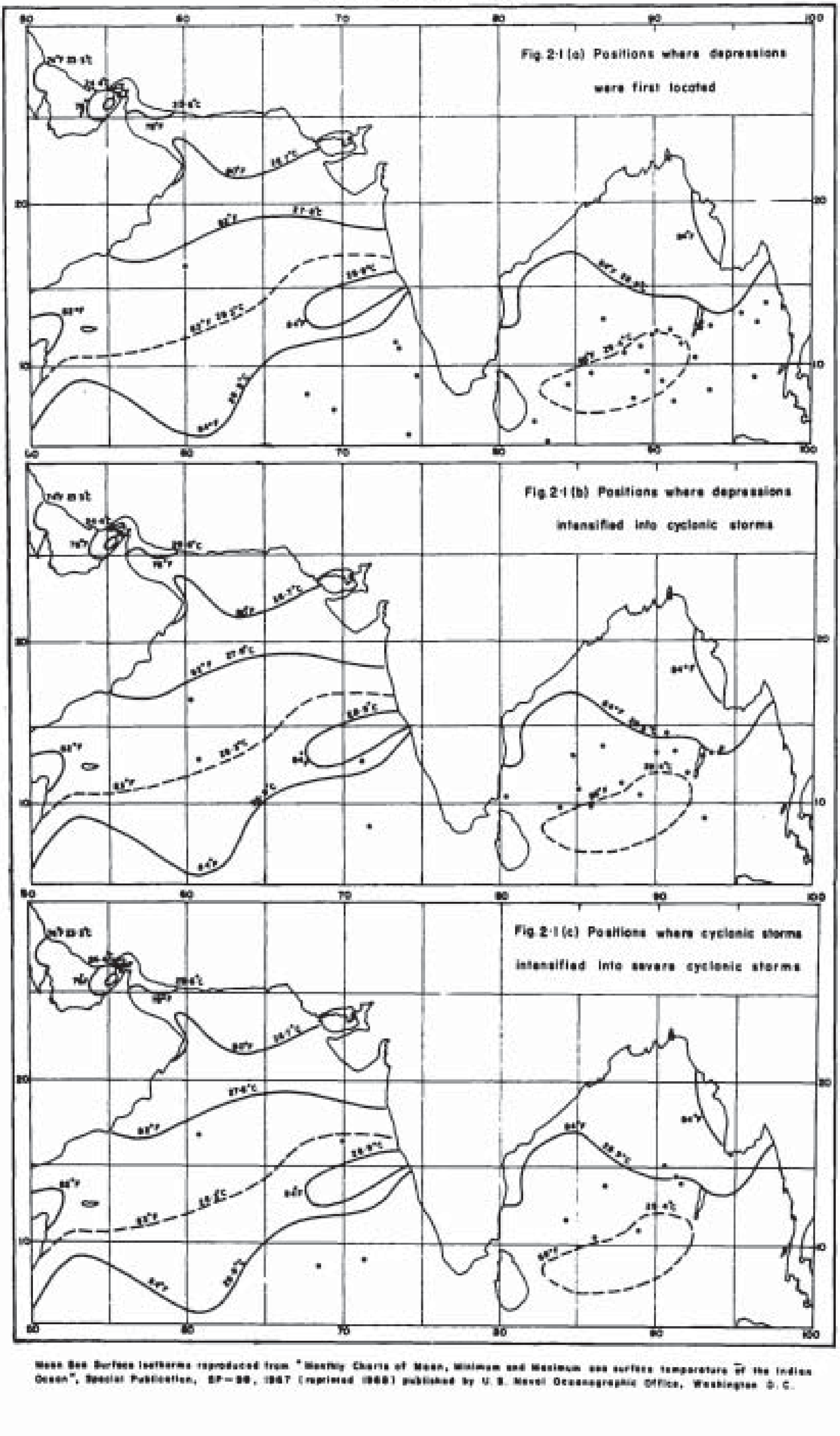
Note: Further references on Tropical Storms and Depressions are available in FMU Rep. No. III - 4.1.

DIAGRAMS

APRIL (1891-1970)



Mean Sea Surface Isotherms reproduced from "Monthly Charts of Mean, Minimum and Maximum sea surface temperature of the Indian Ocean", Special Publication, SP-99, 1967 (reprinted 1968) published by U. S. Naval Oceanographic Office, Washington D. C.

MAY (1891-1970)

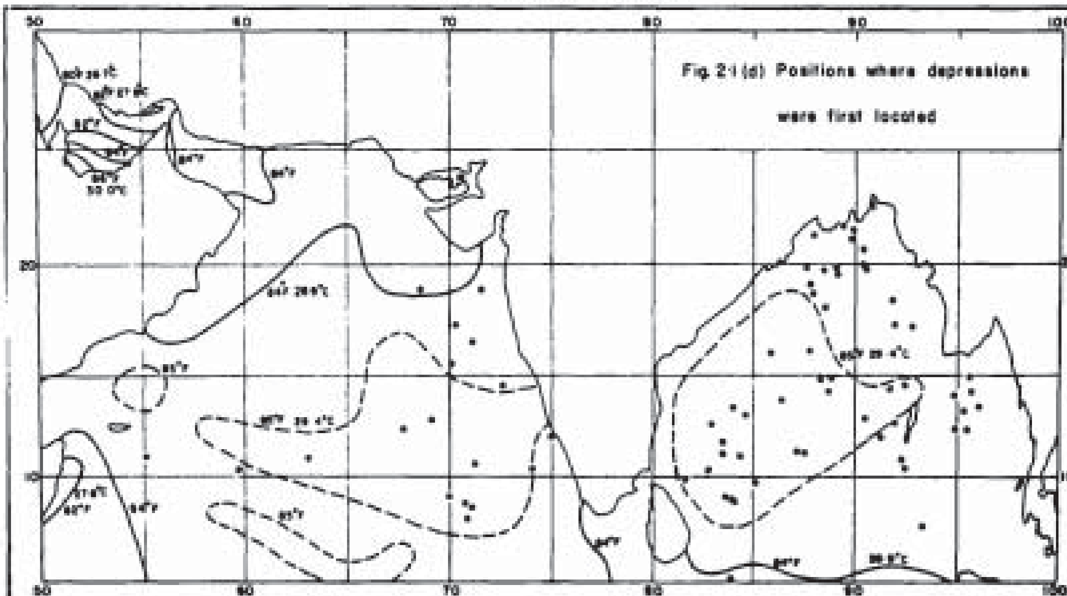


Fig. 2·1 (d) Positions where depressions were first located

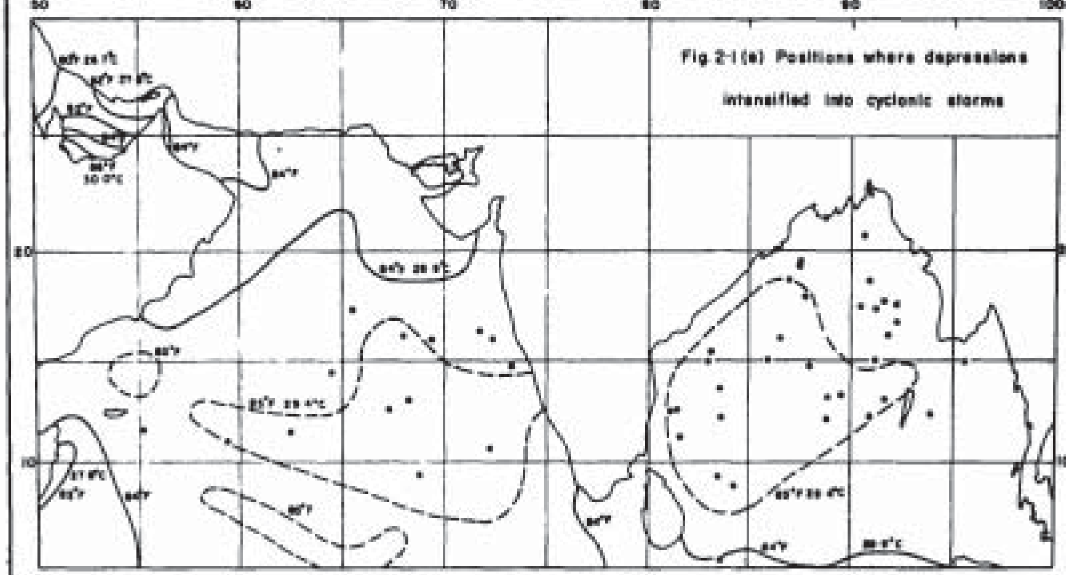


Fig. 2·1 (e) Positions where depressions intensified into cyclonic storms

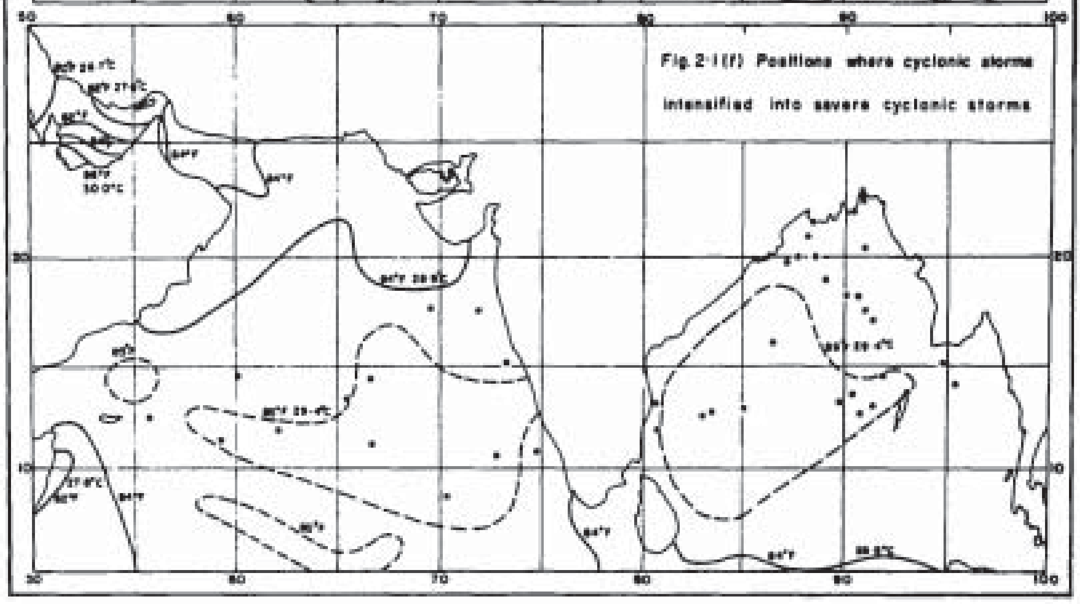
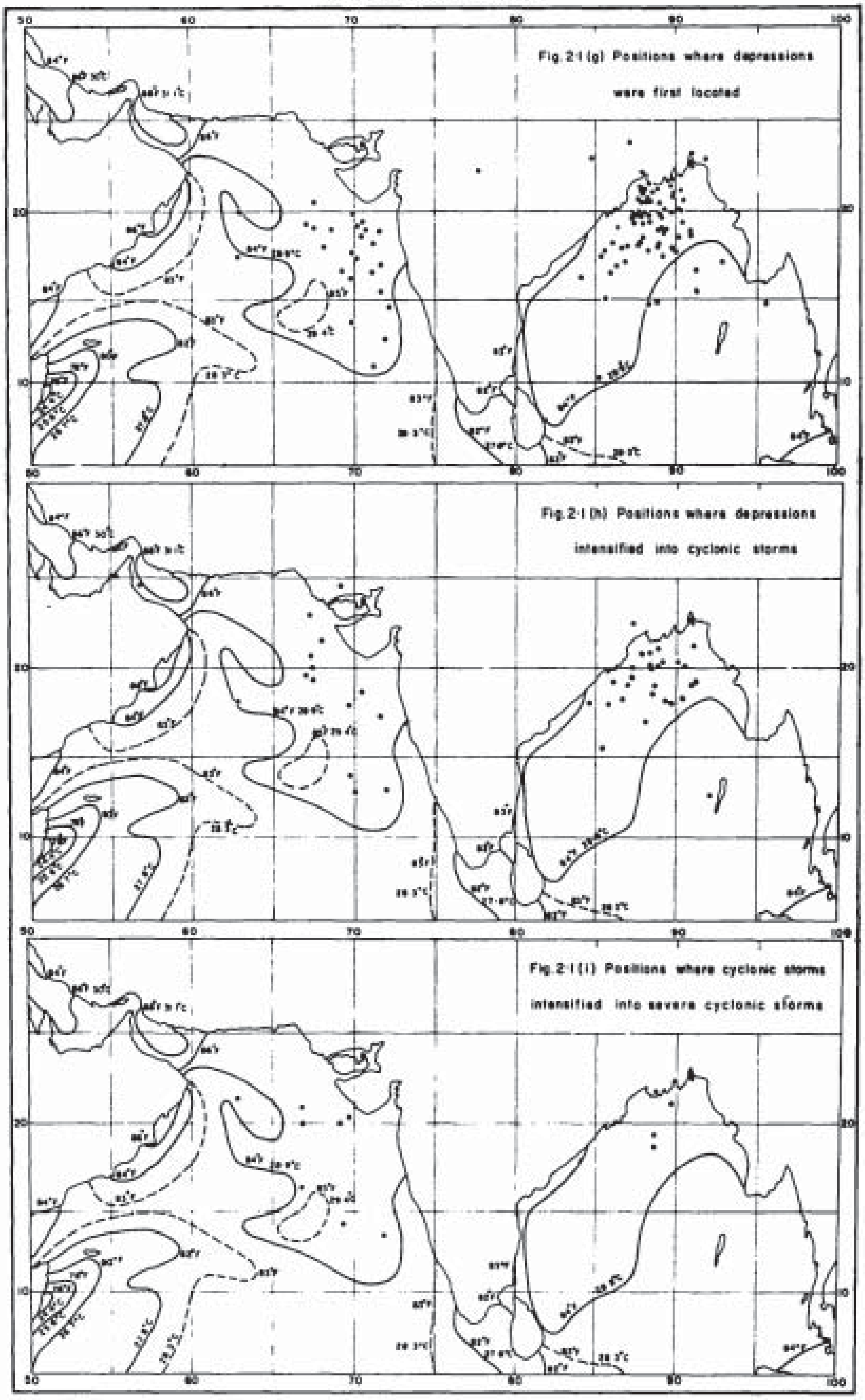


Fig. 2·1 (f) Positions where cyclonic storms intensified into severe cyclonic storms

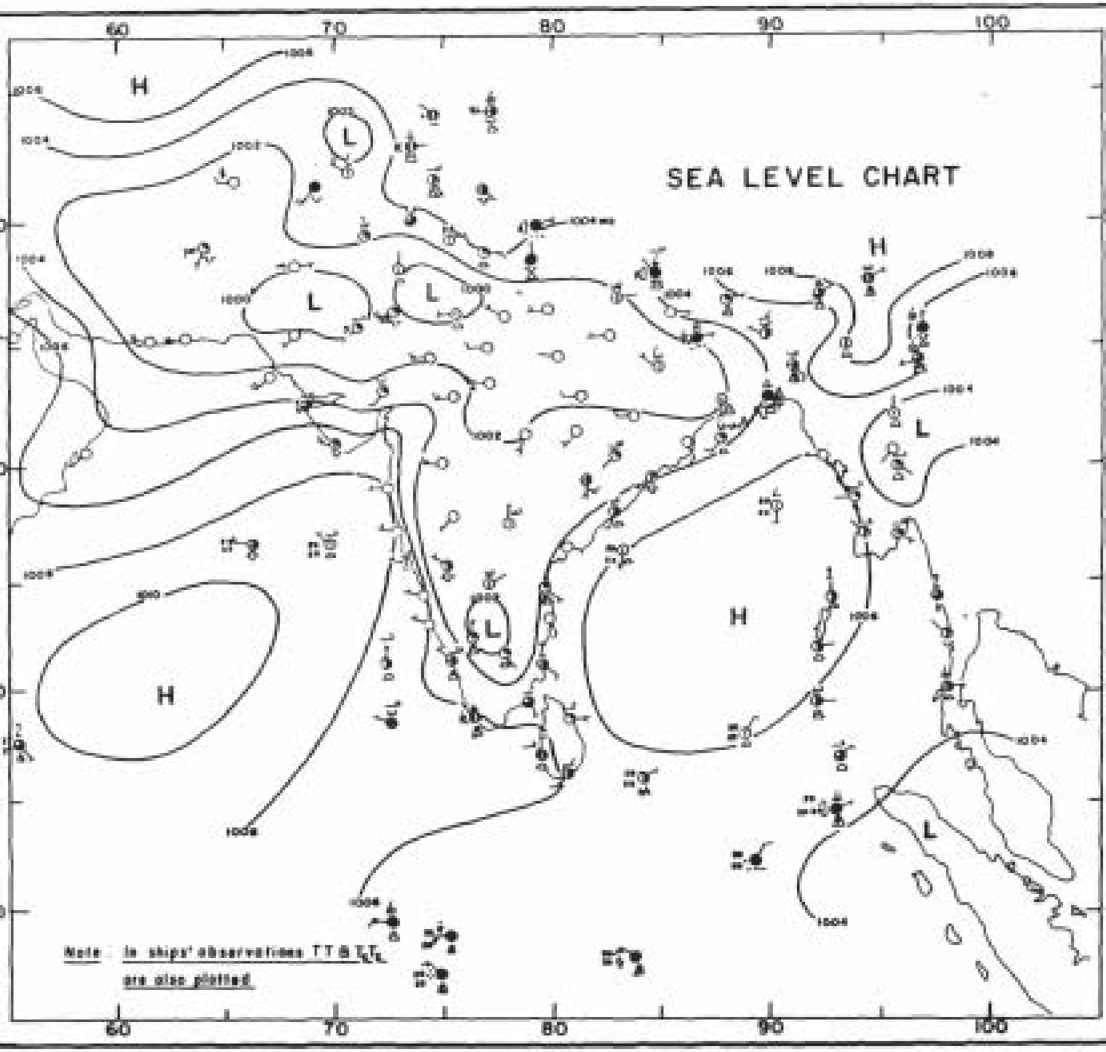
Mean Sea Surface isotherms reproduced from "Monthly Charts of Mean, Minimum and Maximum sea surface temperature of the Indian Ocean", Special Publication, SP-99, 1967 (reprinted 1968) published by U.S. Naval Oceanographic Office, Washington D.C.

JUNE (1891-1970)

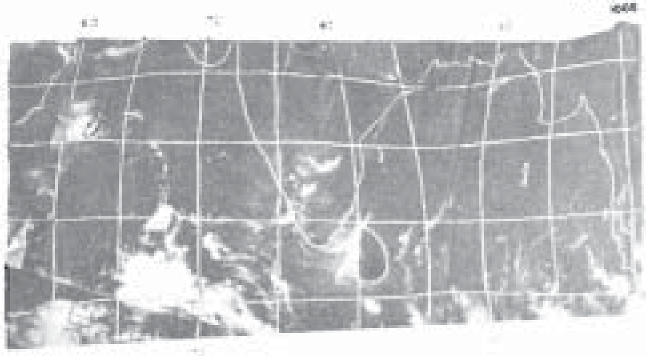


Mean Sea Surface Isotherms reproduced from "Monthly Charts of Mean, Minimum and Maximum sea surface temperature of the Indian Ocean", Special Publication, SP-99, 1967 (reprinted 1968) published by U.S. Naval Oceanographic Office, Washington D.C.

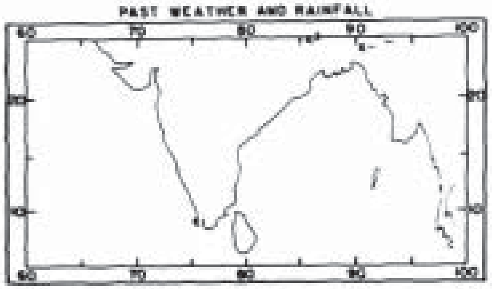
FIG. 4·1 (a) SYNOPTIC CHARTS 1200 GMT 20 MAR. 68



ESSA 6 ORBITS 1636, 1635 & 1634 20 MARCH 68 TIME 0548 Z, 0353 Z & 0159 Z



PAST WEATHER AND RAINFALL



UPPER WINDS 1200 GMT

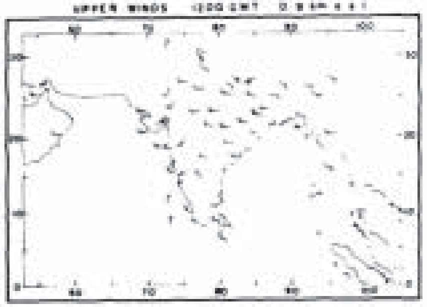
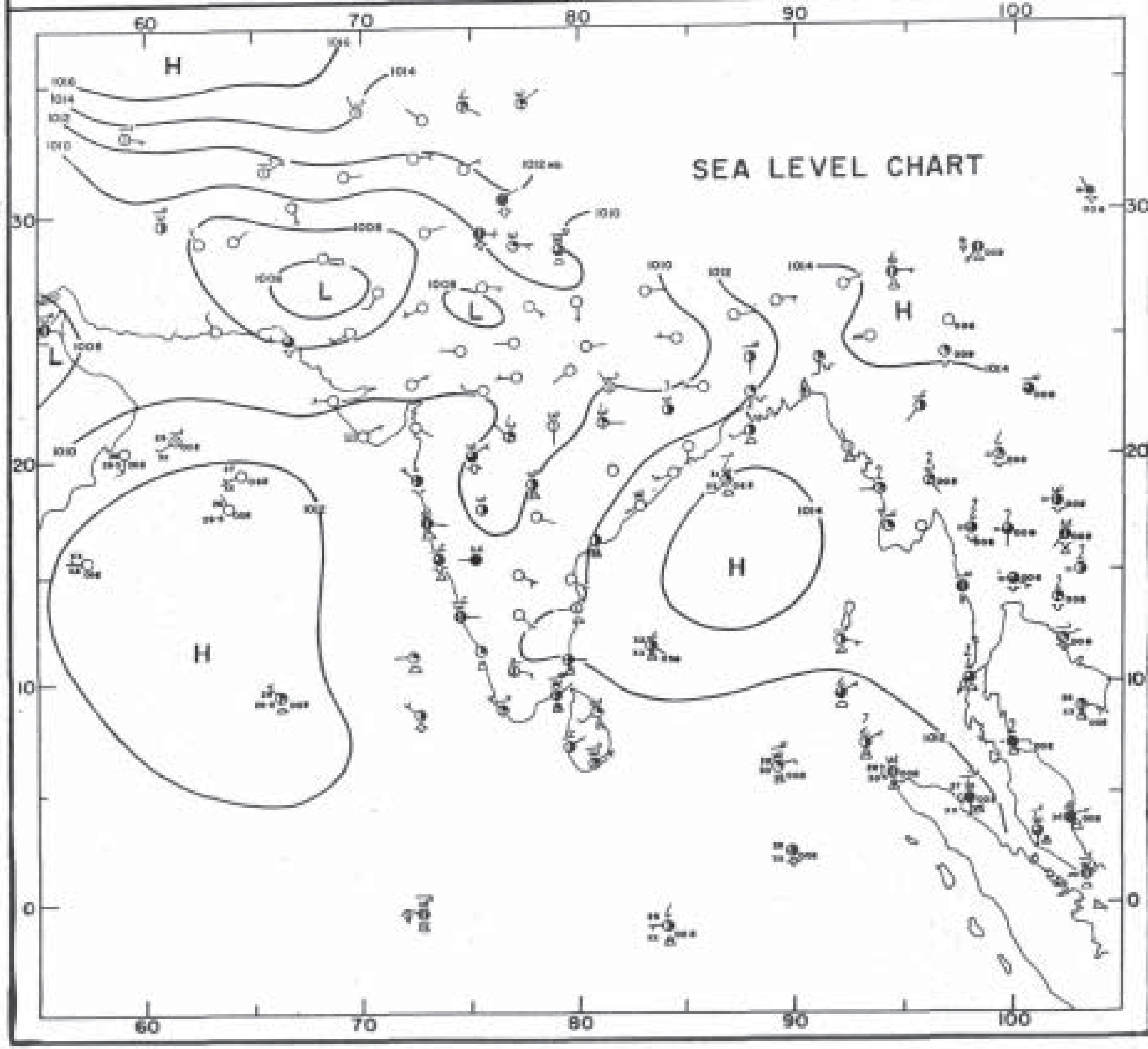
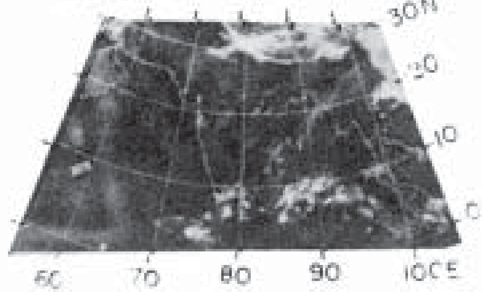


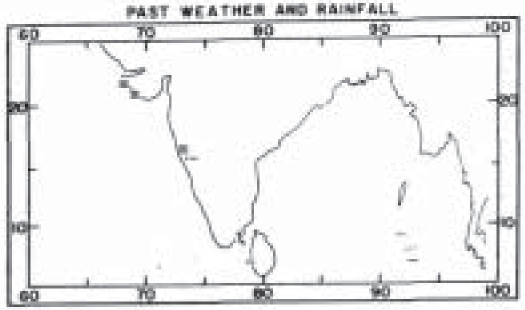
FIG. 4·1(b) SYNOPTIC CHARTS 0300 GMT 4 APR. 69



ESSA 9 ORBITS 461, 462 4 APR. 69



PAST WEATHER AND RAINFALL



UPPER WINDS 0000 GMT

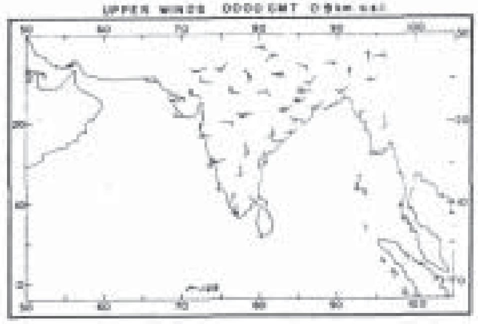


FIG. 6·1 (a) SYNOPTIC CHARTS 0300 GMT 28 MAY 69

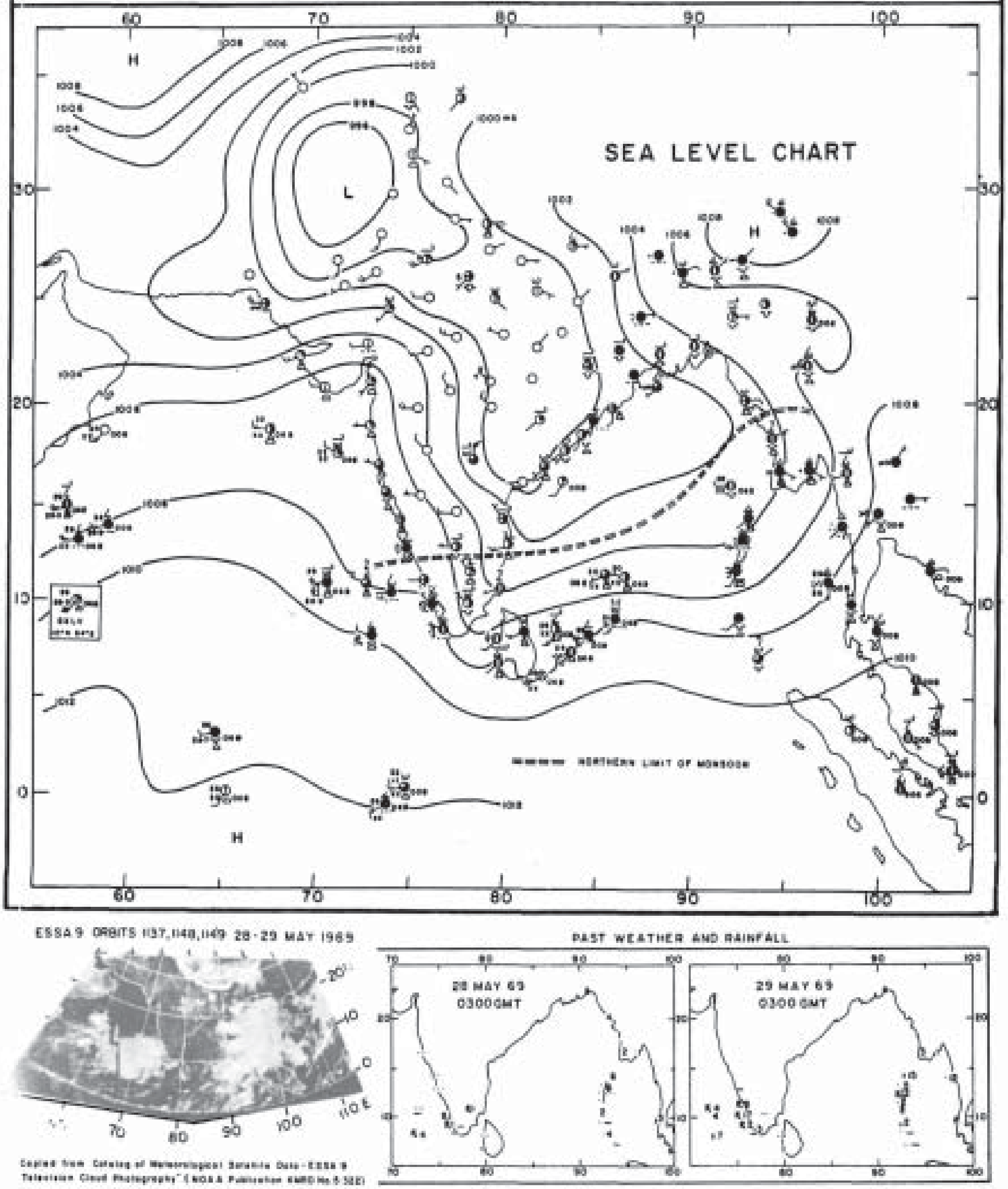


FIG. 6·1 (b) UPPER WINDS 00 GMT 28 MAY 69

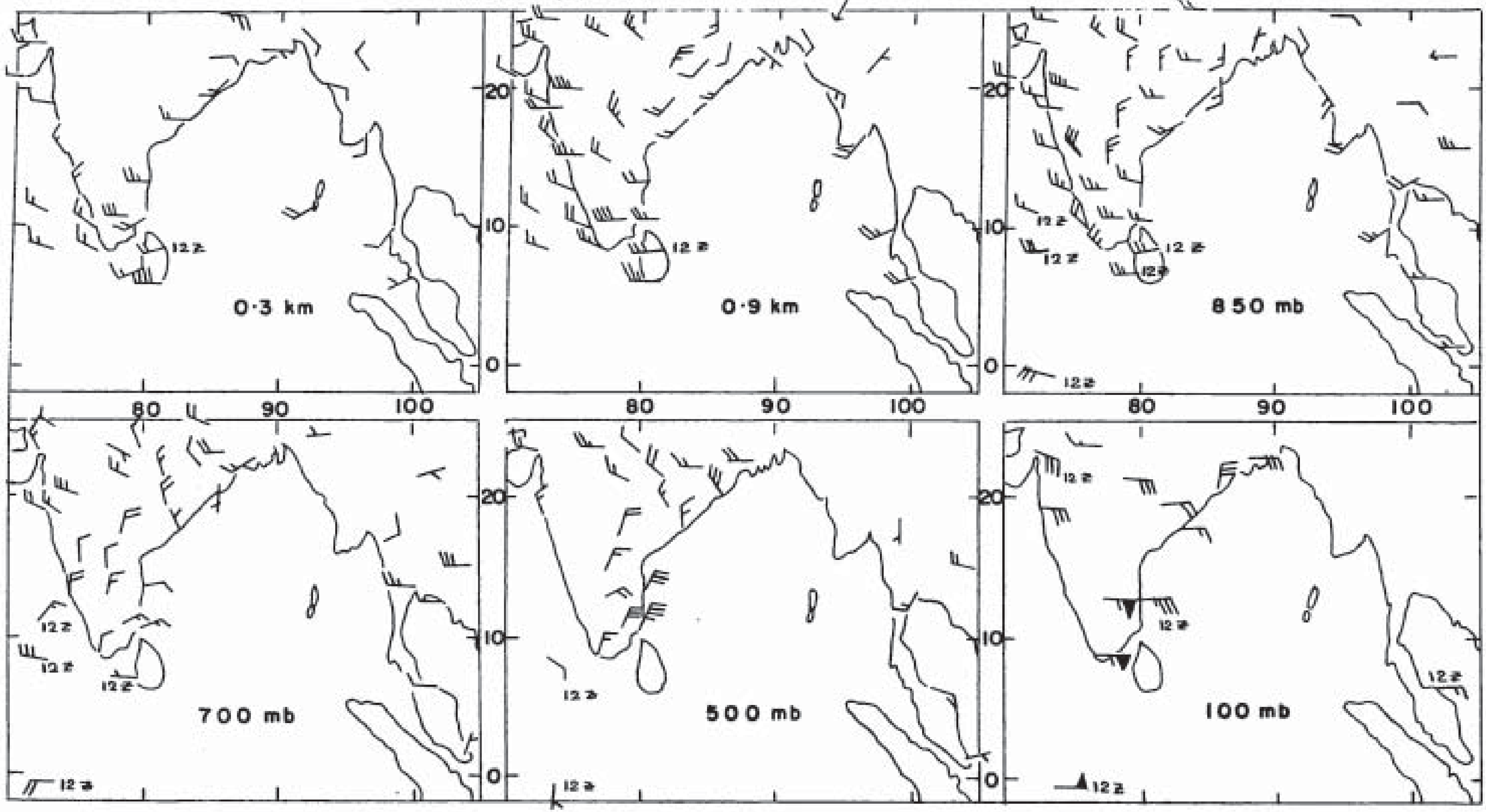
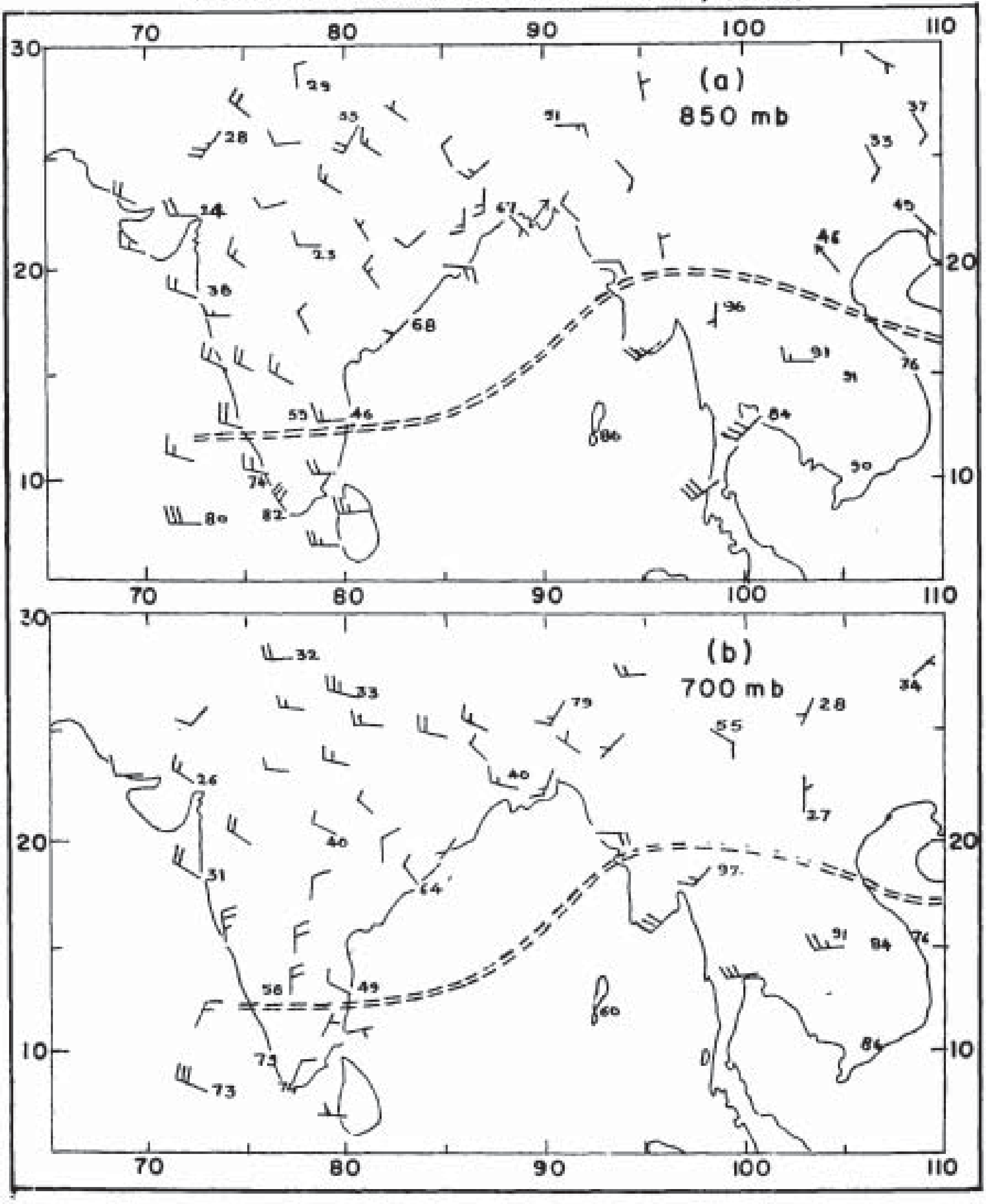


FIG. 6·2 MEAN RELATIVE HUMIDITY DISTRIBUTION

(Based on 1200 GMT data : 27 – 29 May 1969)



===== Northern limit of monsoon on 28 May 69

Winds relate to 1200 GMT of 28 May 69

FIG. 6·3 TEPHIGRAMS OF MONSOON AND NON-MONSOON AREAS

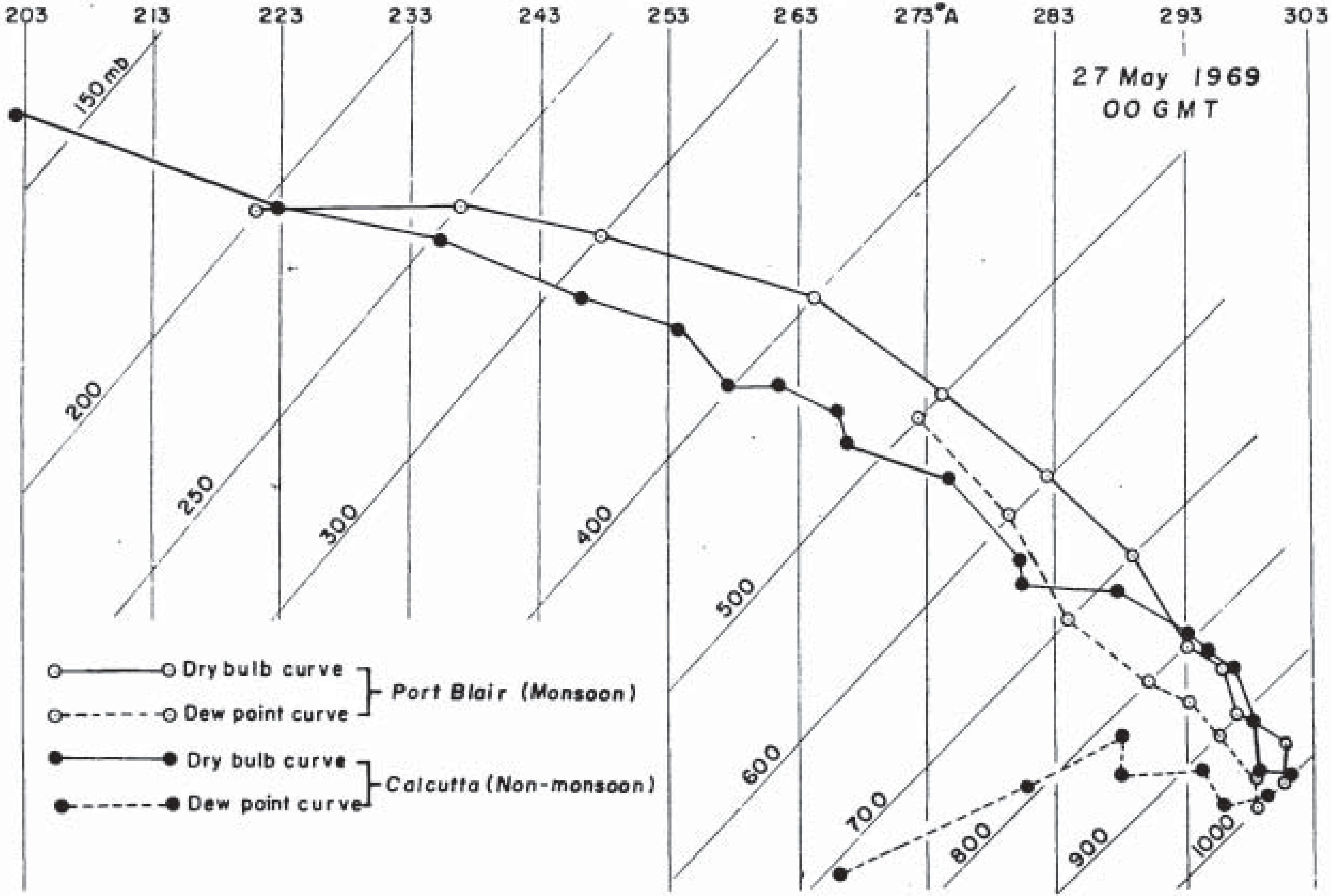


FIG. 7·1 SYNOPTIC CHARTS 0300 GMT 1 MAY 70

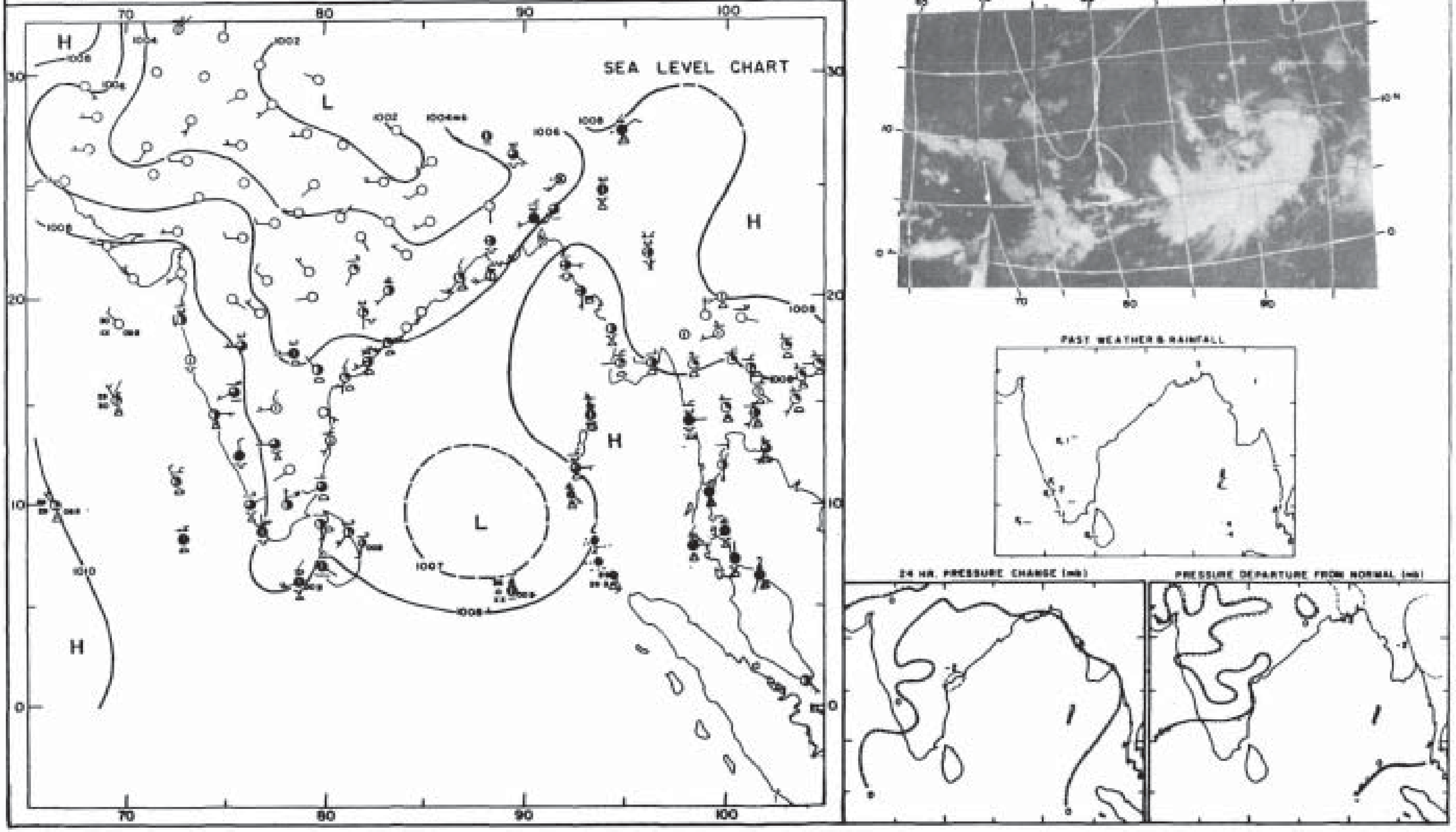
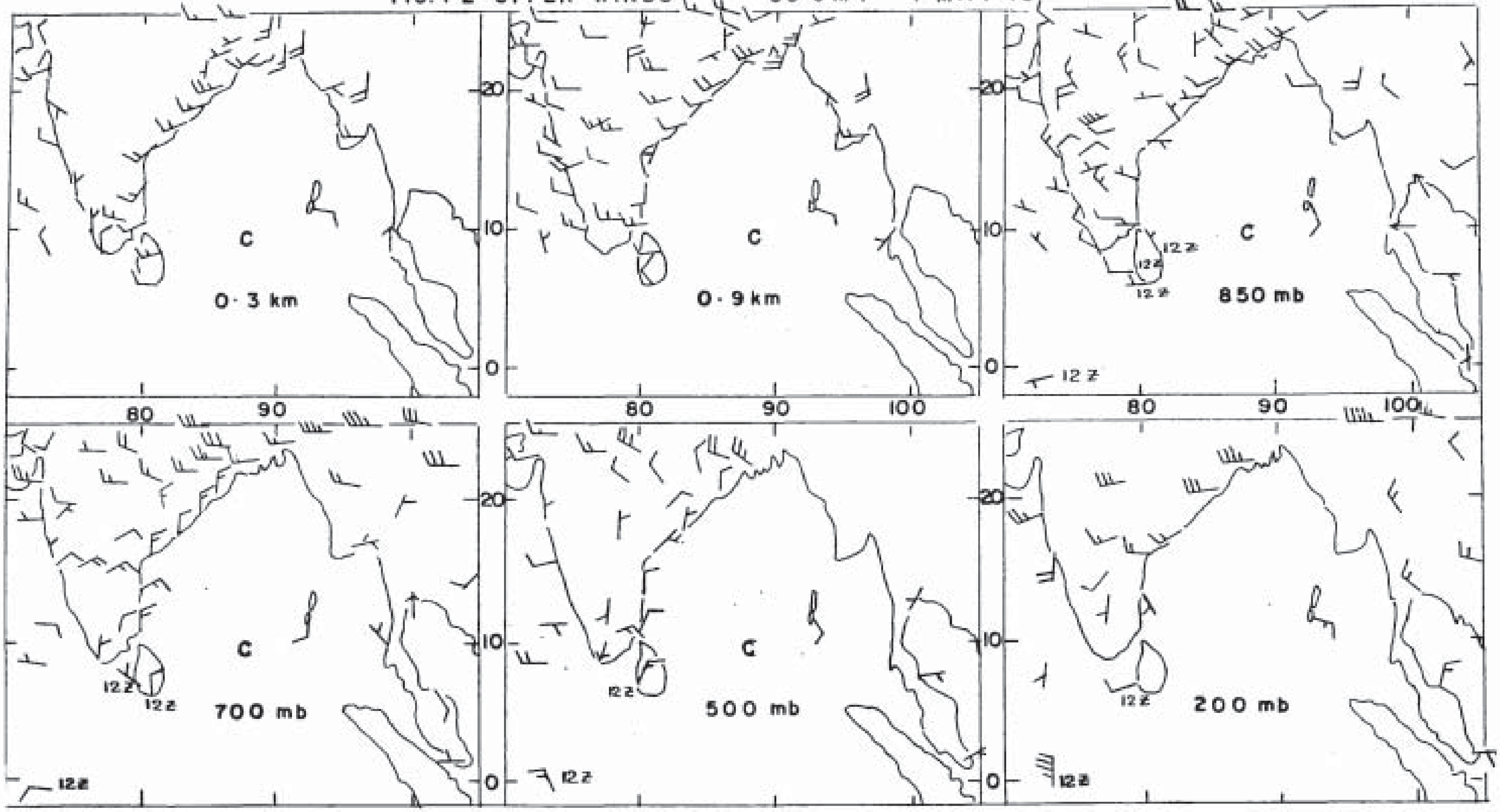


FIG. 7·2 UPPER WINDS 00 GMT 1 MAY 70



C-Centre of cyclonic circulation

FIG. 7·3 SYNOPTIC CHARTS 0300 GMT 2 MAY 70

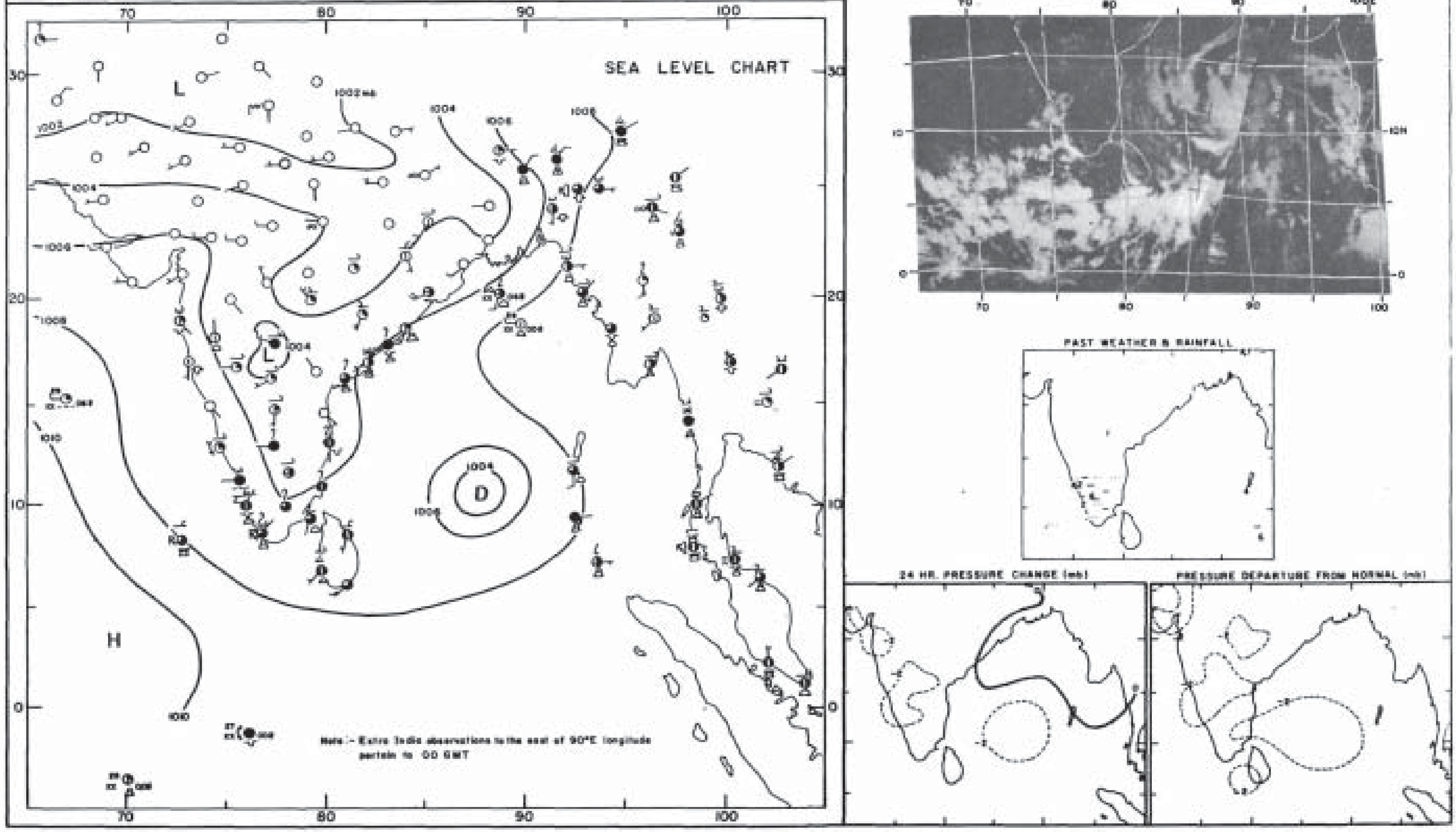
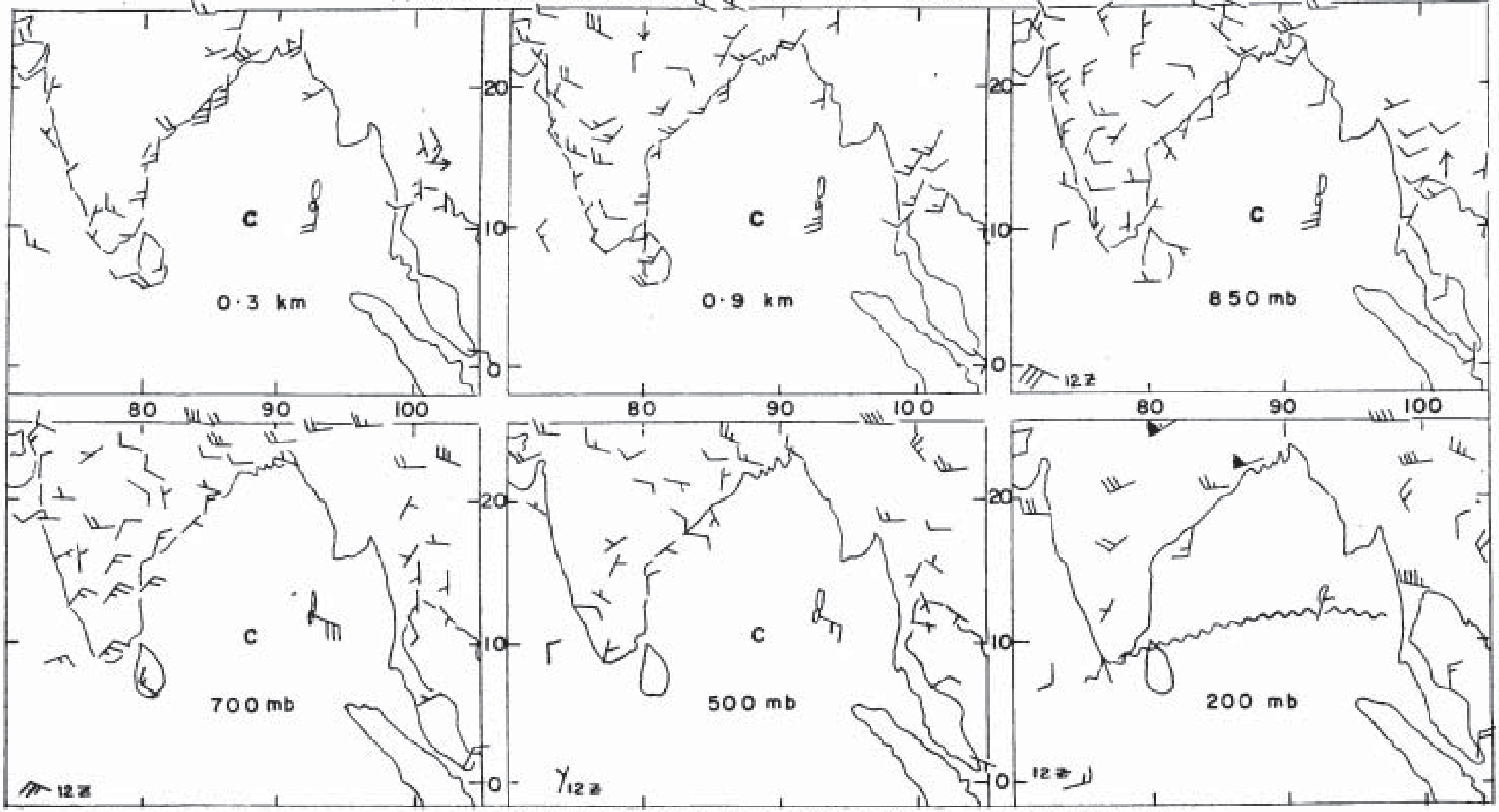


FIG. 7·4 UPPER WINDS 00 GMT 2 MAY 70



C - Centre of cyclonic circulation ~~~~ Ridge line

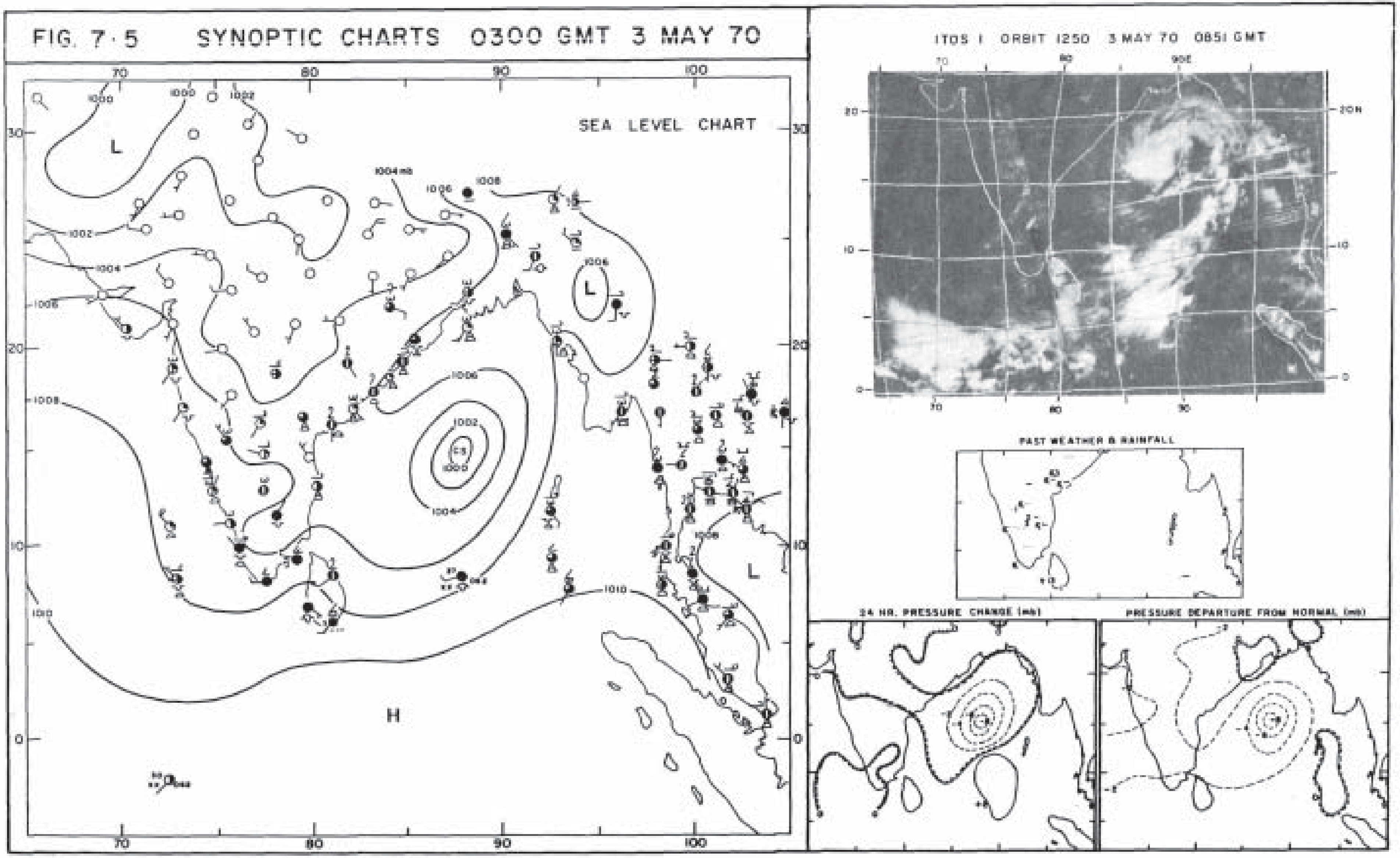
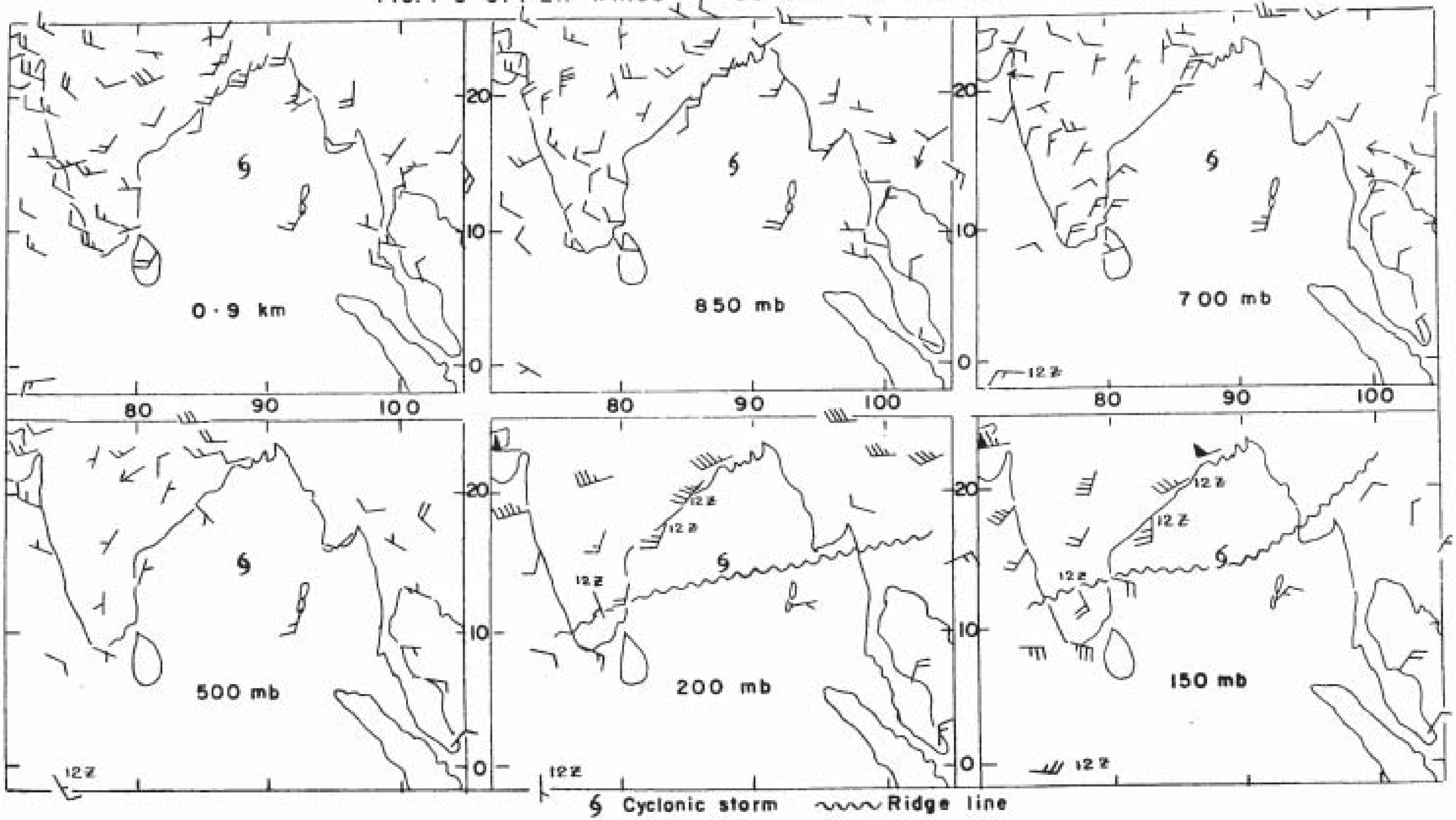


FIG. 7·5 SYNOPTIC CHARTS 0300 GMT 3 MAY 70

FIG. 7·6 UPPER WINDS 00 GMT 3 MAY 70



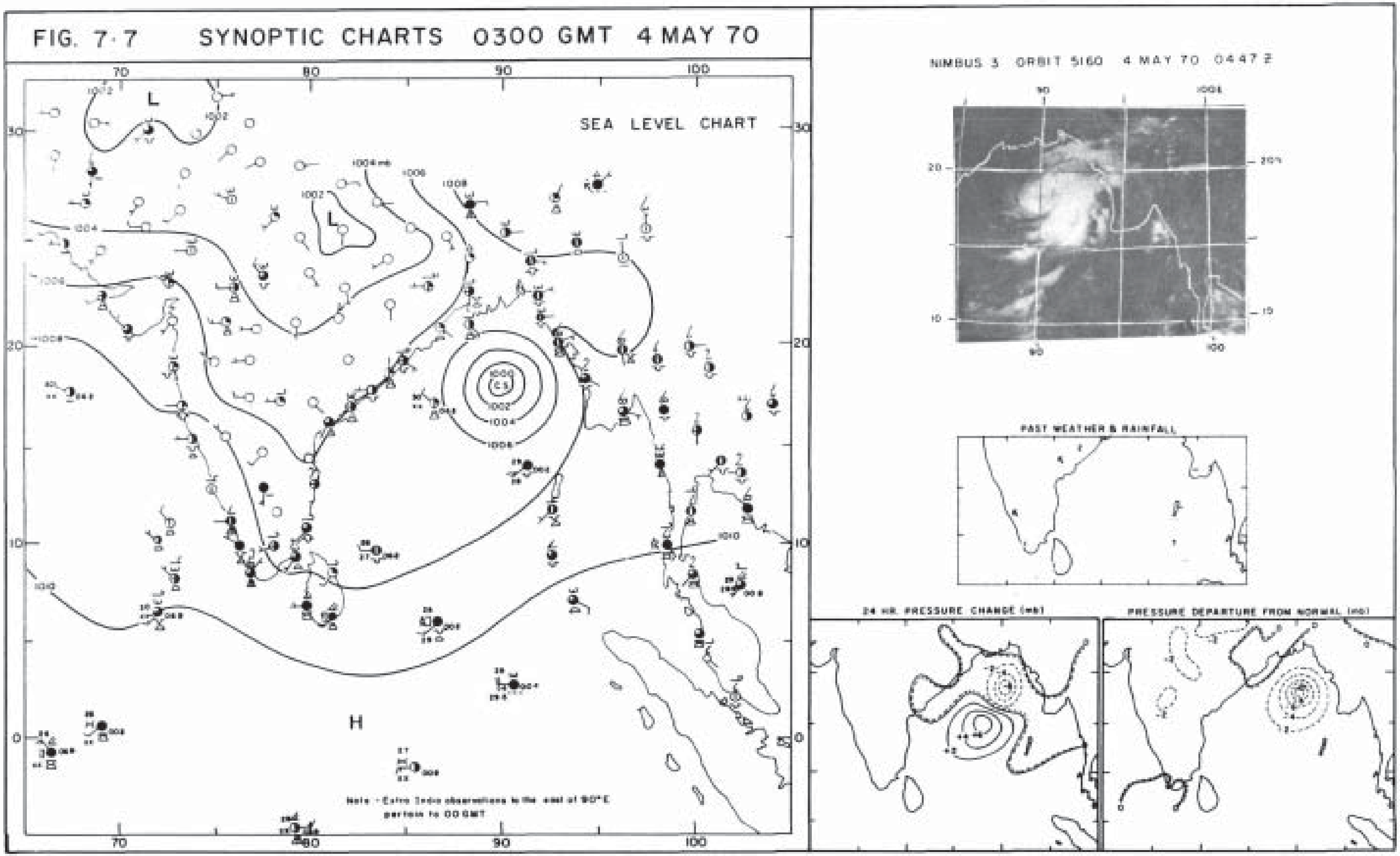


FIG. 7·7 SYNOPTIC CHARTS 0300 GMT 4 MAY 70

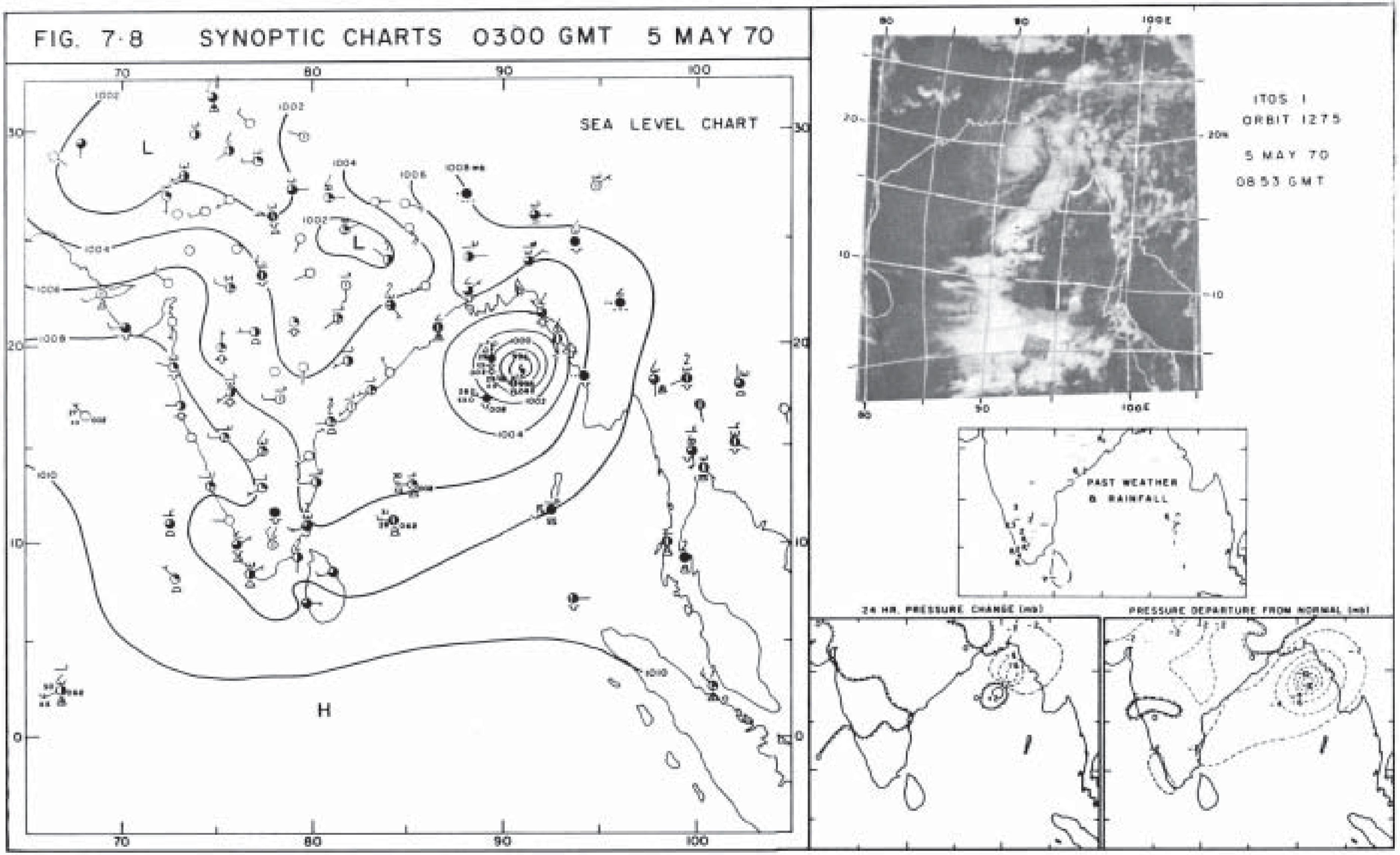


FIG. 7·8 SYNOPTIC CHARTS 0300 GMT 5 MAY 70

FIG. 7·9 SYNOPTIC CHARTS 0300 GMT 6 MAY 70

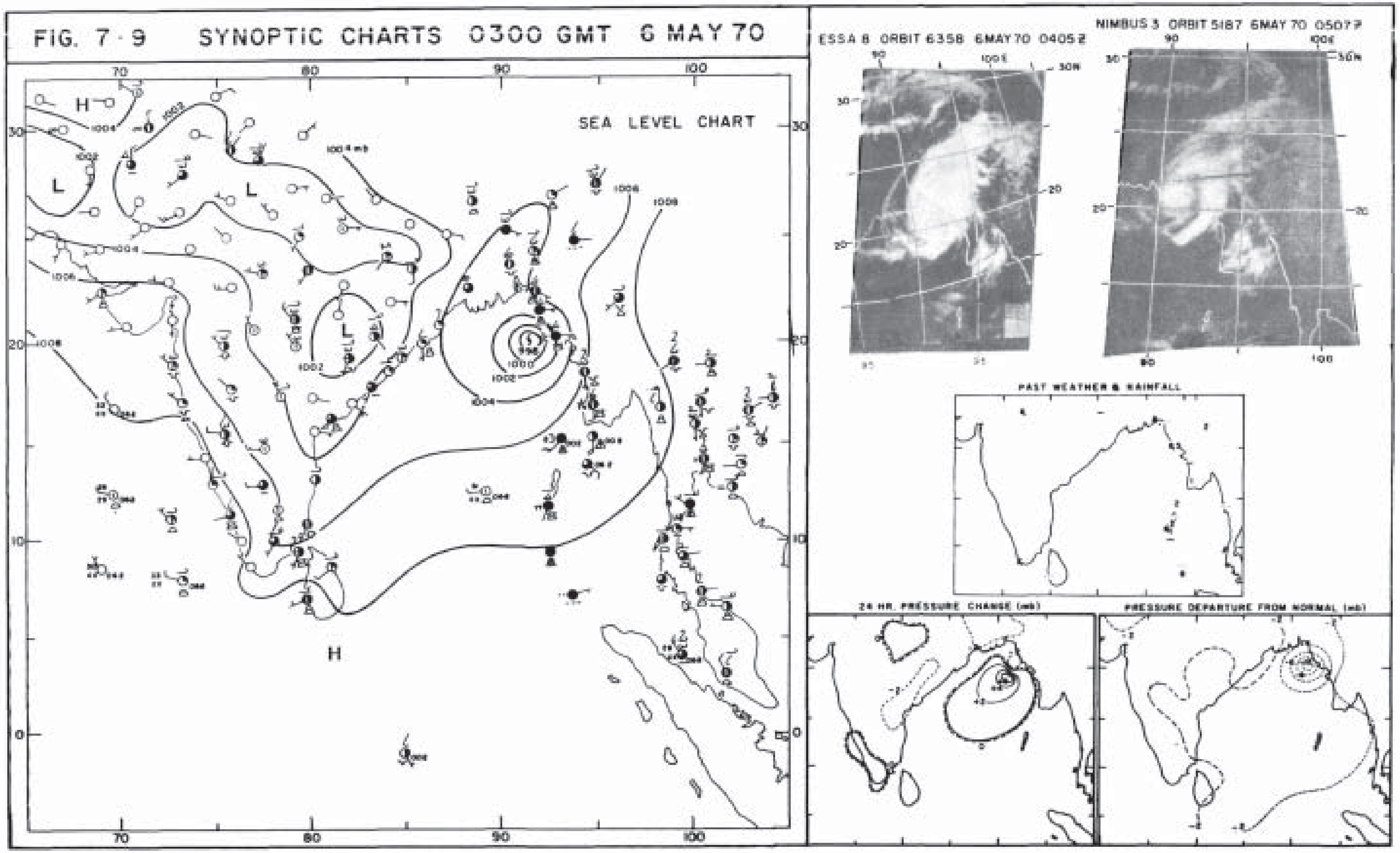


FIG. 7·10 UPPER WINDS 00GMT 6 MAY 70

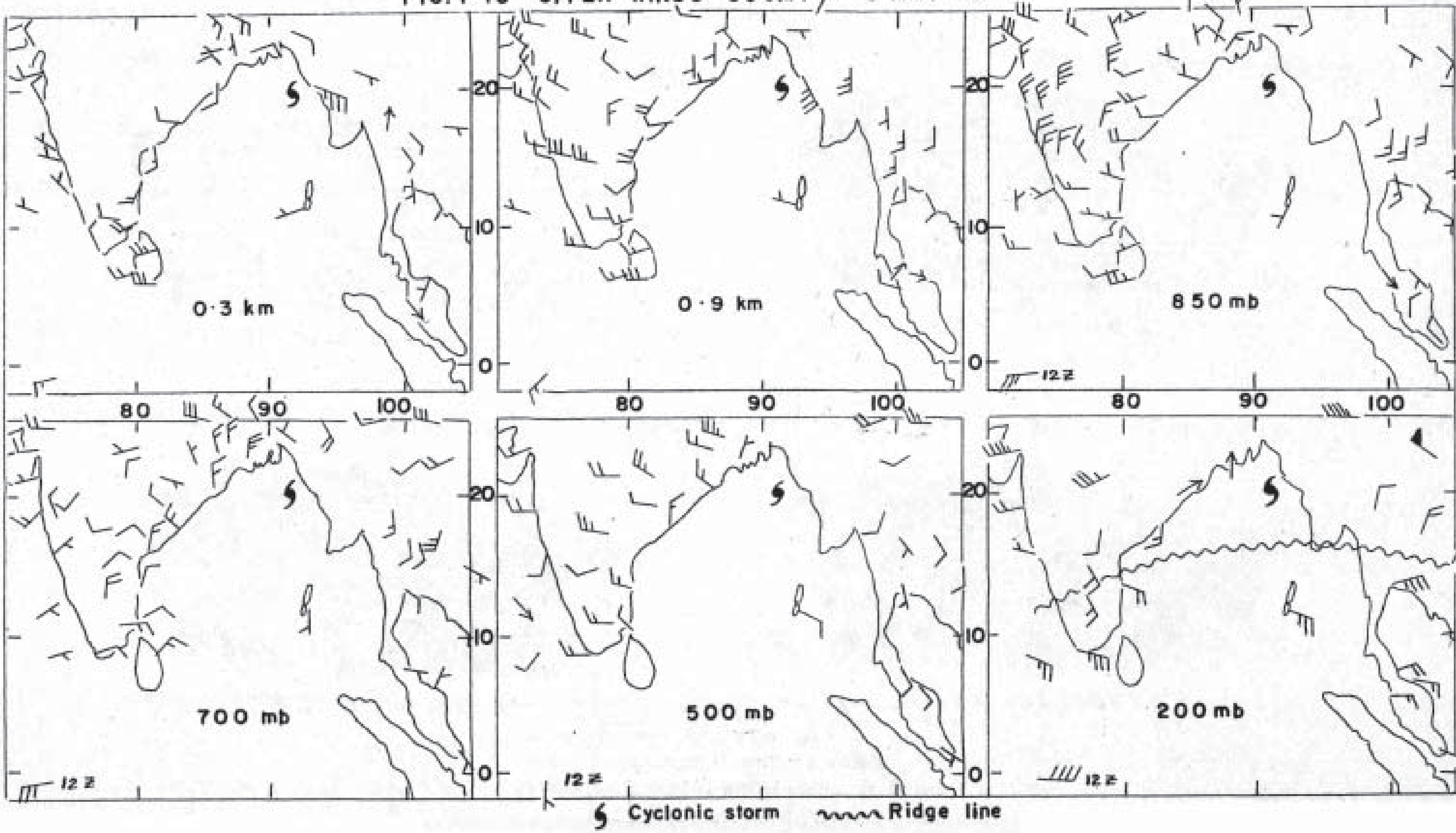


FIG. 7-11 SEQUENCE OF SATELLITE PICTURES
26-29 APRIL 1970

Copied from "Catalog of Meteorological Satellite Data
ESSA-9 & ITOS-1 Television Cloud Photography."
(NOAA Publication KMRD No. 5-326)

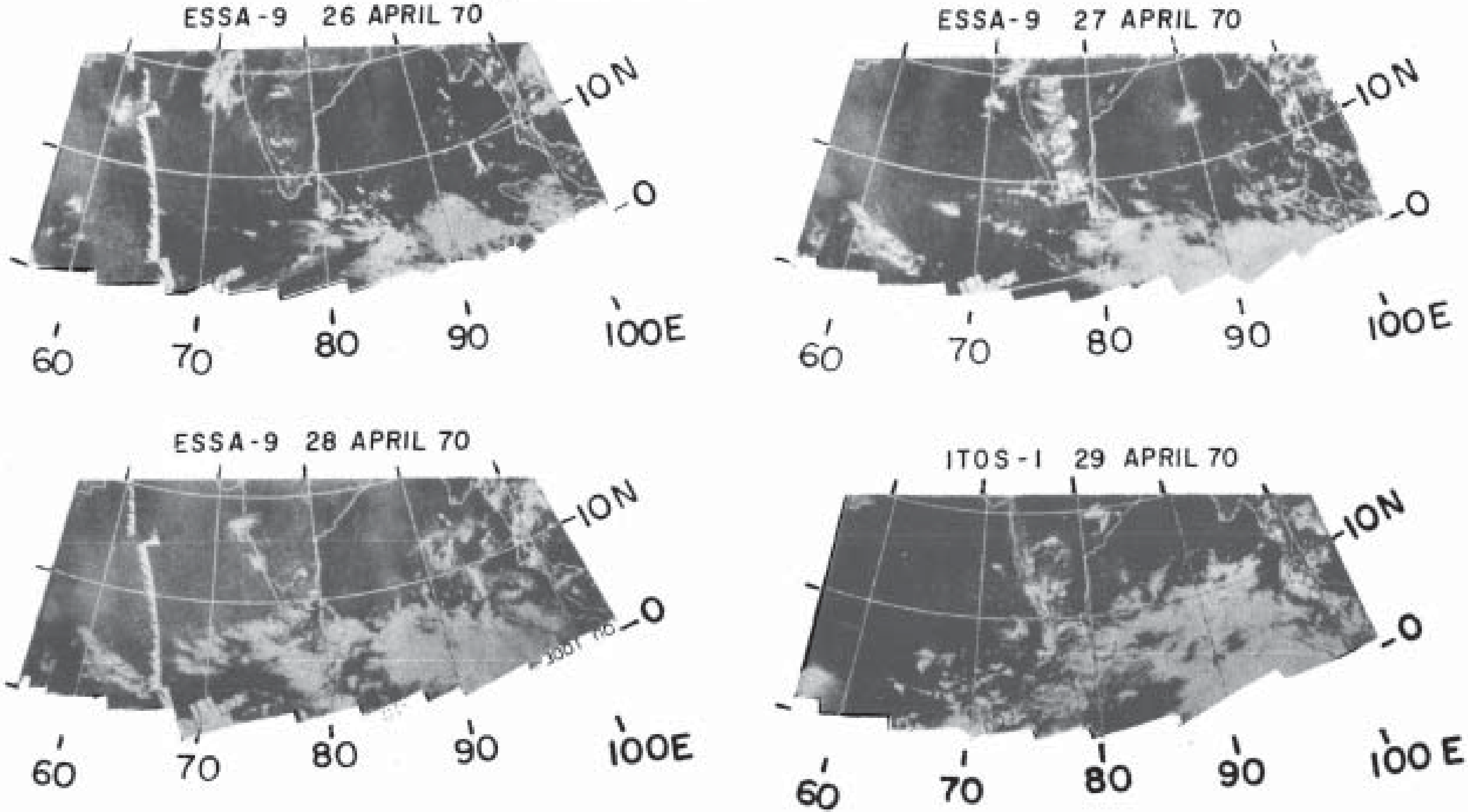


FIG. 8·1 SYNOPTIC CHARTS 0300 GMT 8 JUN. 64

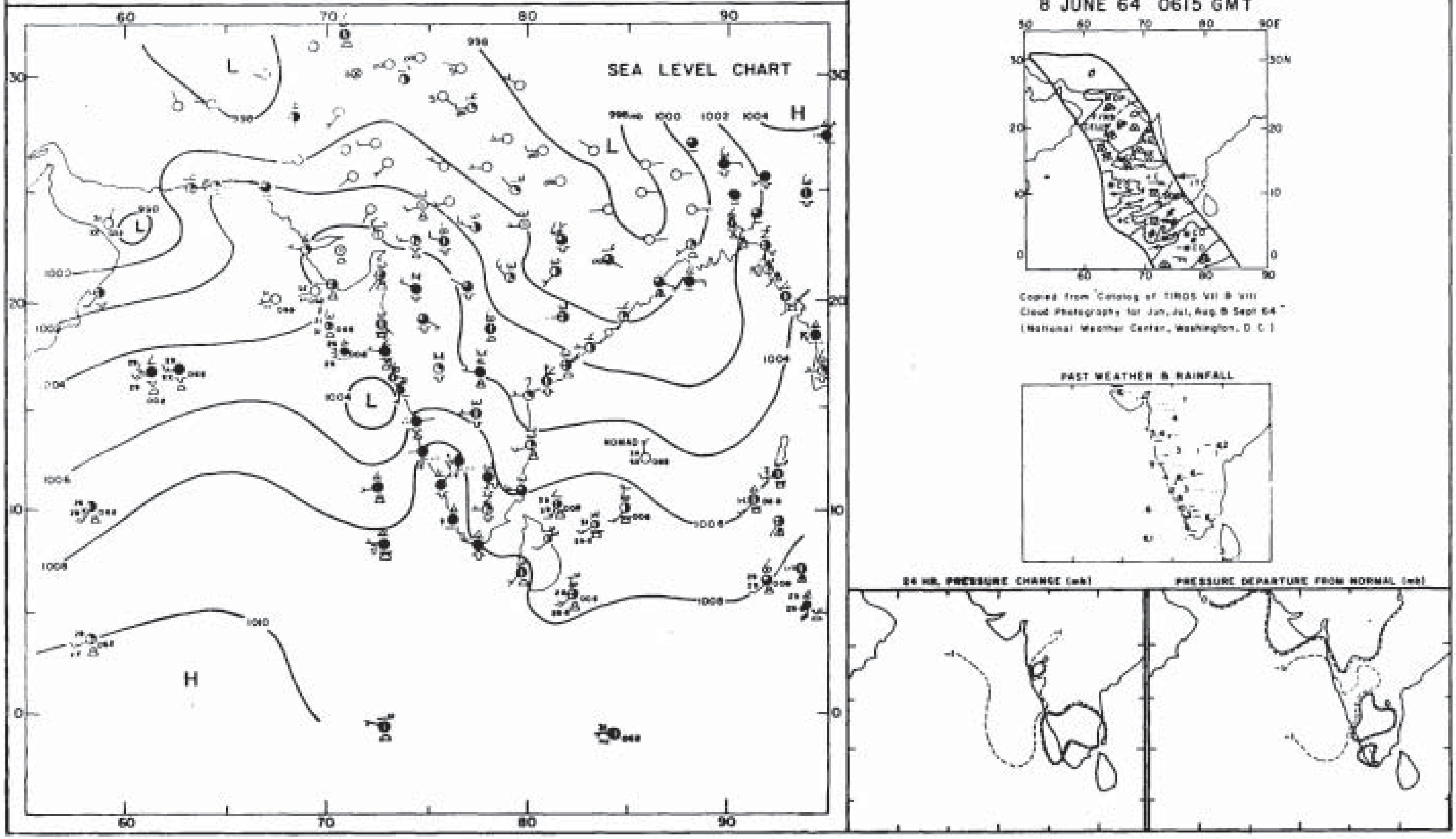
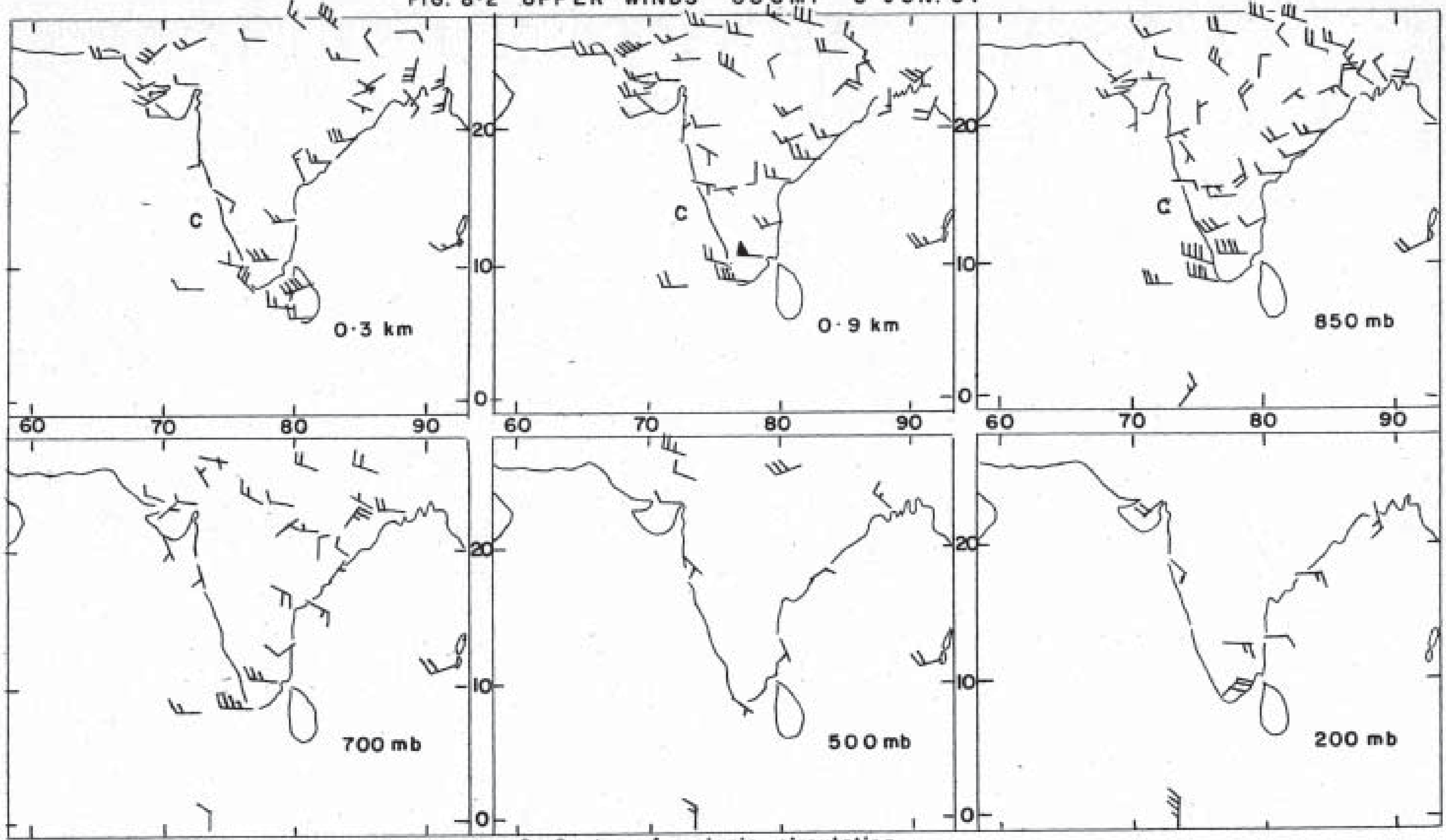
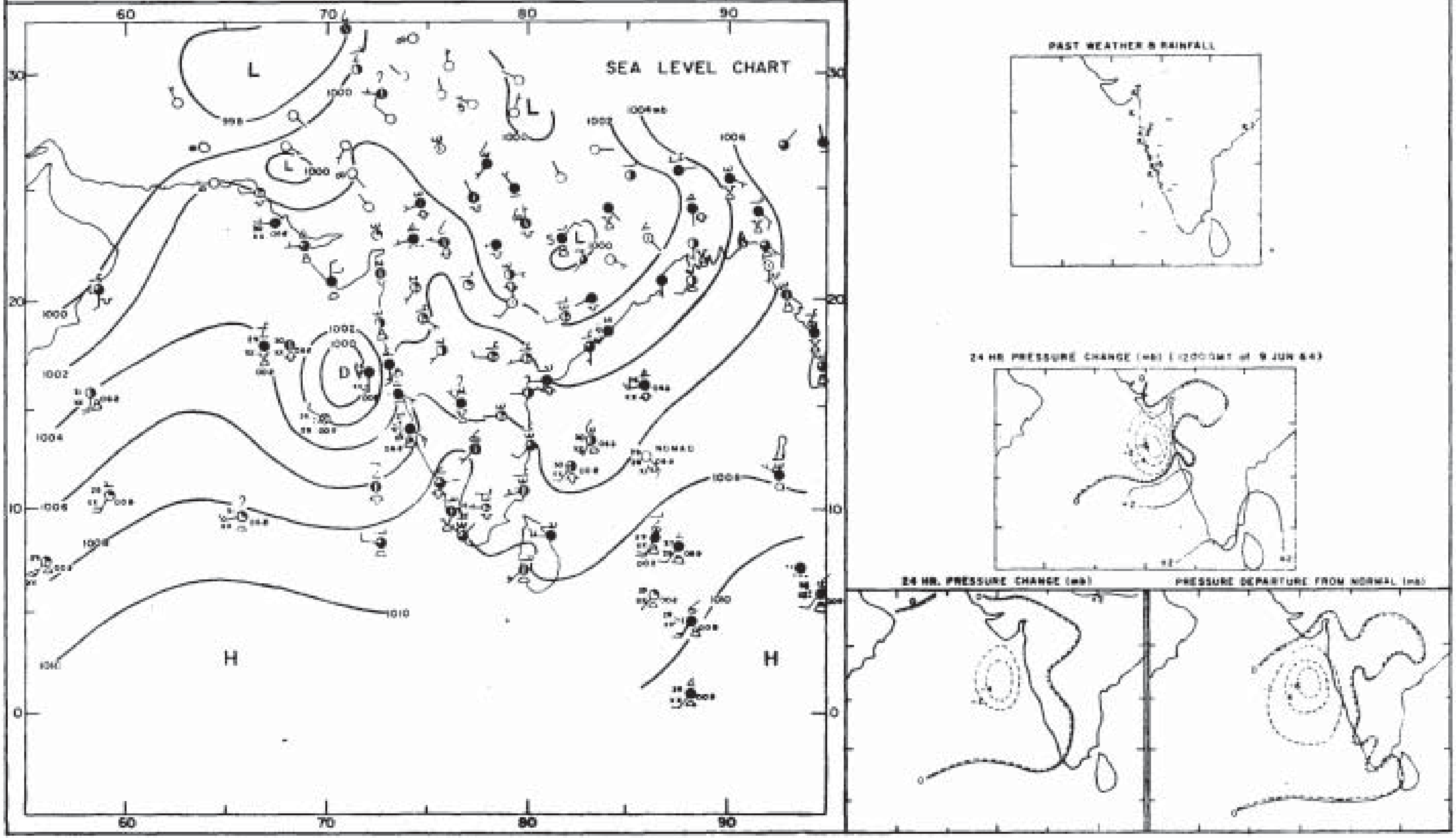


FIG. 8·2 UPPER WINDS 00GMT 8 JUN. 64



C - Centre of cyclonic circulation

FIG. 8·3 SYNOPTIC CHARTS 0300 GMT 9 JUN. 64



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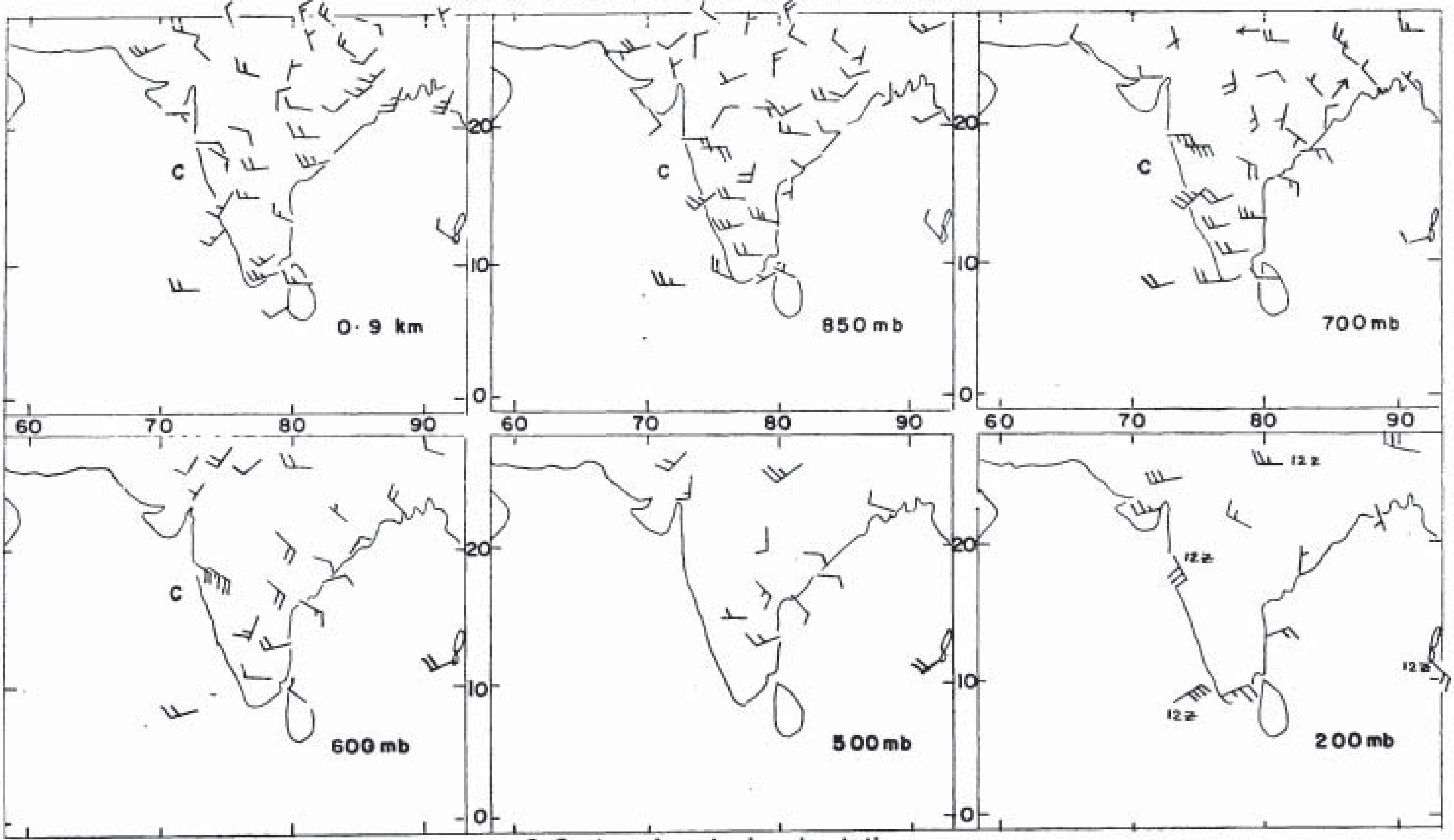


C-Centre of cyclonic circulation

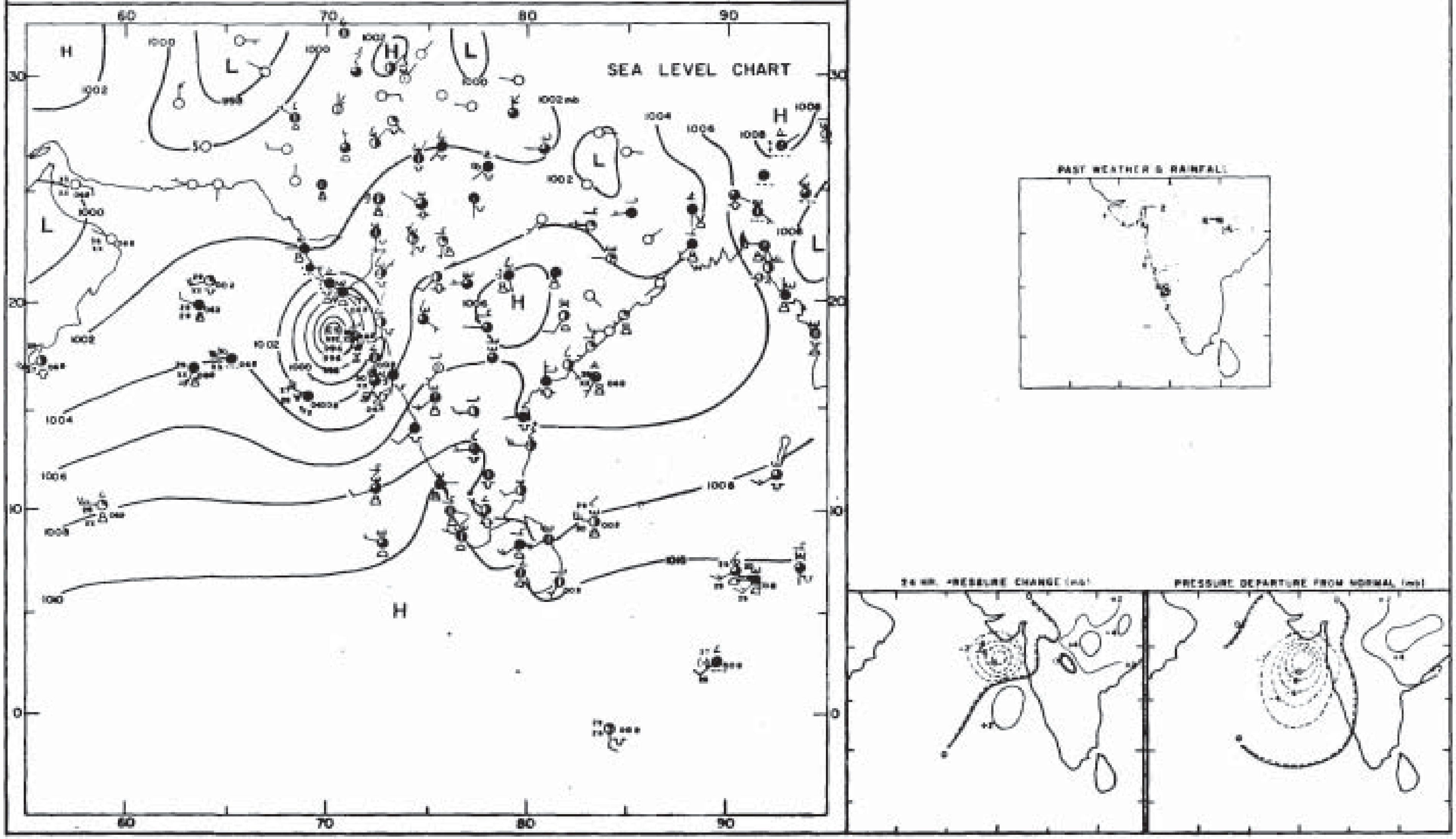
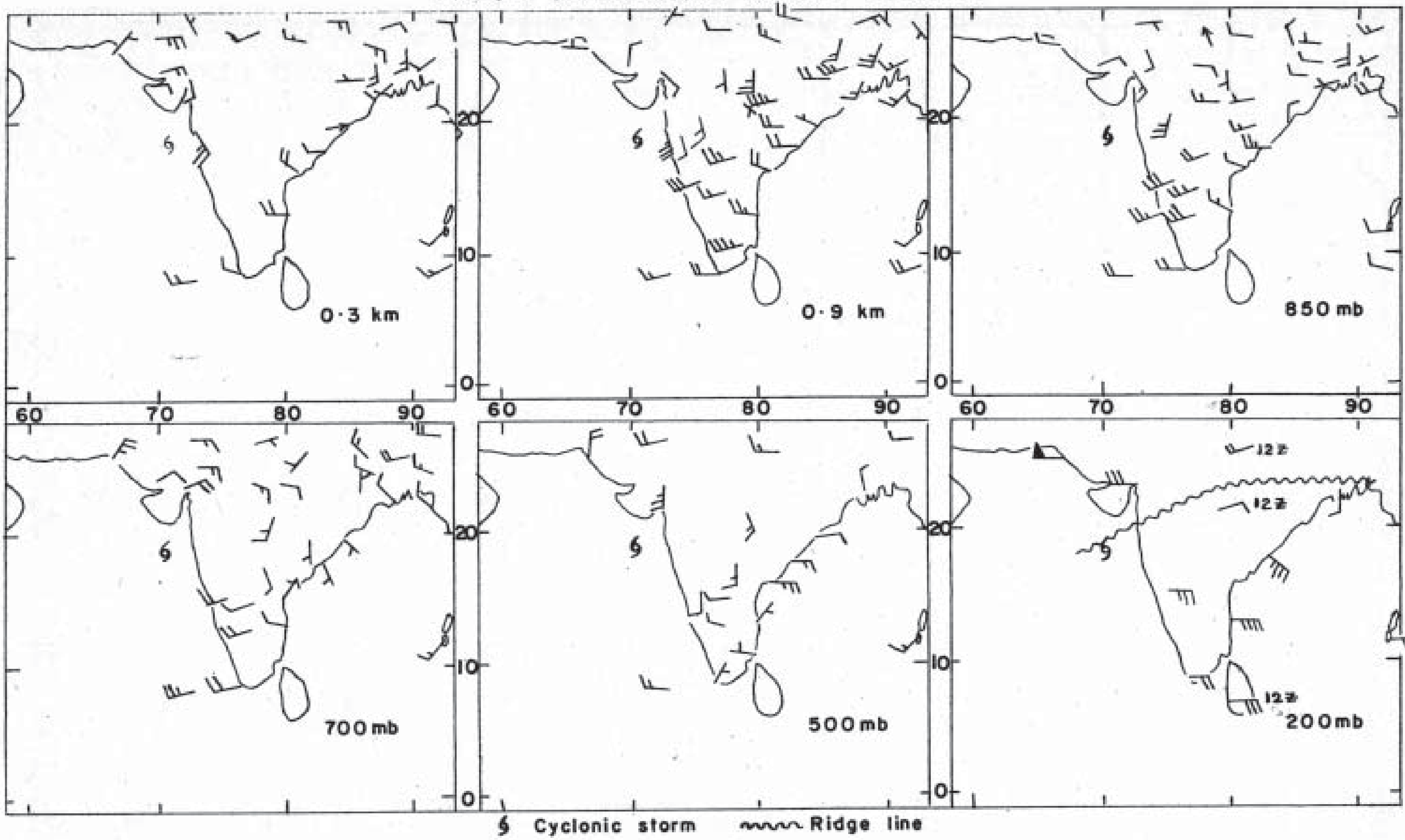


FIG. 8·5 SYNOPTIC CHARTS 0300 GMT 10 JUN. 64

FIG. 8·6 UPPER WINDS 00 GMT 10 JUN. 64



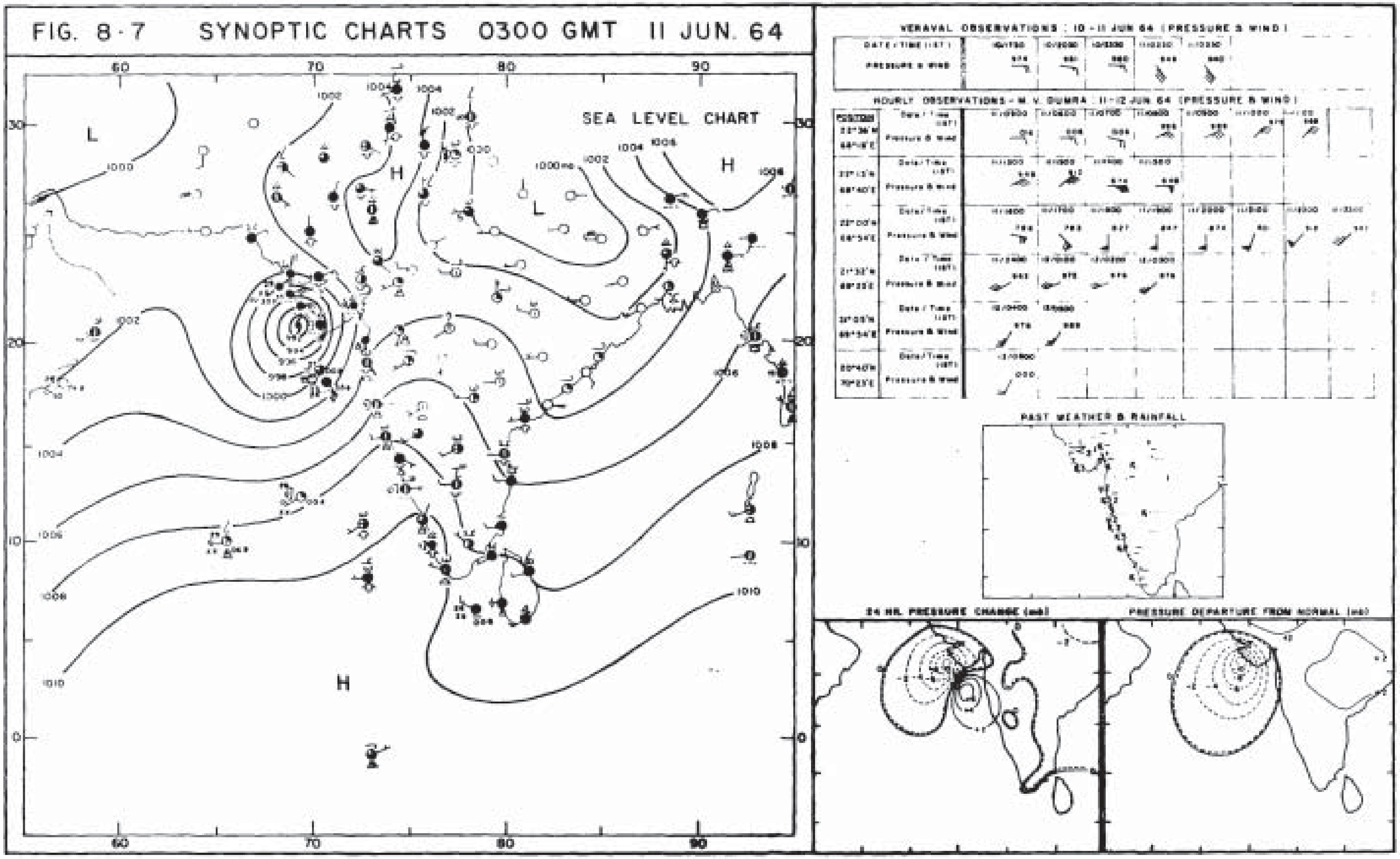
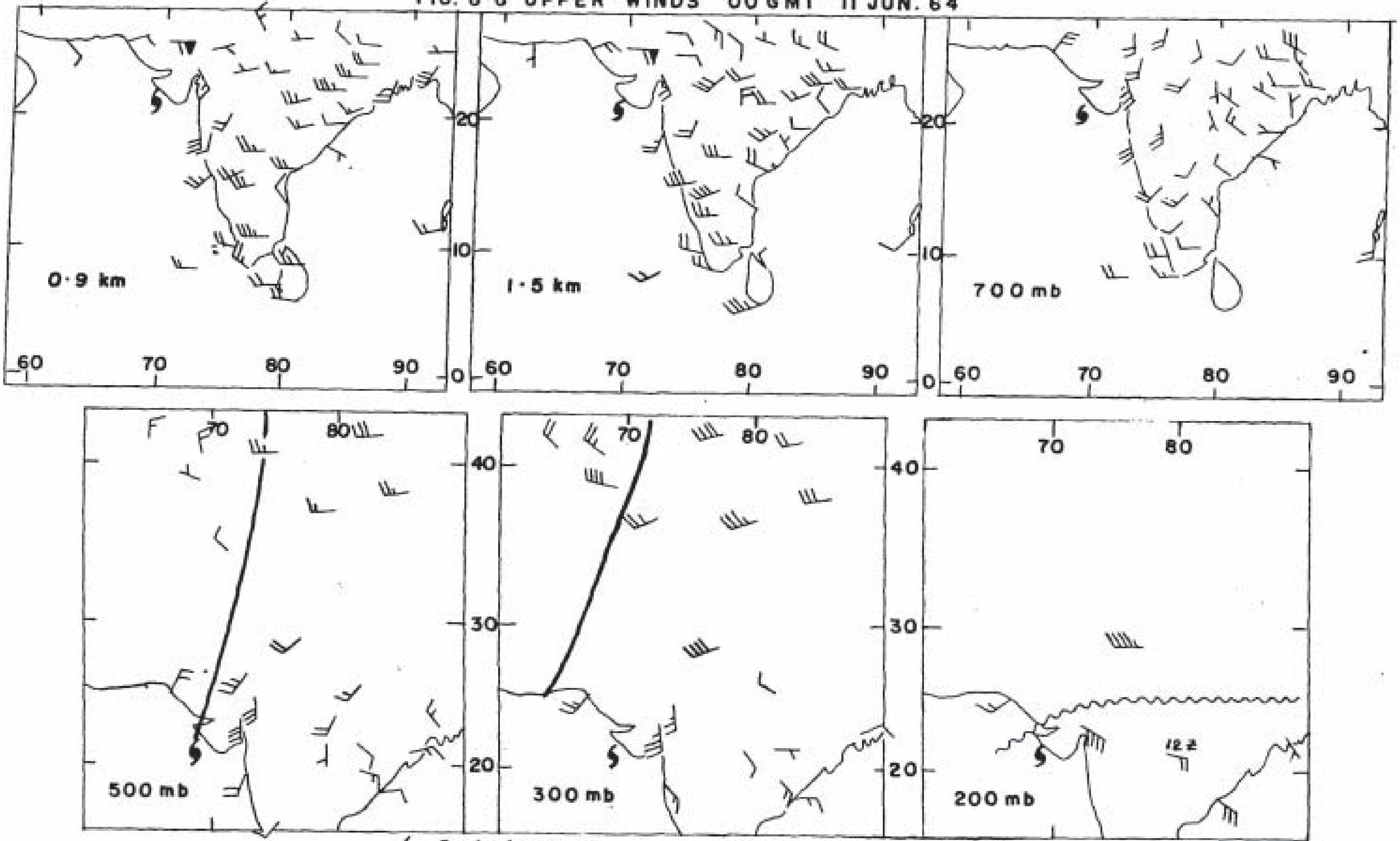


FIG. 8·7 SYNOPTIC CHARTS 0300 GMT 11 JUN. 64

FIG. 8·8 UPPER WINDS 00 GMT 11 JUN. 64



Cyclonic storm — Trough line — Ridge line

FIG. 8 · 9   SYNOPTIC CHARTS 0300 GMT 12 JUN. 64

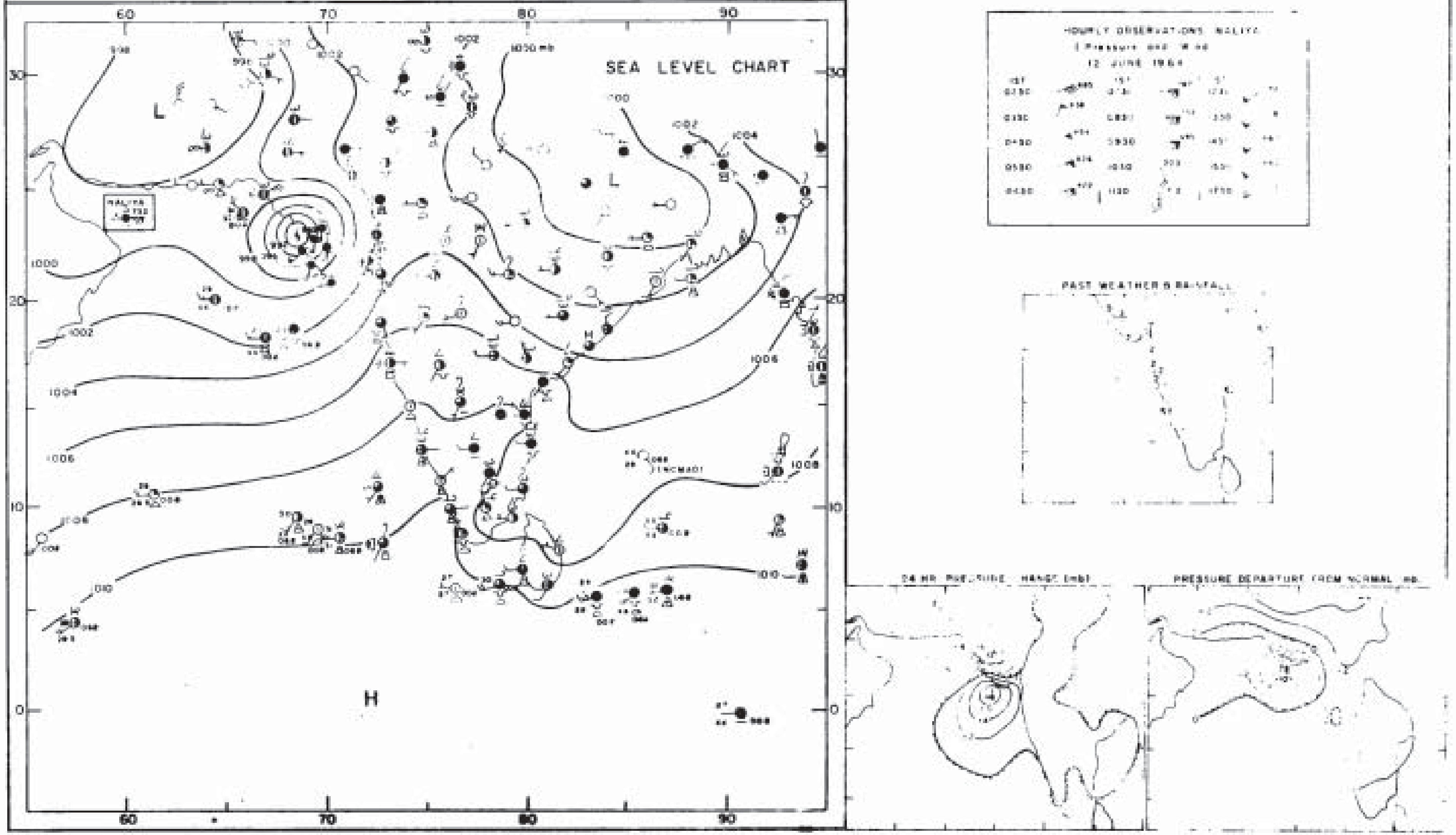


FIG. 8·10 UPPER WINDS 00 GMT 12 JUN. 64

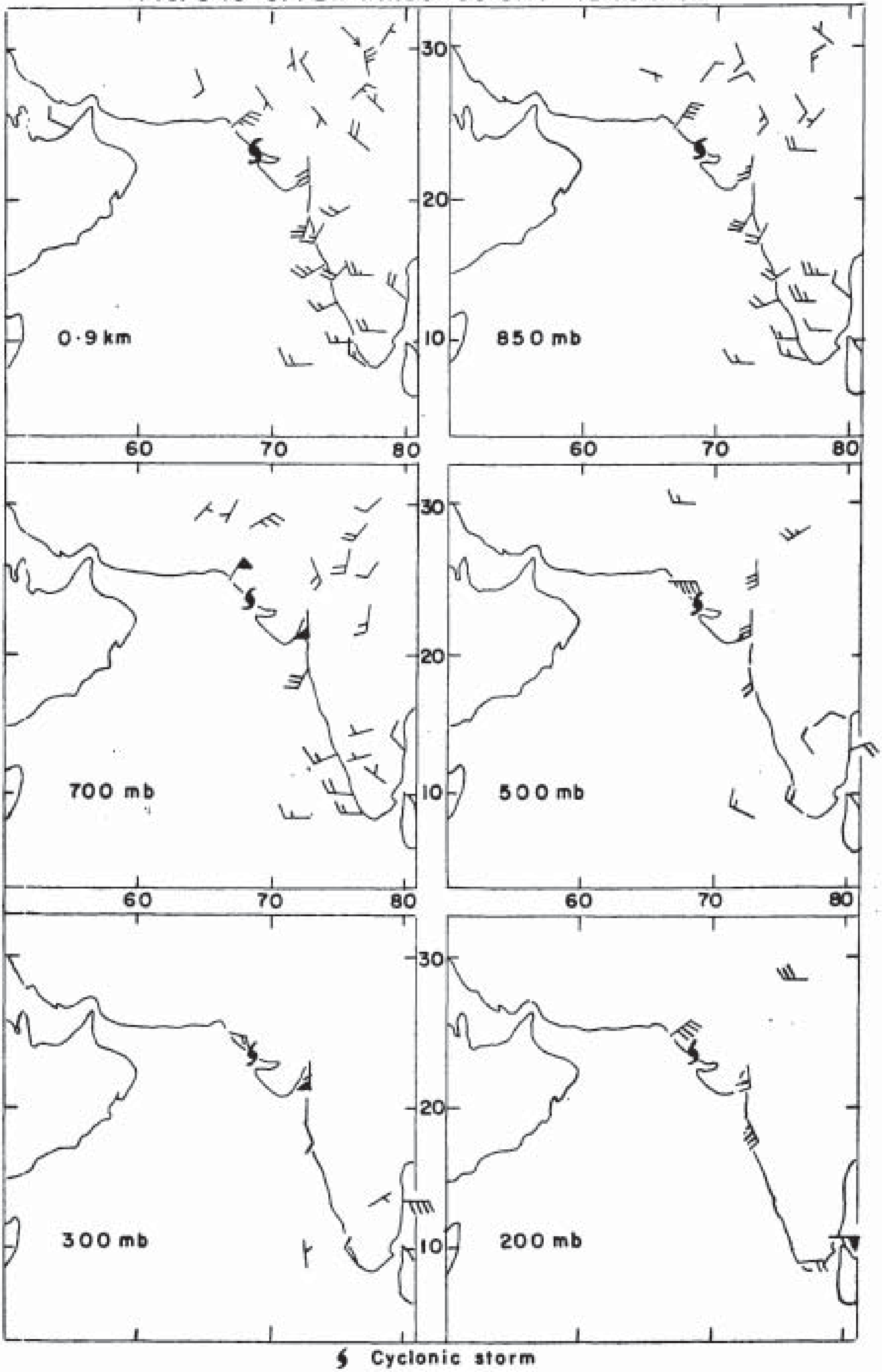


FIG. 9·1 SYNOPTIC CHARTS 0300 GMT 27 MAY 70

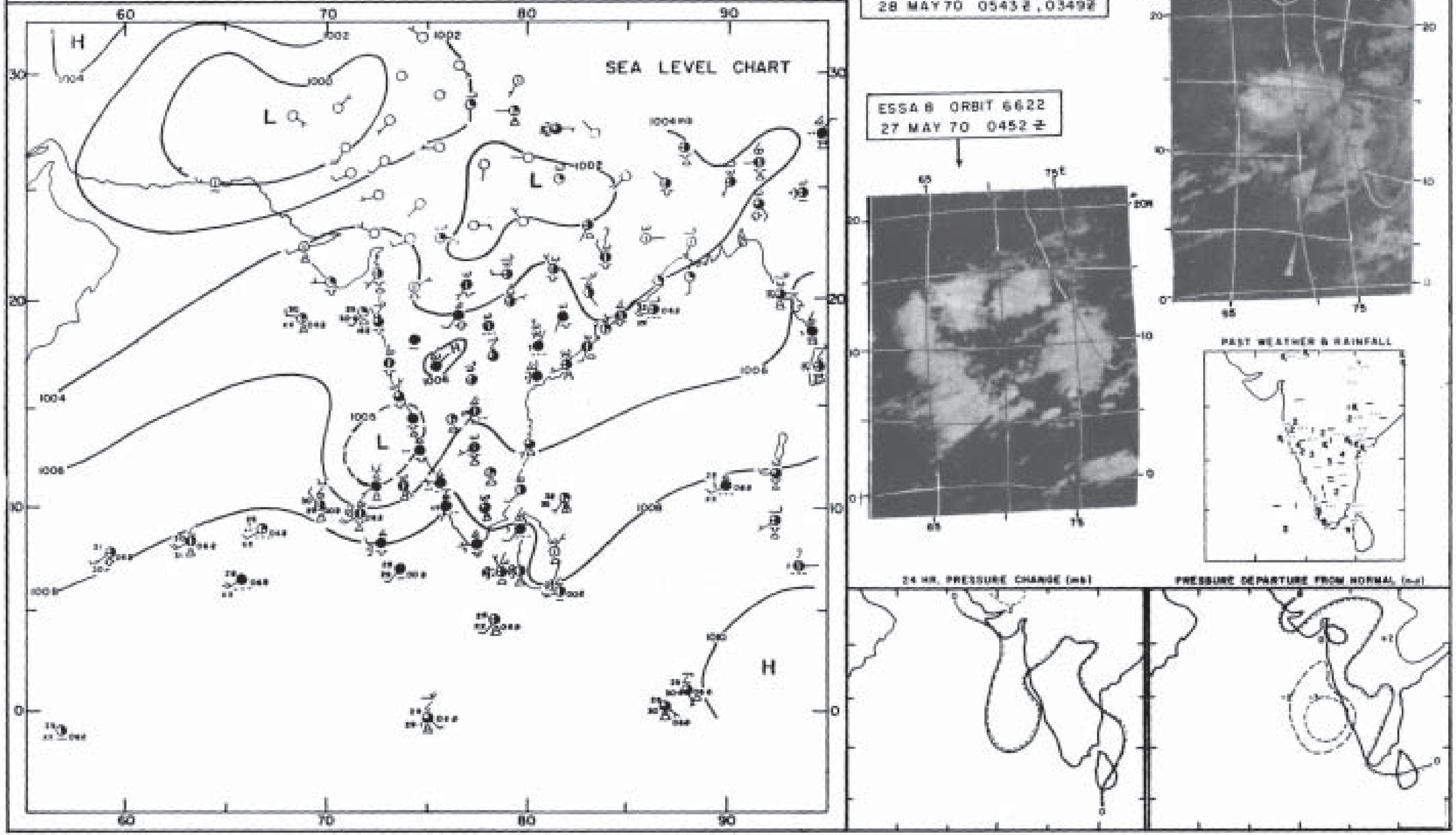
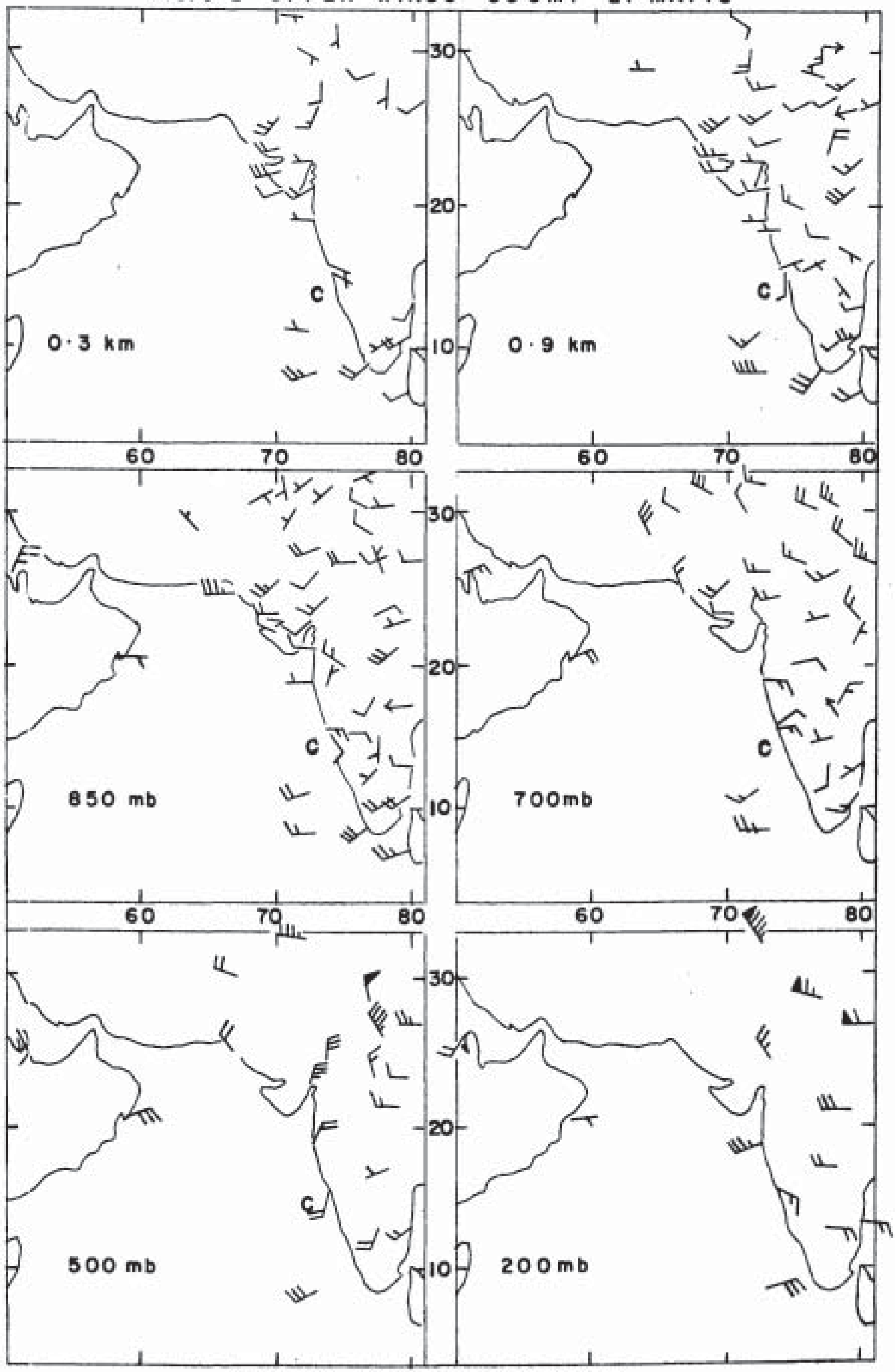
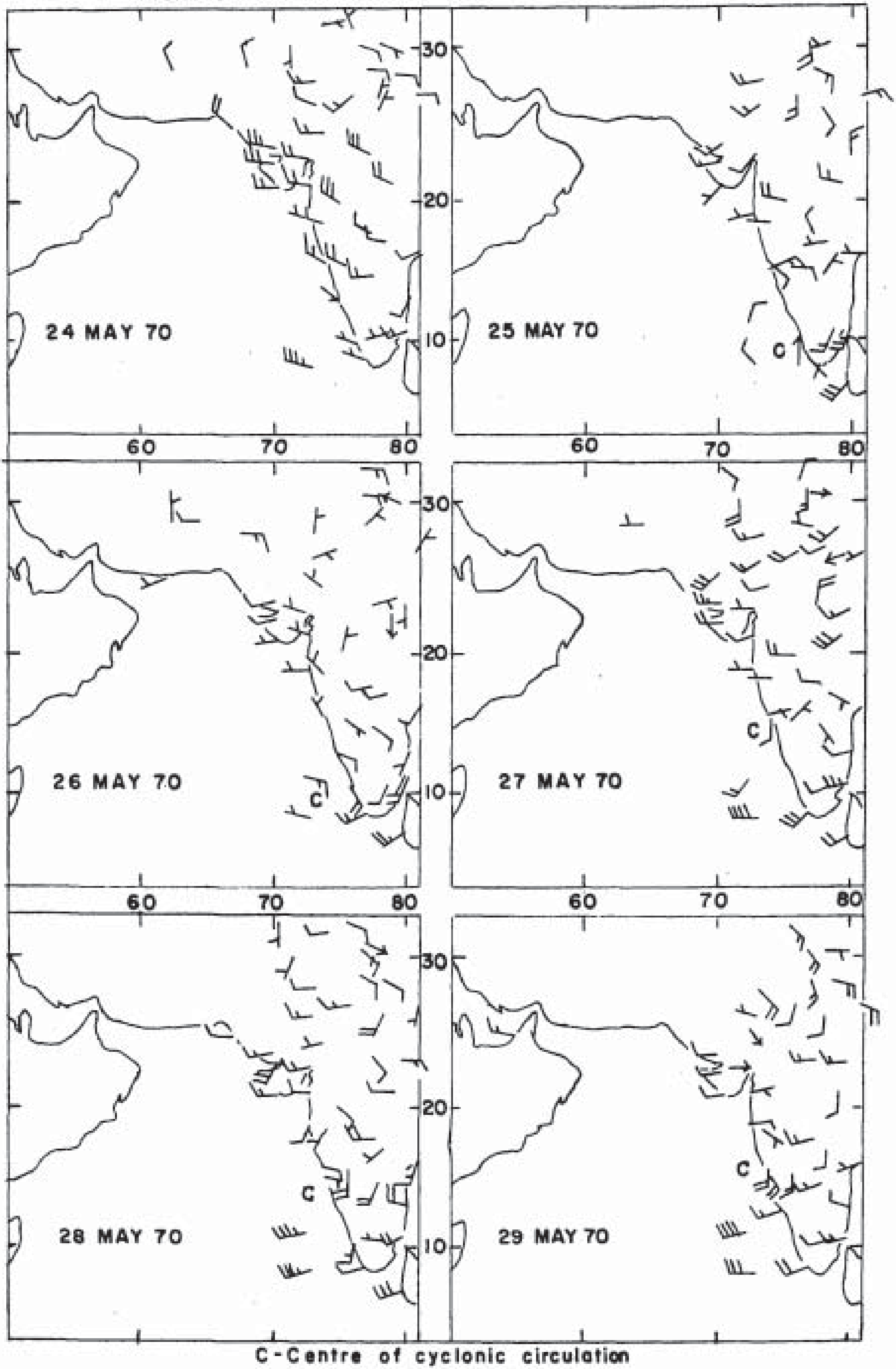


FIG. 9·2 UPPER WINDS 00GMT 27 MAY 70



C-Centre of cyclonic circulation

FIG. 9·3 UPPER WINDS 00 GMT 0·9 km. MAY 70



C - Centre of cyclonic circulation

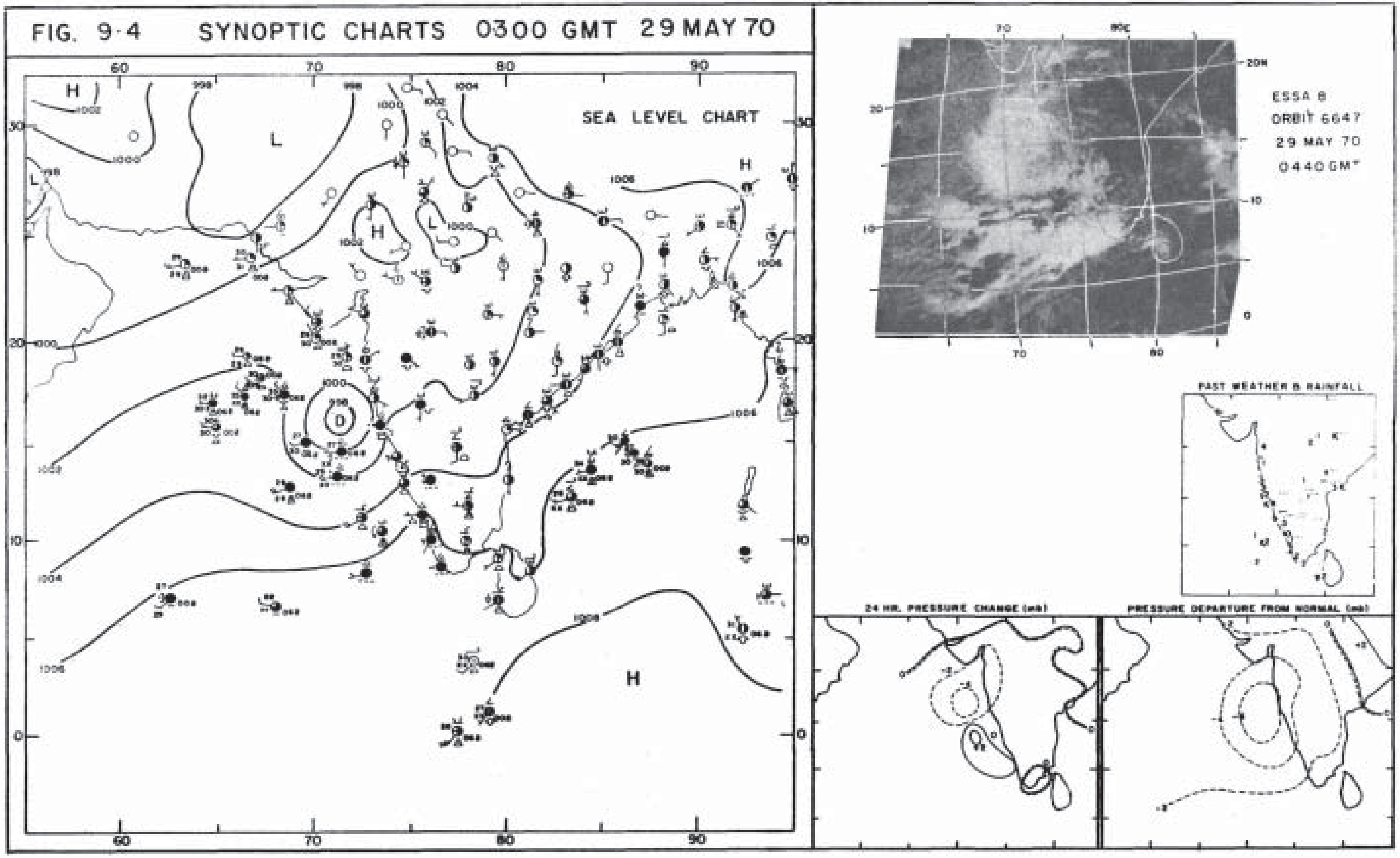
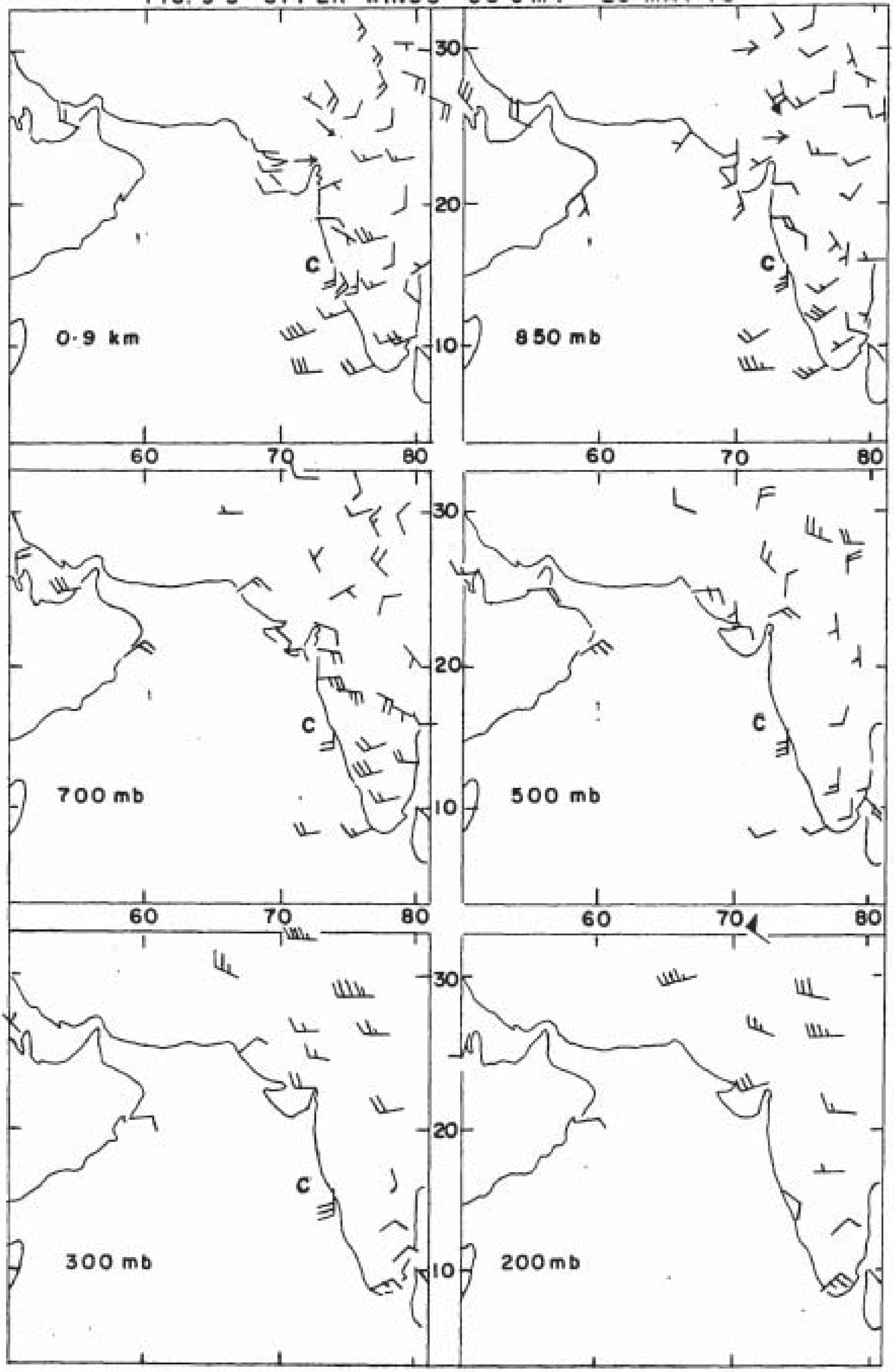


FIG. 9·4 SYNOPTIC CHARTS 0300 GMT 29 MAY 70

FIG. 9·5 UPPER WINDS 00 GMT 29 MAY 70



C - Centre of cyclonic circulation

FIG. 9·6 SYNOPTIC CHARTS 0300 GMT 30 MAY 70

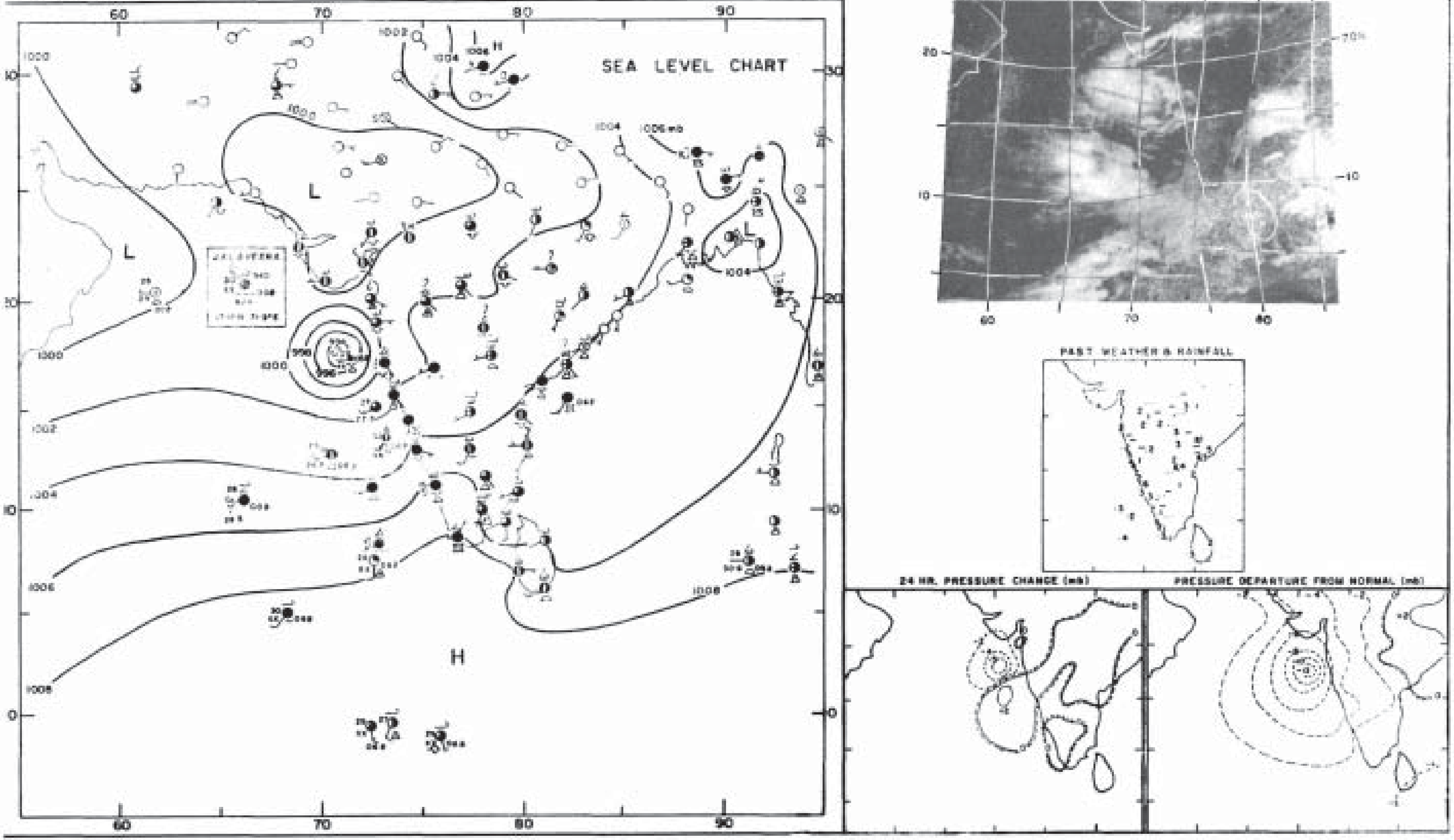


FIG. 9·7 UPPER WINDS 00 GMT 30 MAY 70

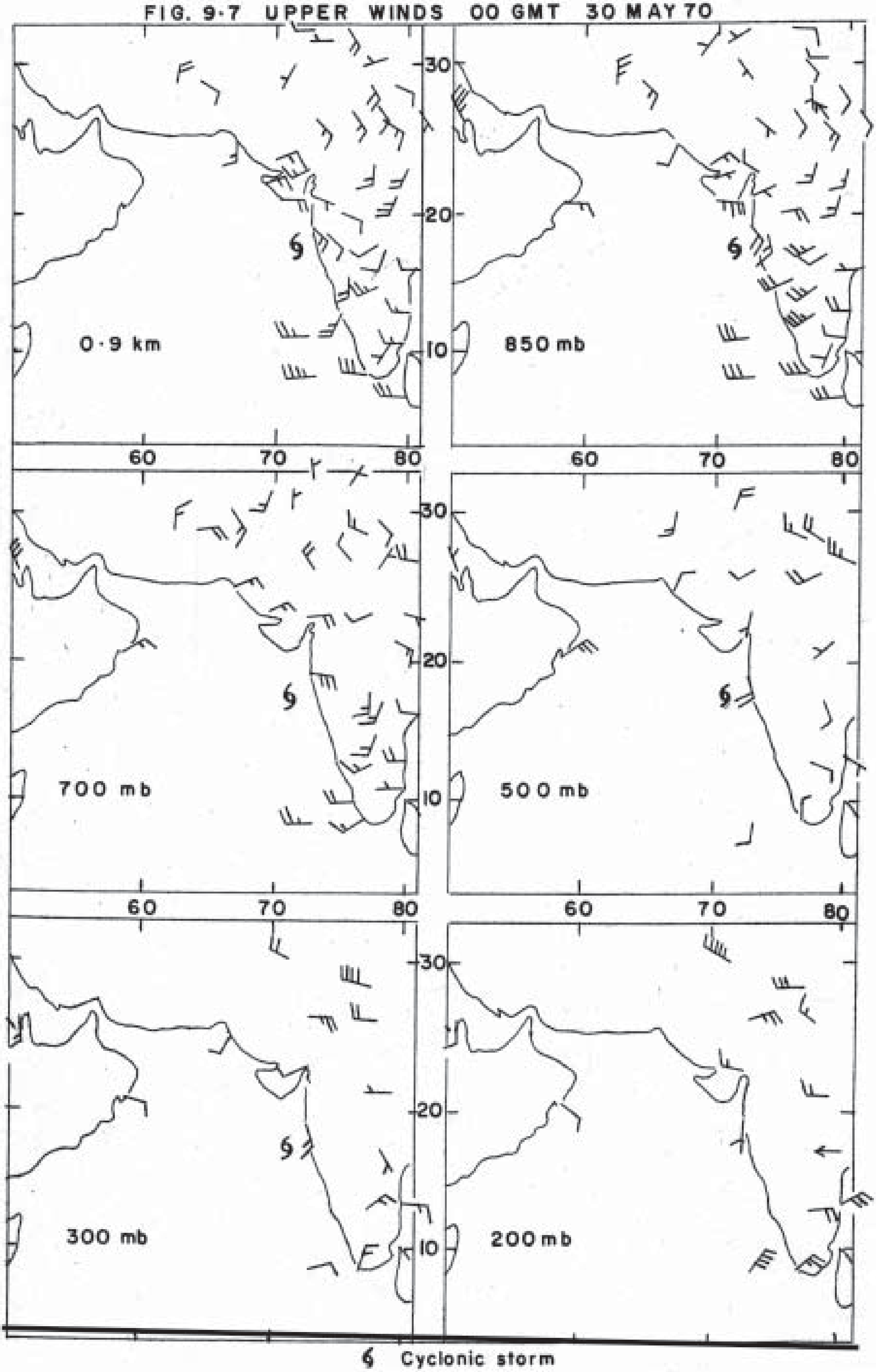
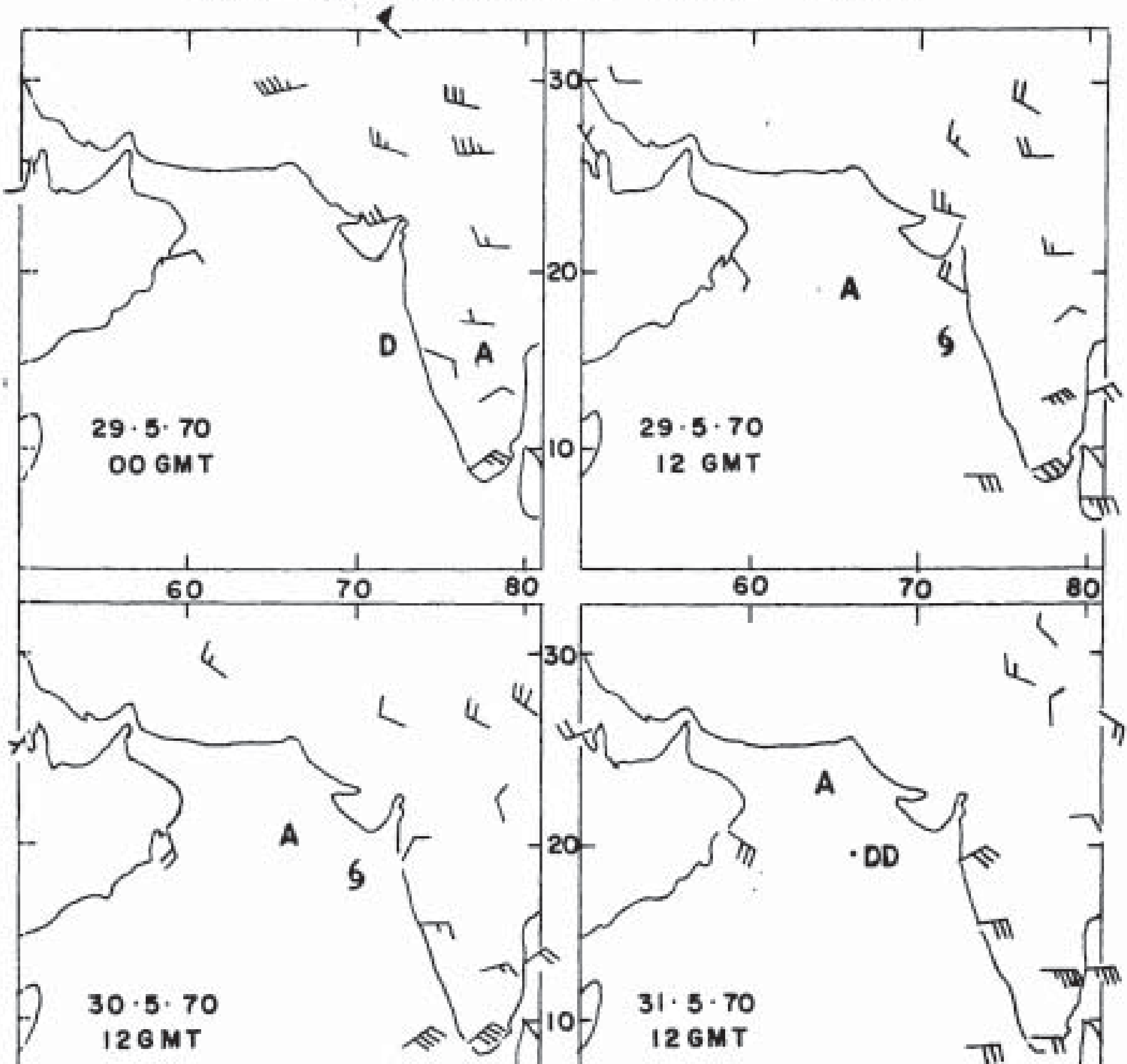
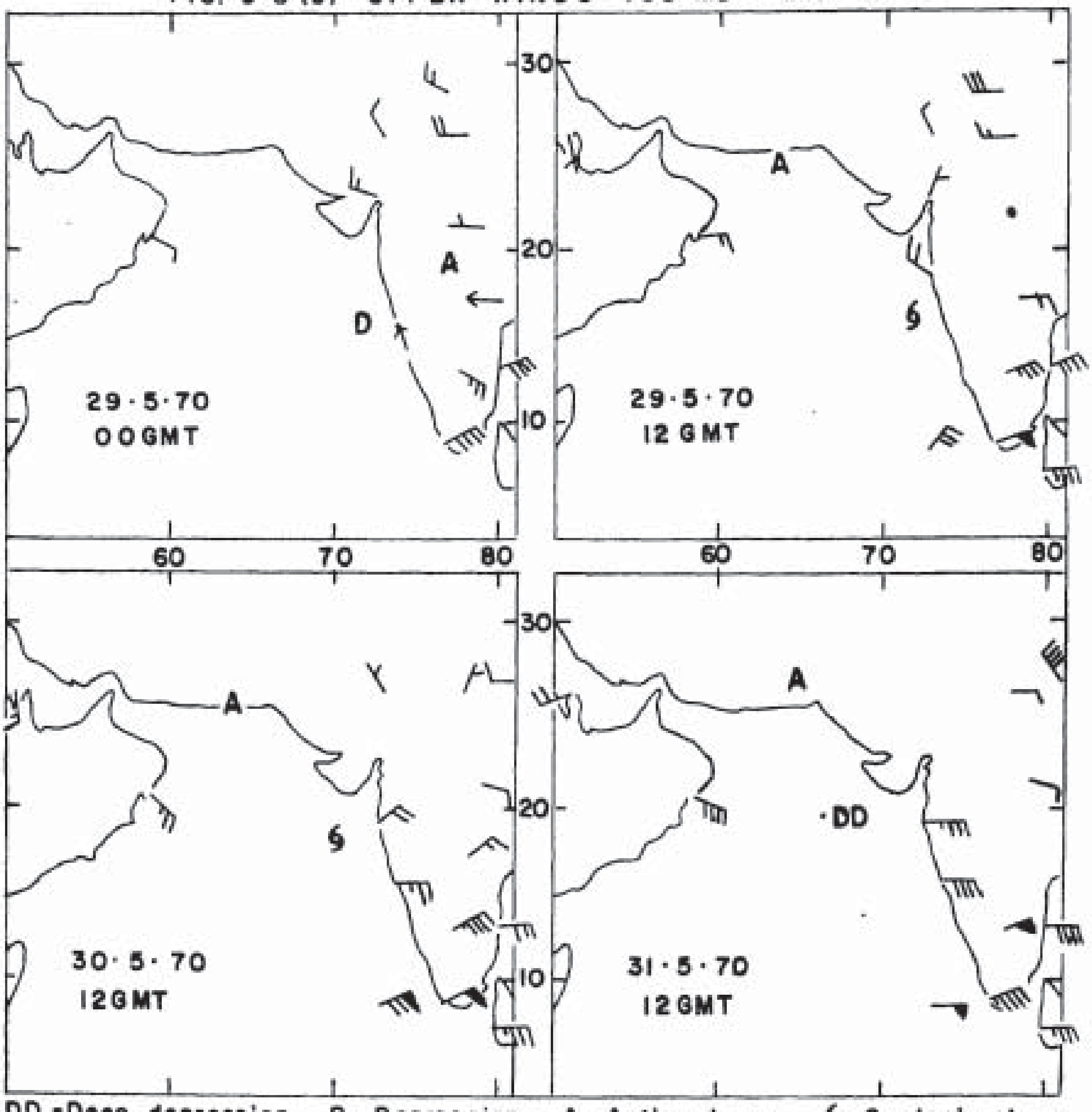


FIG. 9·8 (a) UPPER WINDS 200 mb MAY 70



DD - Deep Depression D - Depression A - Anticyclone § Cyclonic storm

FIG. 9·8 (b) UPPER WINDS 150 mb MAY 70



DD - Deep depression   D - Depression   A - Anti cyclone   ʂ Cyclonic storm

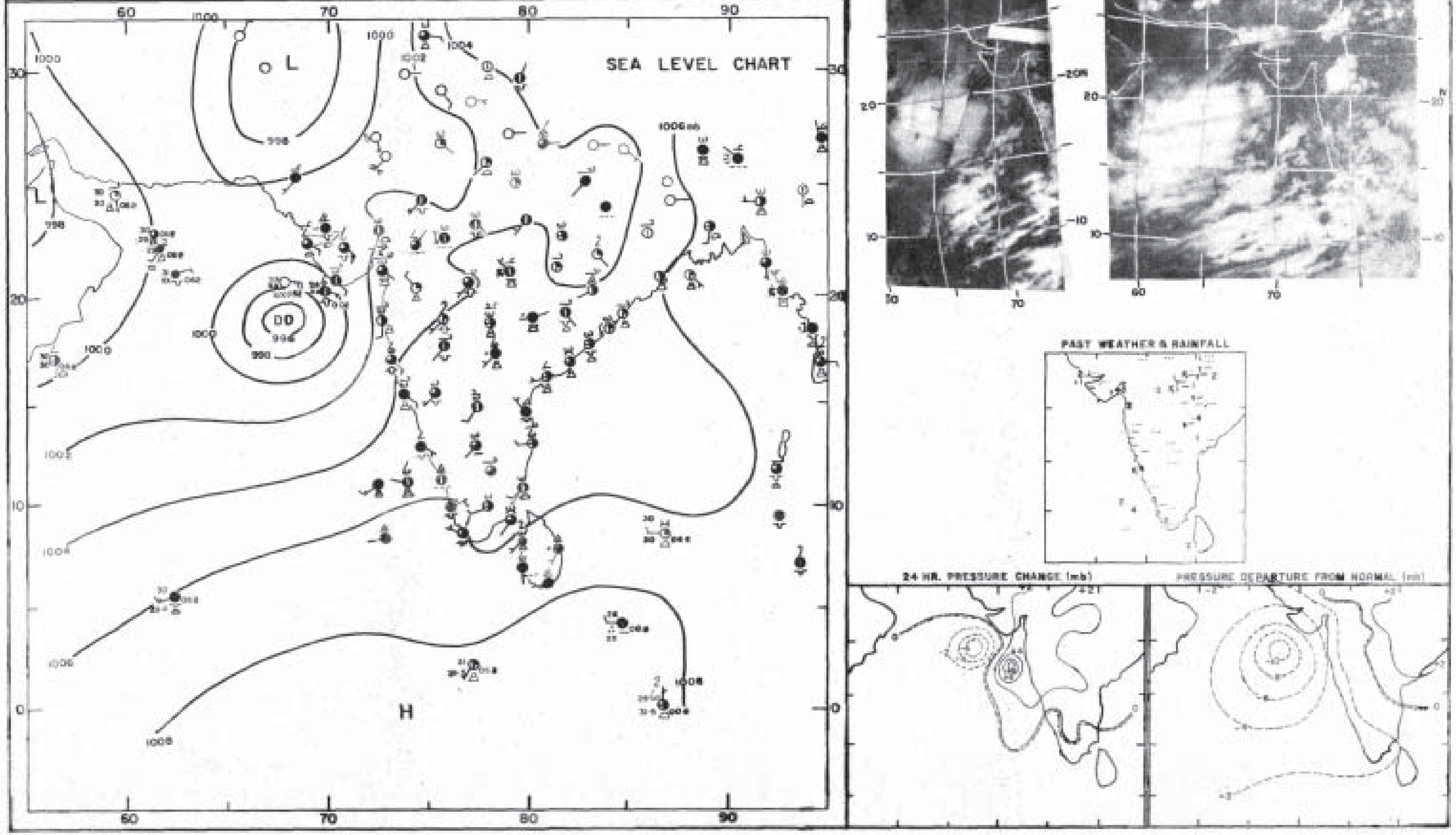
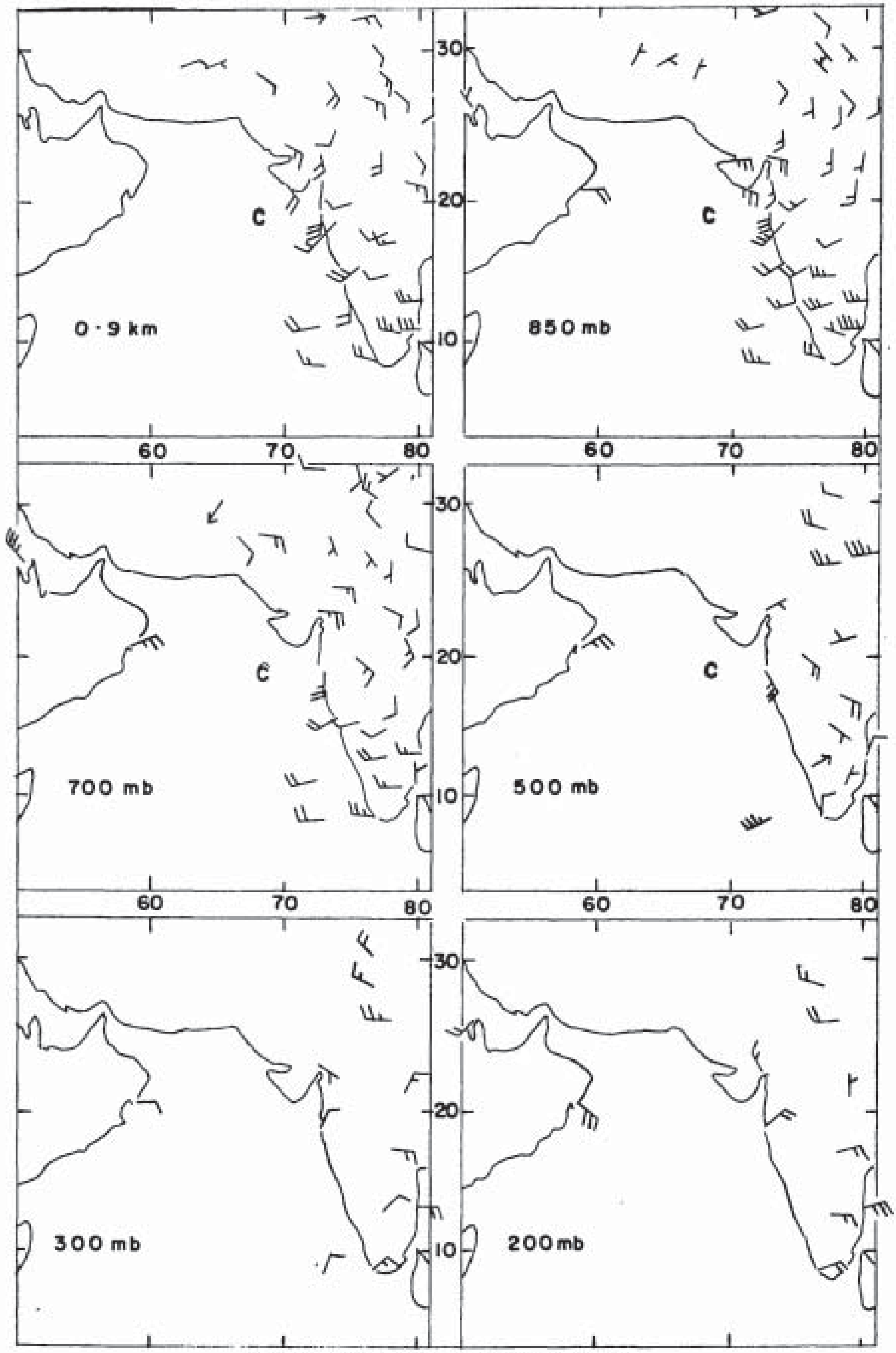


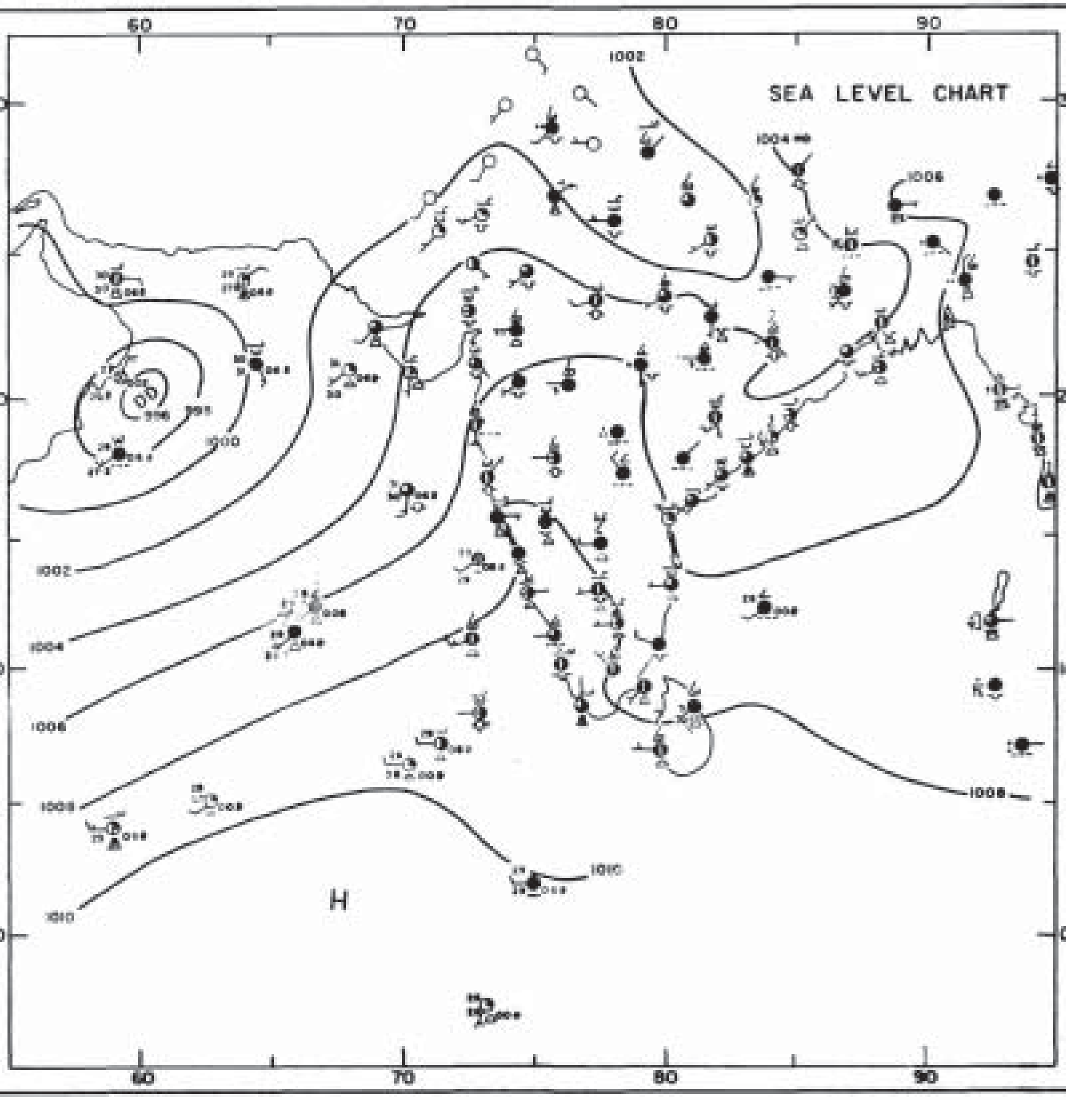
FIG. 9·9 SYNOPTIC CHARTS 0300 GMT 31 MAY 70

FIG. 9·10 UPPER WINDS 00 GMT 31 MAY 70

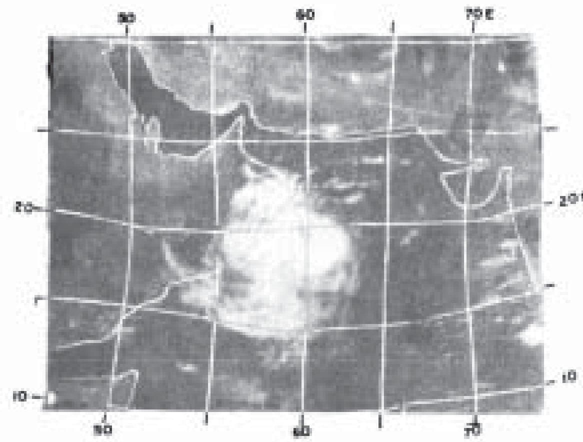


C - Centre of cyclonic circulation

FIG. 9·11 SYNOPTIC CHARTS 0300 GMT 2 JUN. 70



ESSA 8 ORBIT 6698 DATE 2 JUNE 1970 TIME 0604GMT



SURFACE OBSERVATIONS OF MASIRAH

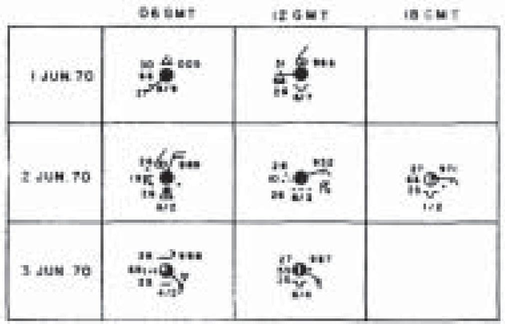
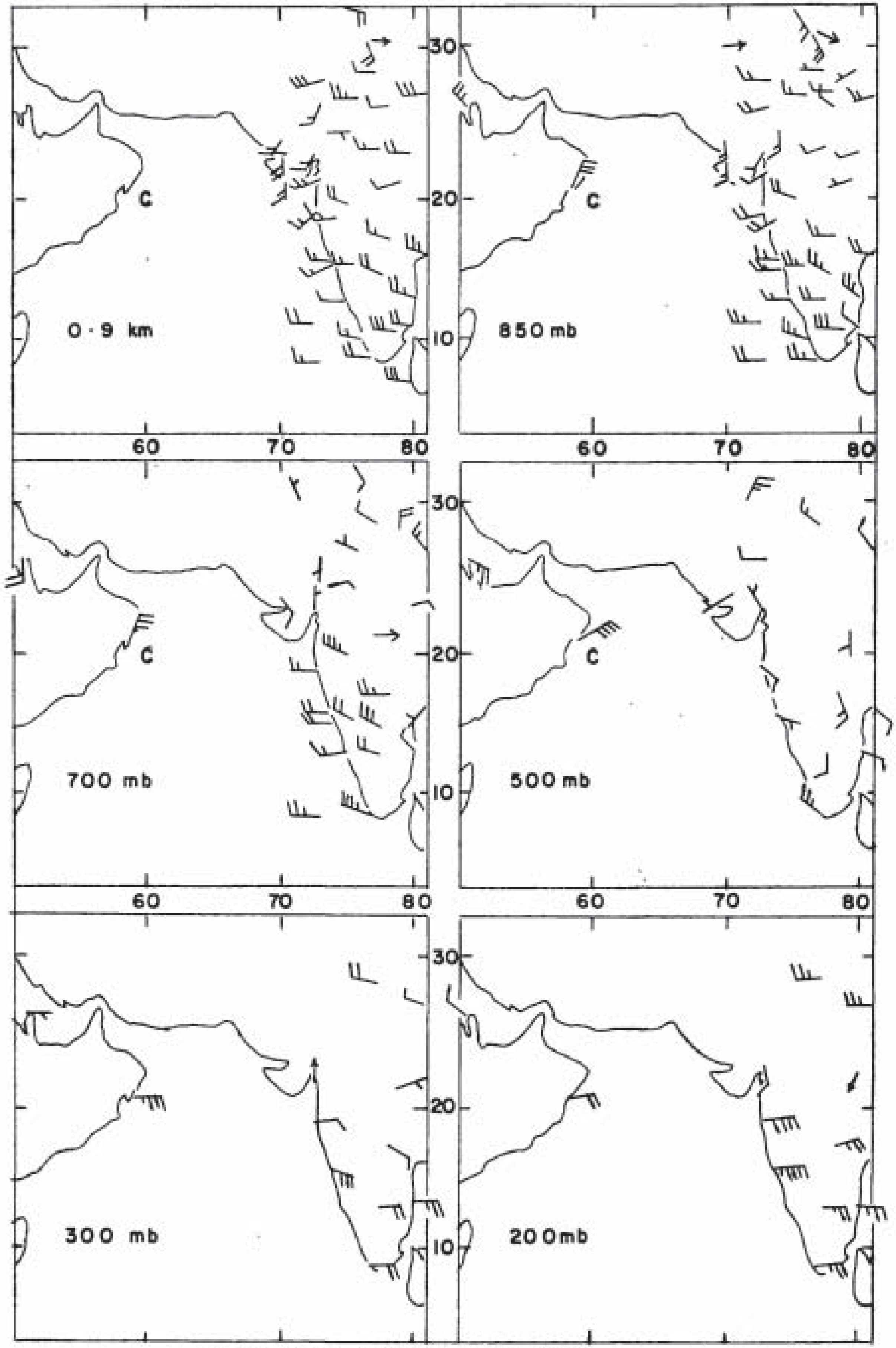


FIG. 9·12 UPPER WINDS 00 GMT 2 JUN. 70



C - Centre of cyclonic circulation

FIG. 10·1 SYNOPTIC CHARTS 0300 GMT 11 APR. 70

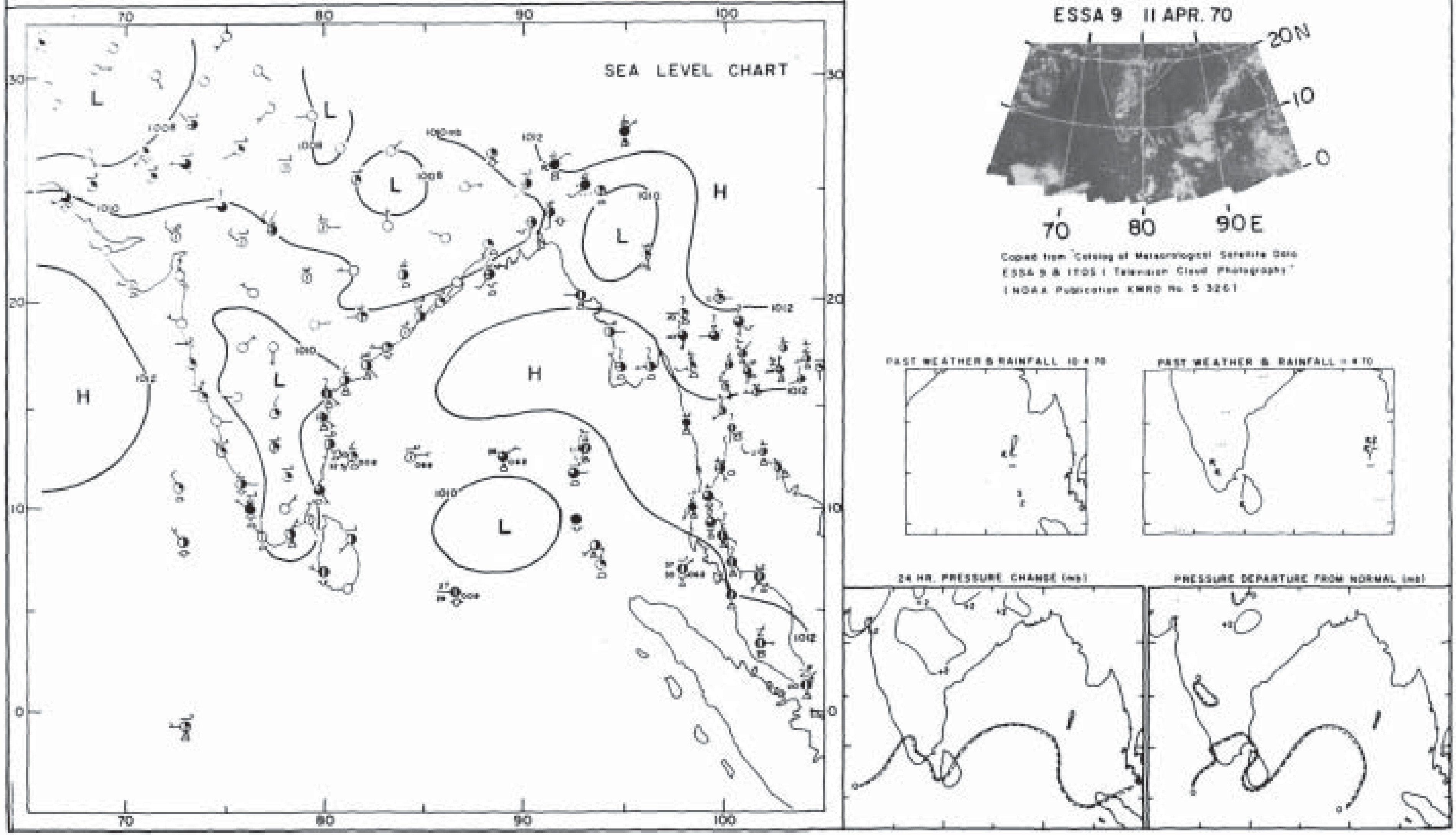
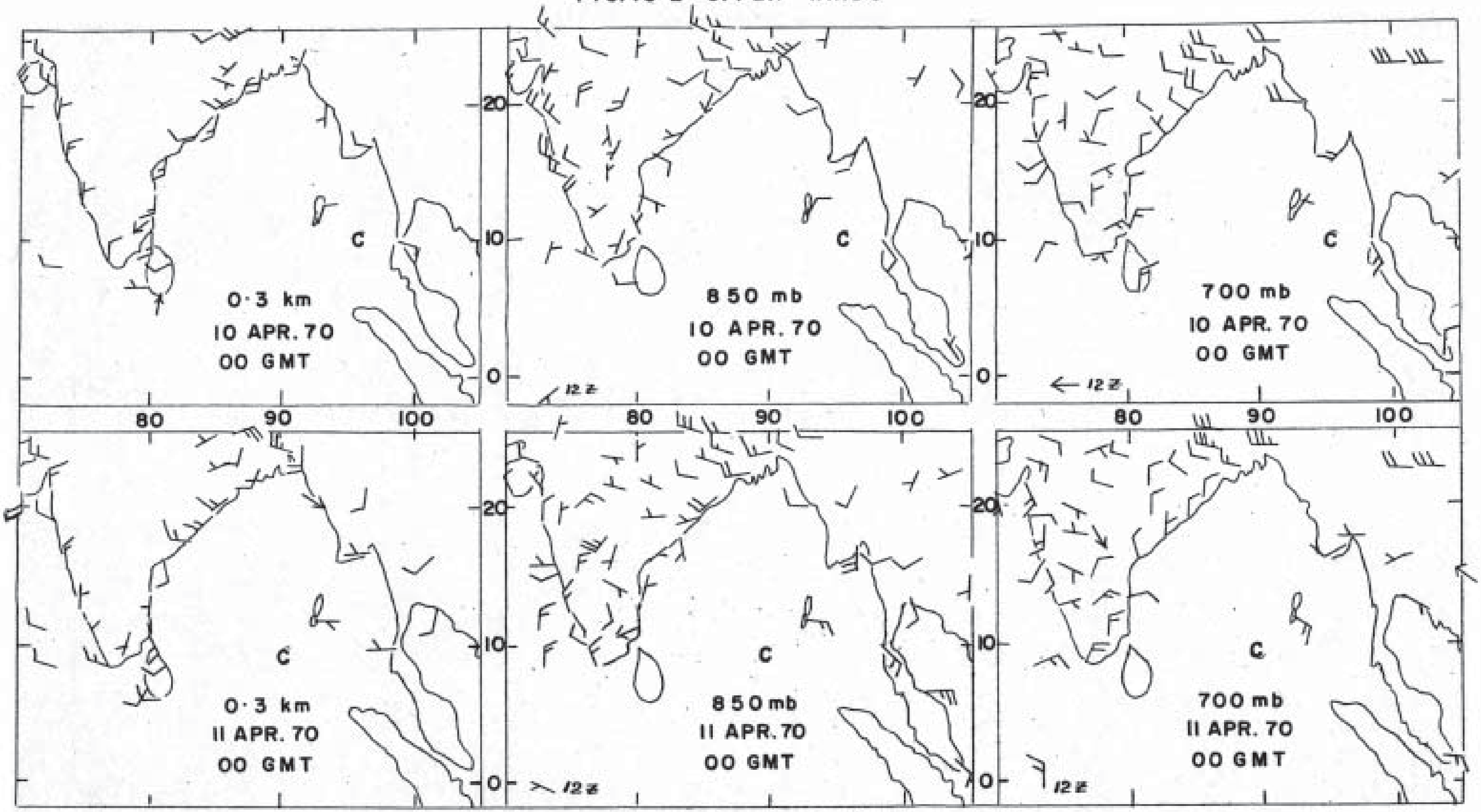


FIG. 10·2 UPPER WINDS



C-Centre of cyclonic circulation

FIG. 10 3(a) SYNOPTIC CHARTS 0300GMT 13 APR. 70

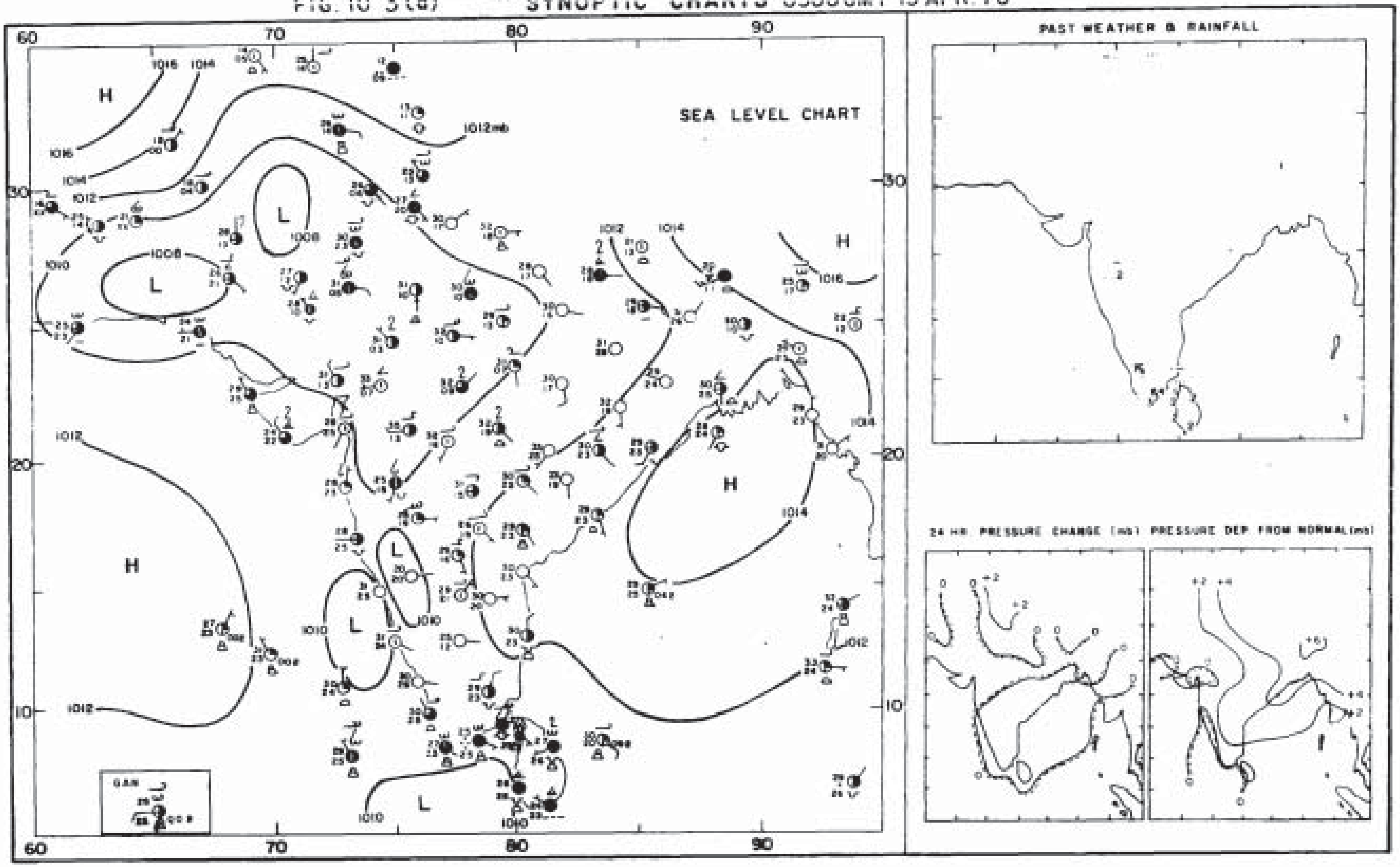
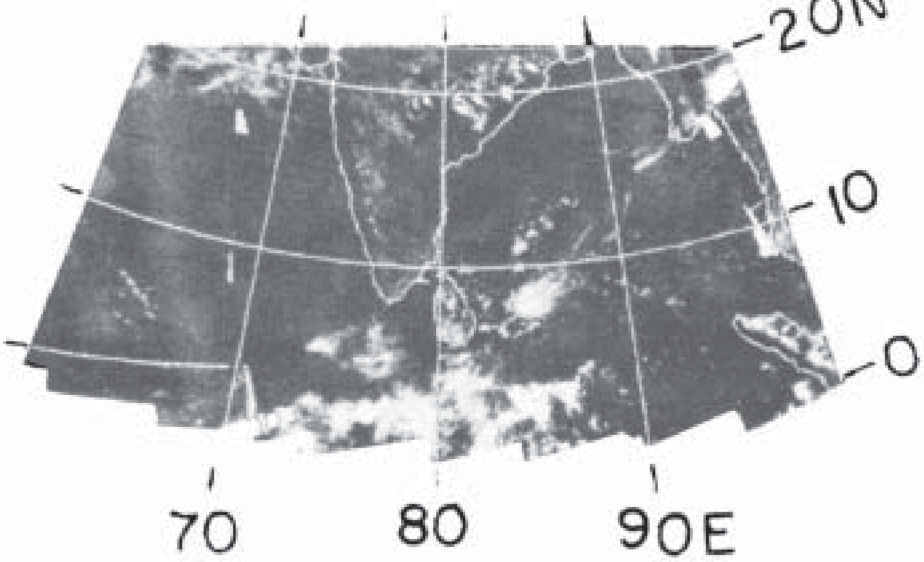
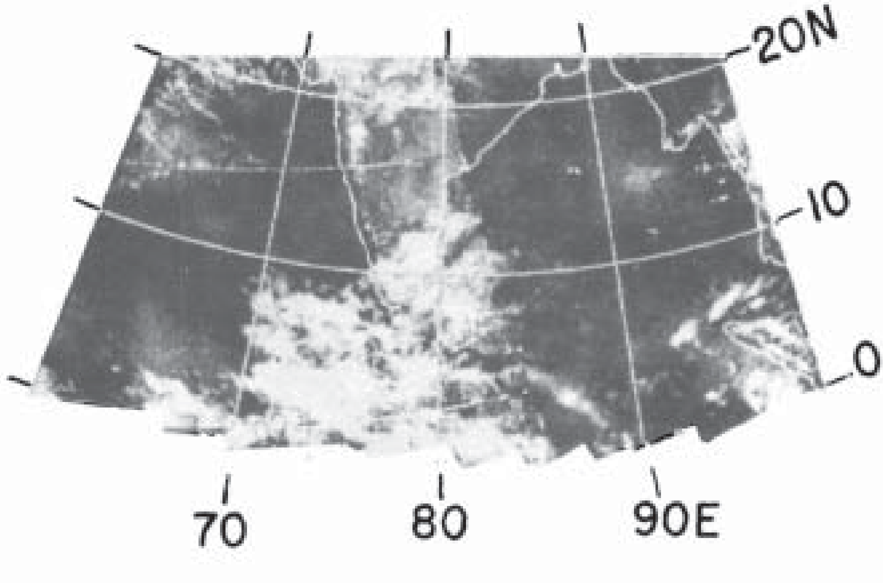


FIG. 10·3 (b)

ESSA 9 12 APR. 70

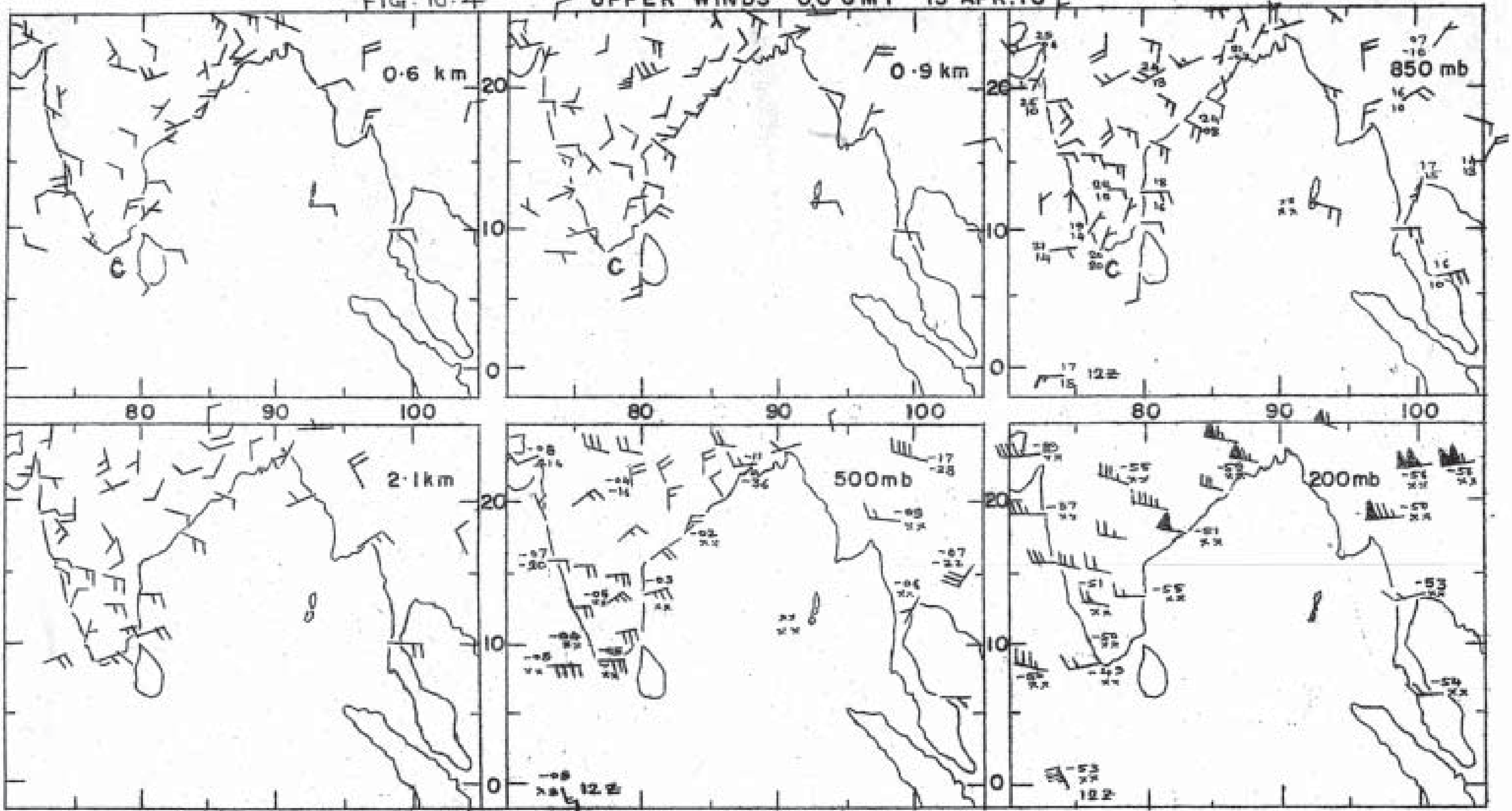


ESSA 9 13 APR. 70



Copied from "Catalog of Meteorological Satellite Data ESSA 9 & ITOS I Television Cloud Photography." (NOAA Publication KMRD No. 5-326)

FIG. 10.4 UPPER WINDS 00 GMT 13 APR. 70



C - Centre of cyclonic circulation   Plotted figures TT & $T_d T_d$

FIG. 10·5 SYNOPTIC CHARTS 0300 GMT 15 APR. 70

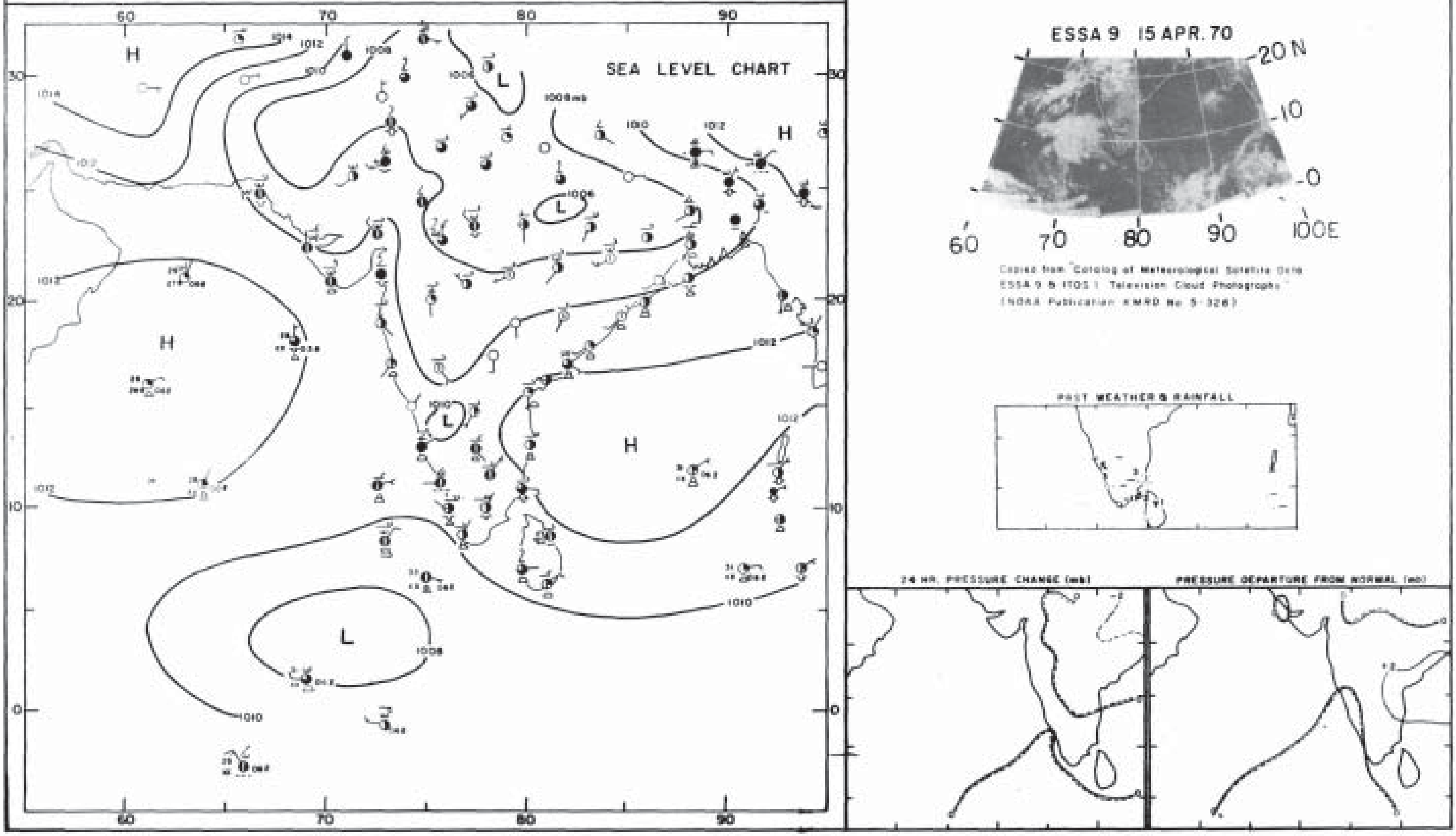
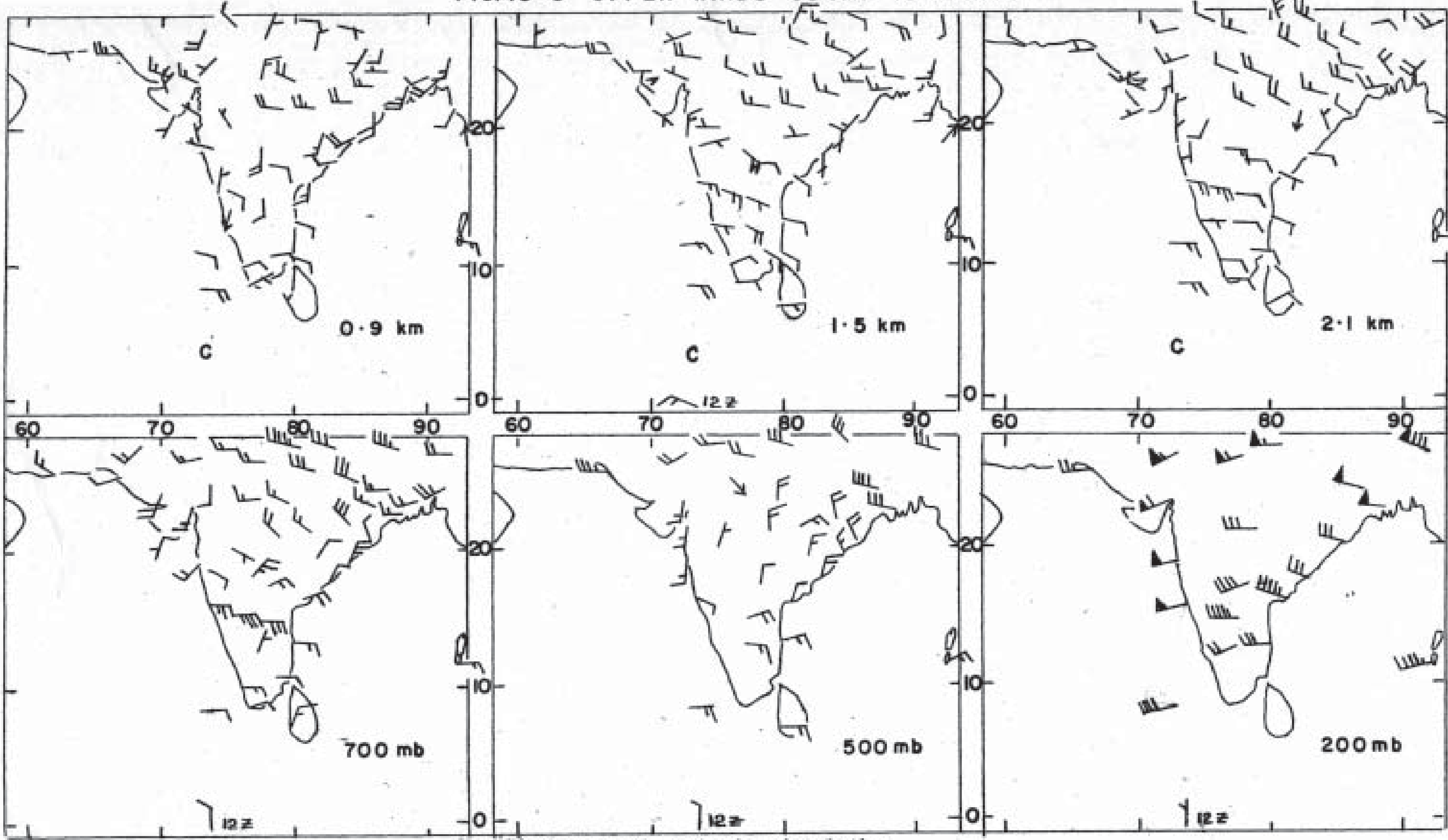


FIG. 10·6 UPPER WINDS 00GMT 15 APR.70



C-Centre of cyclonic circulation

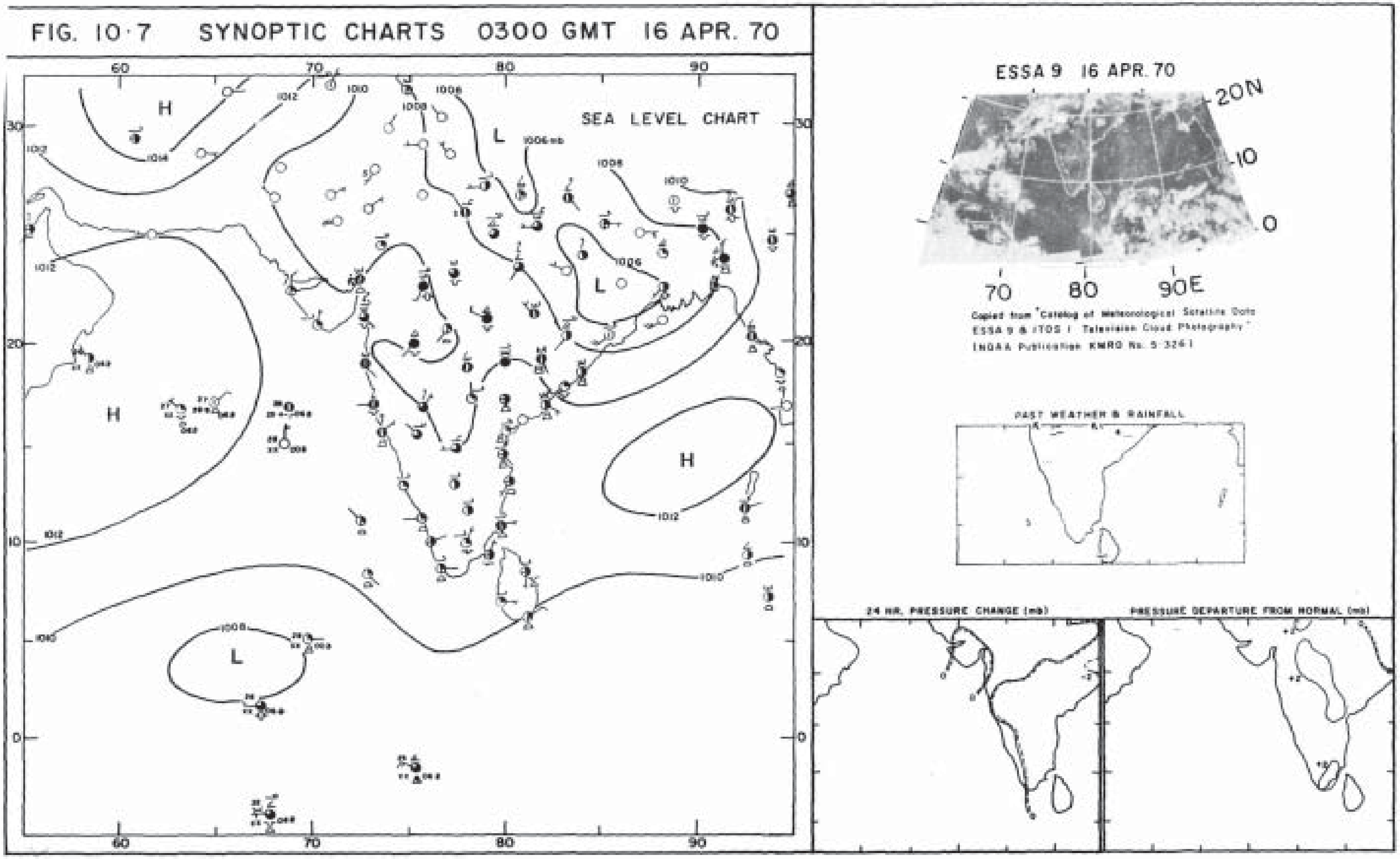
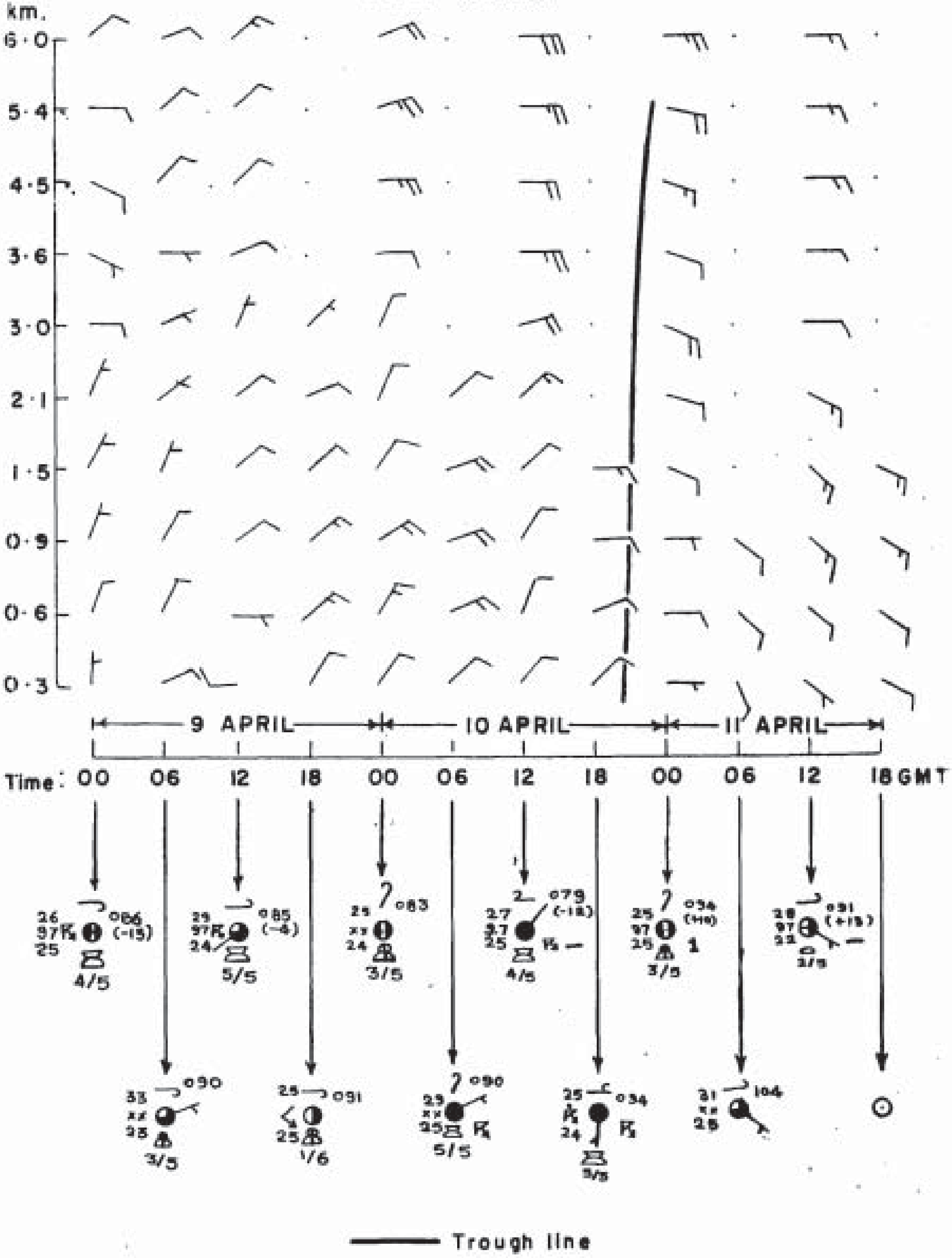


FIG. 10·7 SYNOPTIC CHARTS 0300 GMT 16 APR. 70

FIG. 10·8 TIME SECTION CHART (9-11 APRIL 1970)
PORT BLAIR



Trough line

FIG. 10·8 TIME SECTION CHART 13 – 15 APRIL 1970

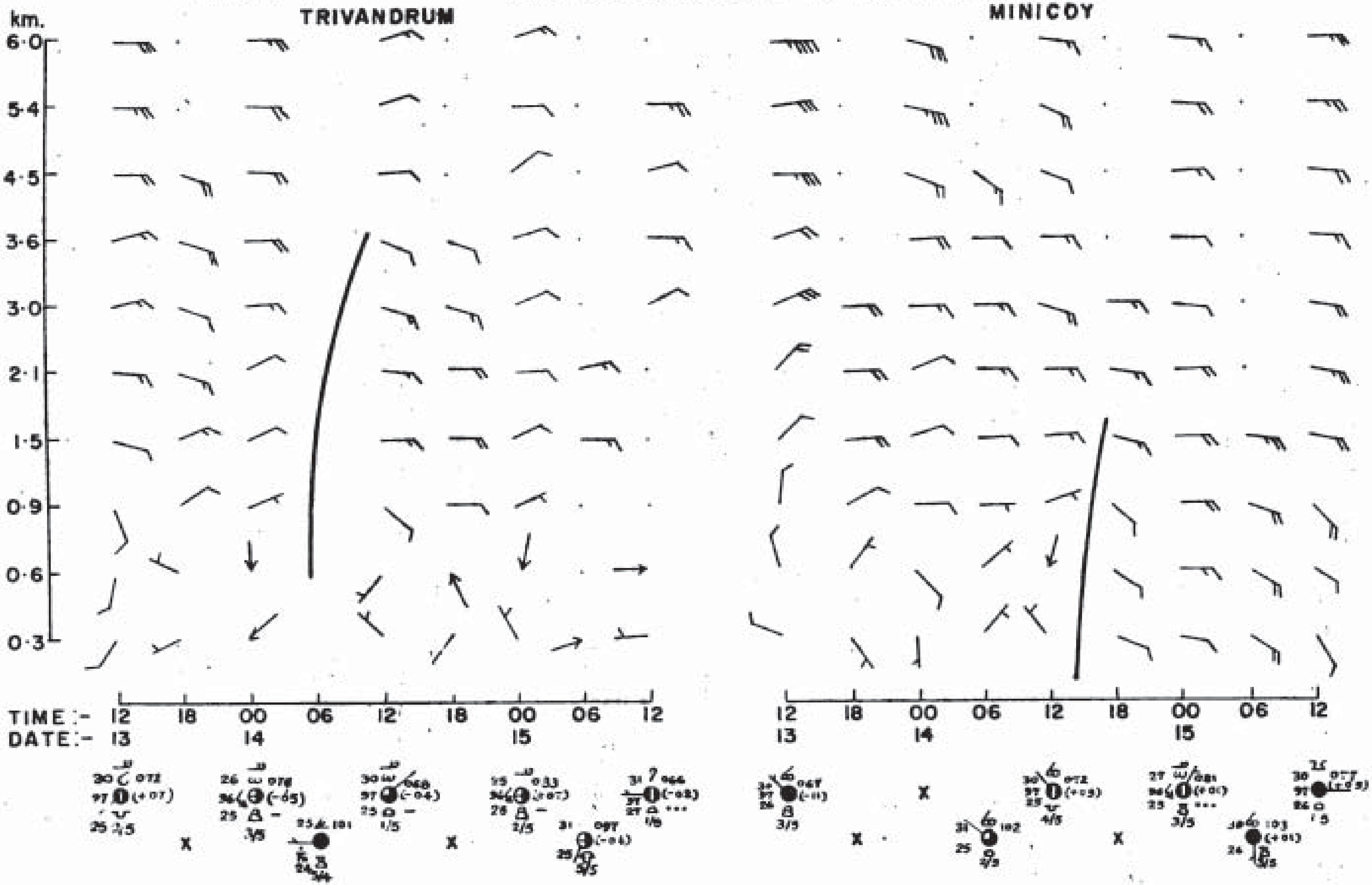


FIG. II·1 SYNOPTIC CHARTS 0300 GMT 7 MAY 70

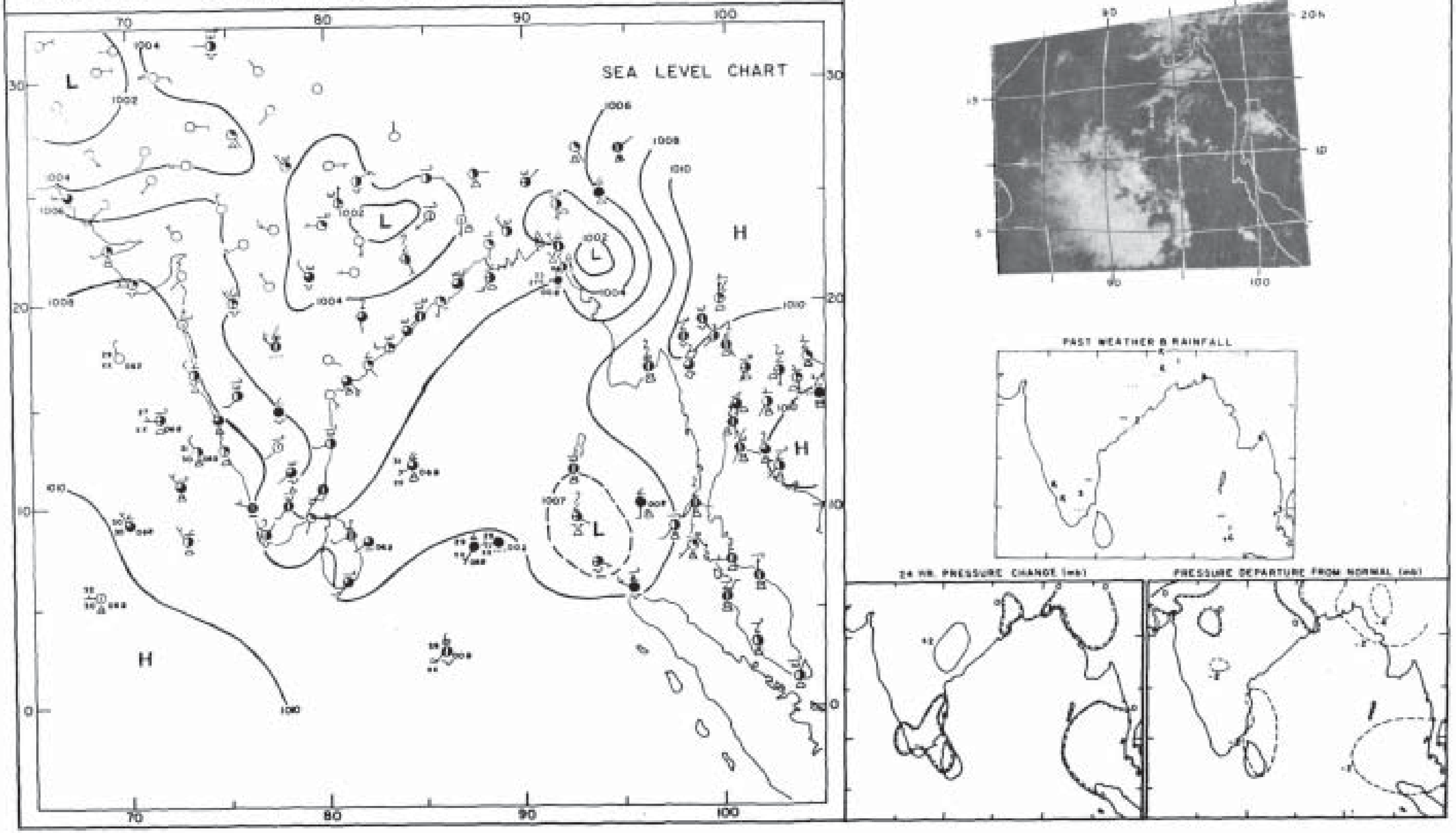
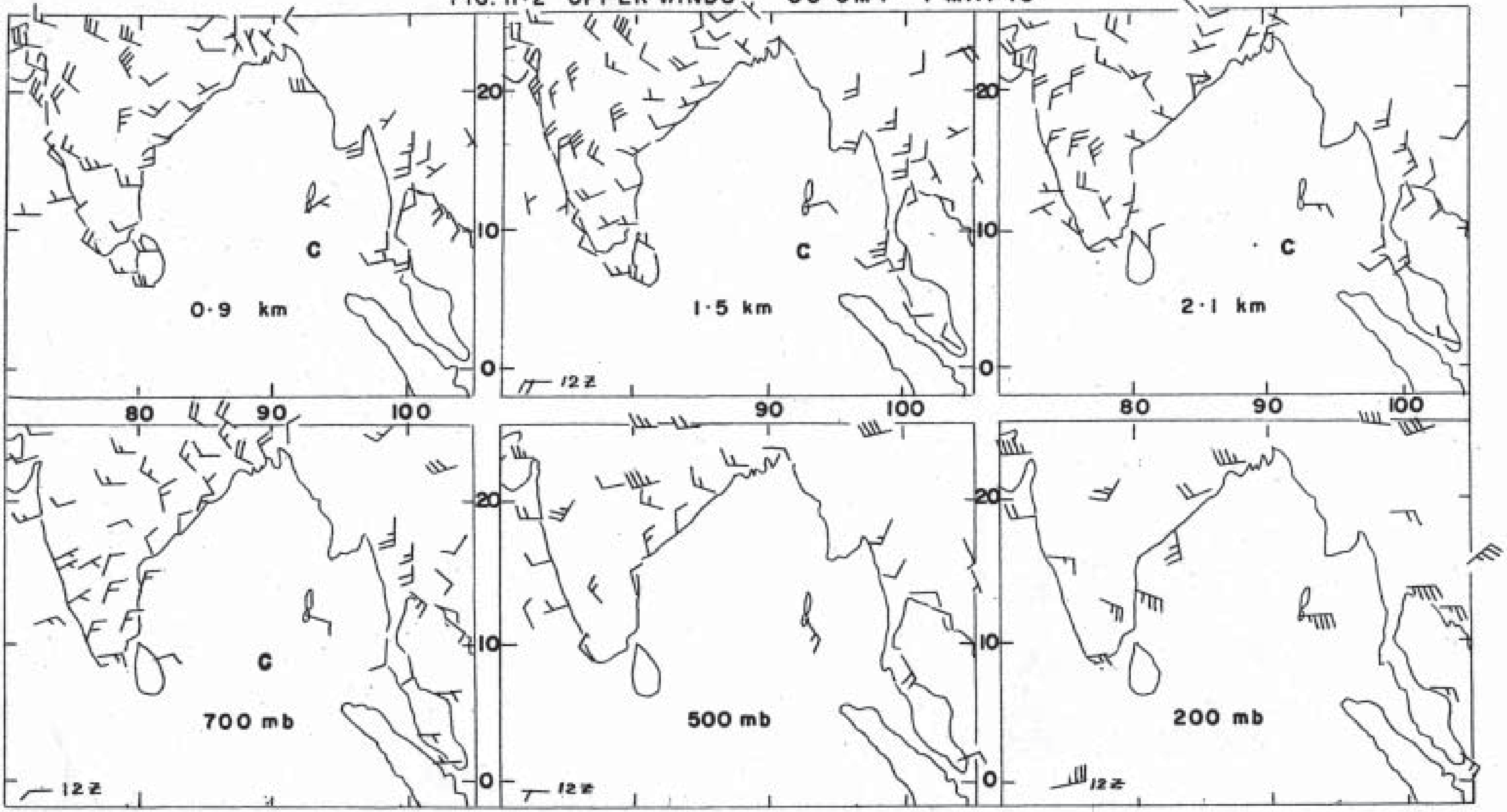


FIG. II·2 UPPER WINDS 00 GMT 7 MAY 70



C-Centre of cyclonic circulation

FIG. 11·3 SYNOPTIC CHARTS 0300 GMT 8 MAY 70

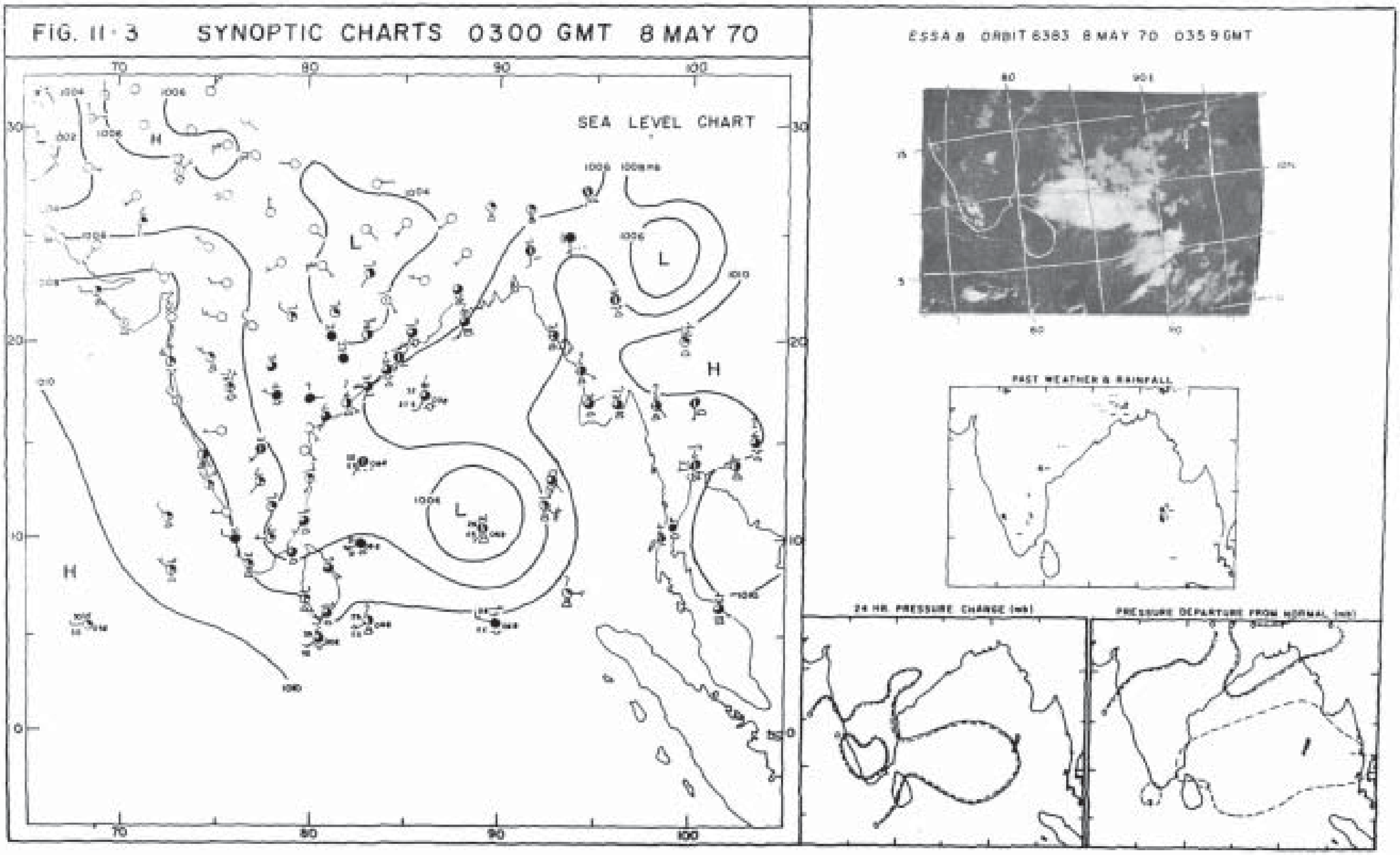
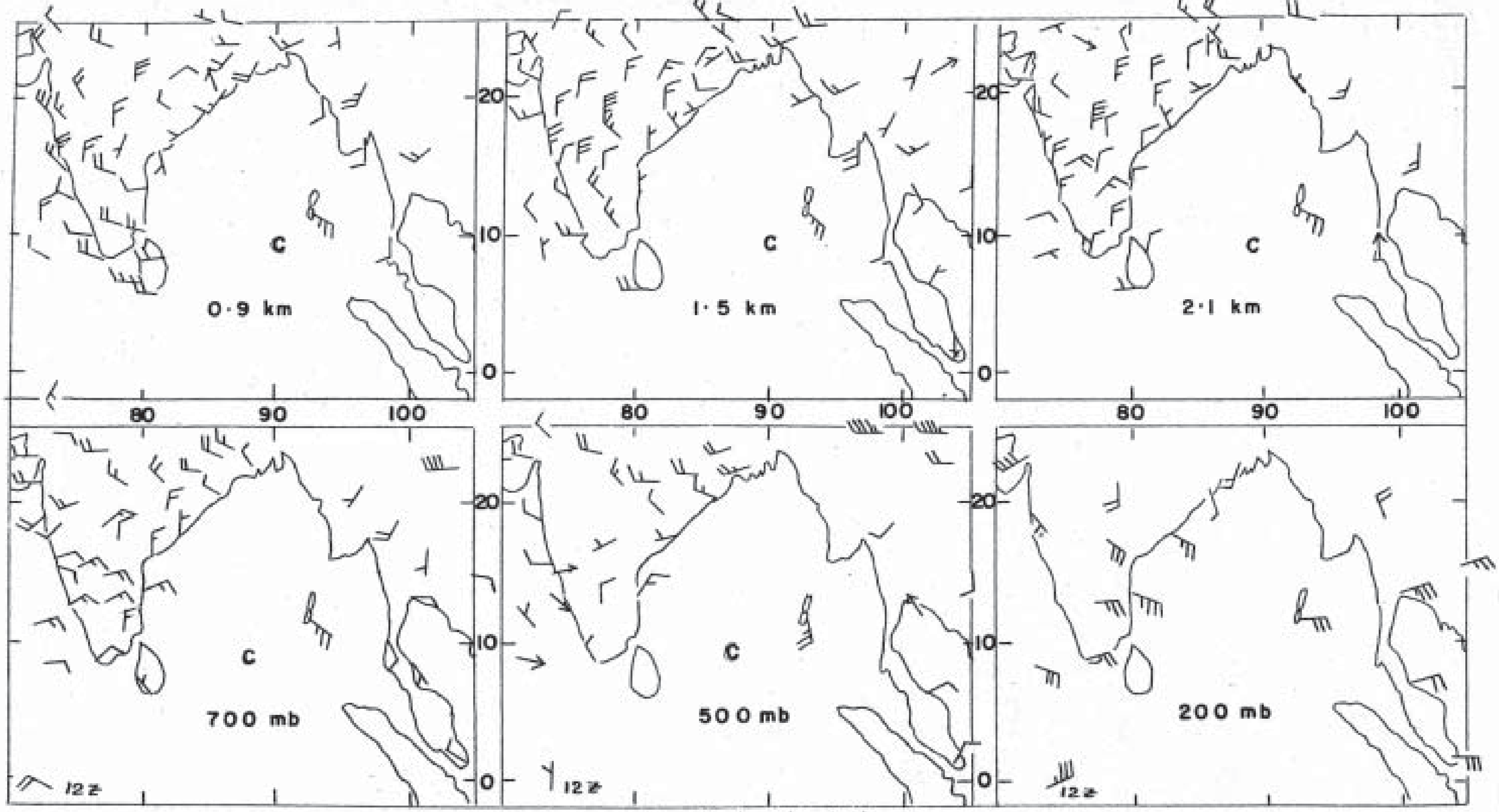


FIG. II·4 UPPER WINDS 00 GMT 8 MAY 70



C - Centre of cyclonic circulation

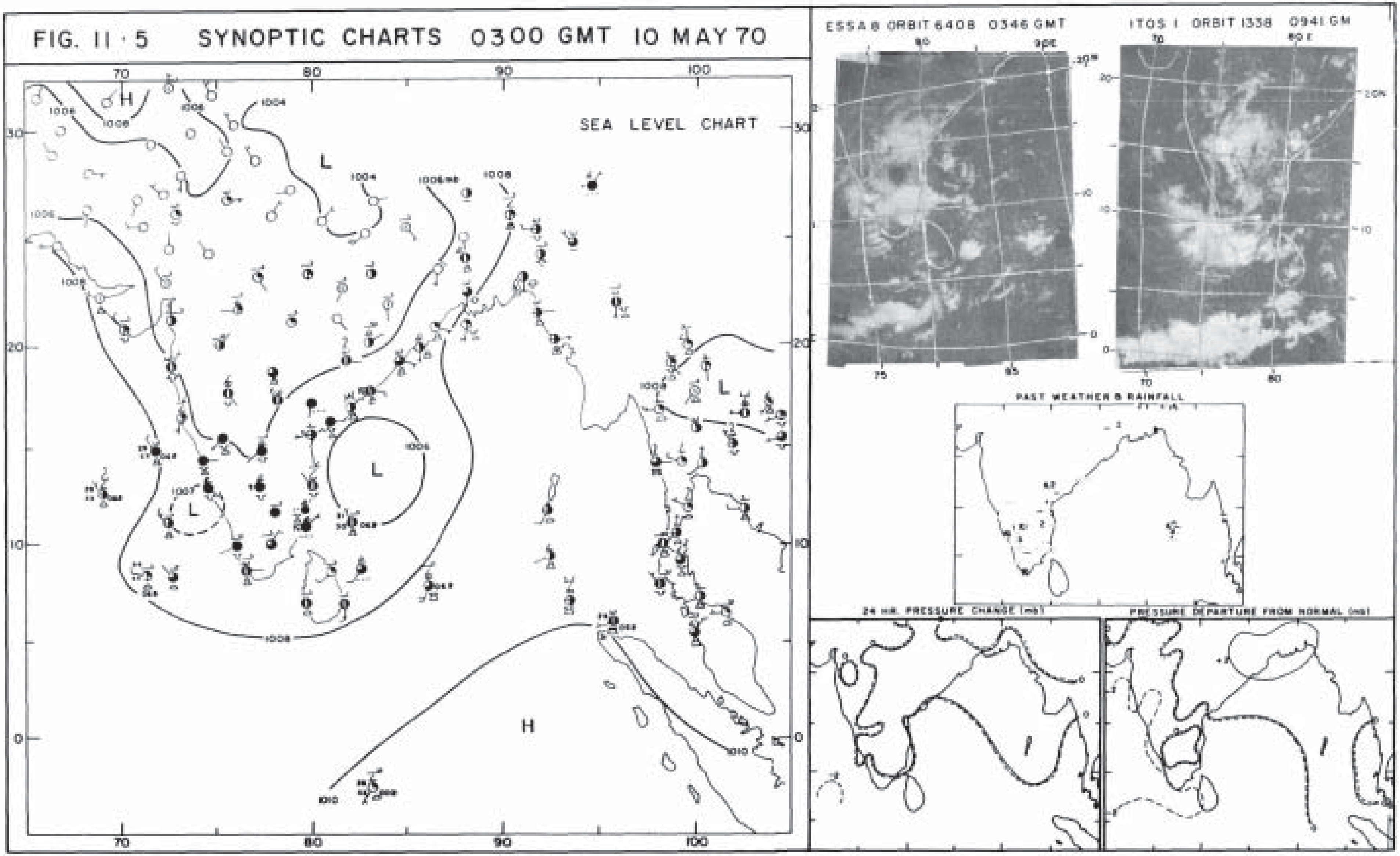
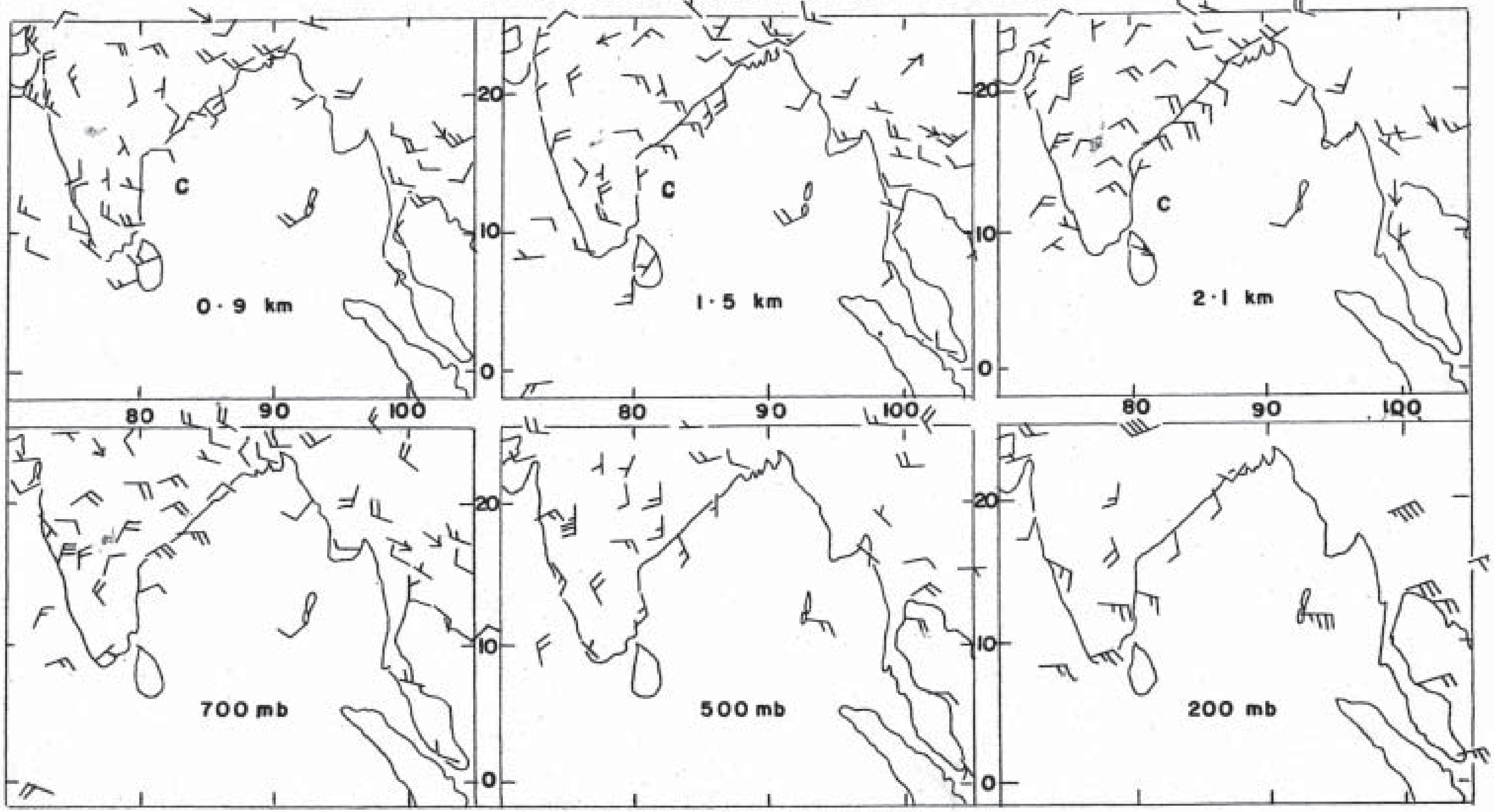


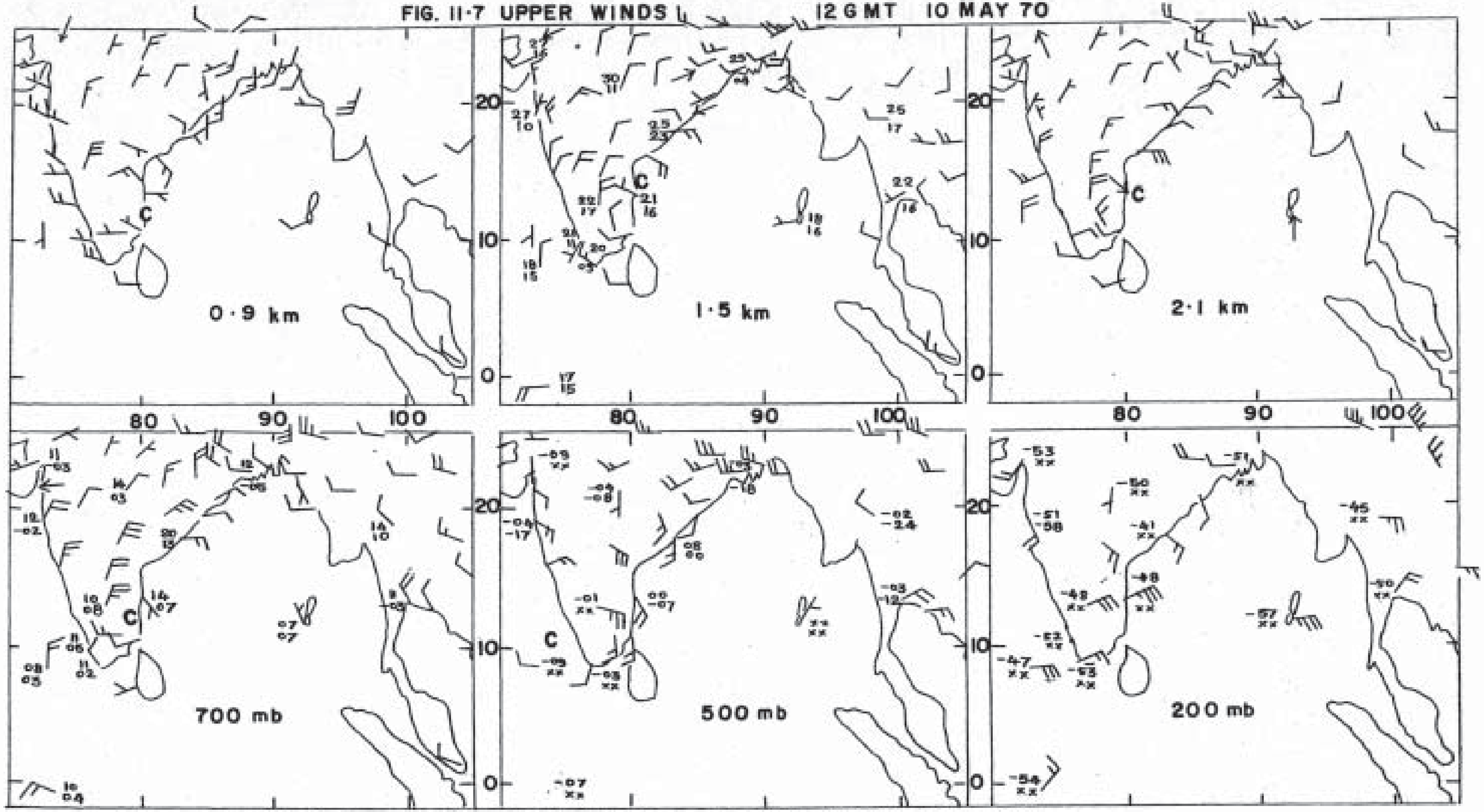
FIG. 11·5 SYNOPTIC CHARTS 0300 GMT 10 MAY 70

FIG. II·6 UPPER WINDS 00 GMT 10 MAY 70



C-Centre of cyclonic circulation

FIG. 11·7 UPPER WINDS 12 GMT 10 MAY 70



C - Centre of cyclonic circulation   Plotted figures TT & T_dT_d

FIG. II·8 TIME SECTION CHART (7 – 12 MAY 1970)

(a) MADRAS

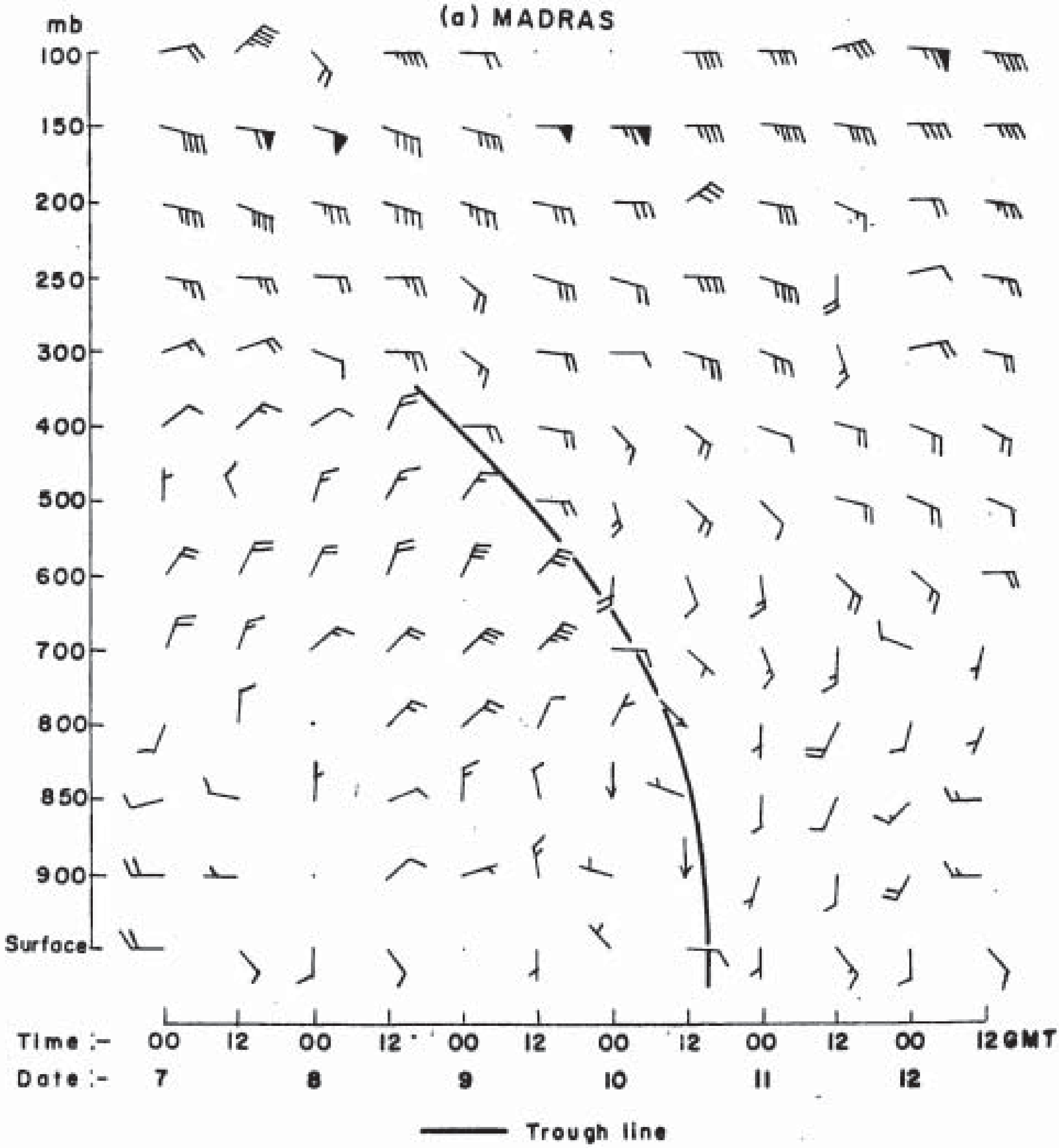
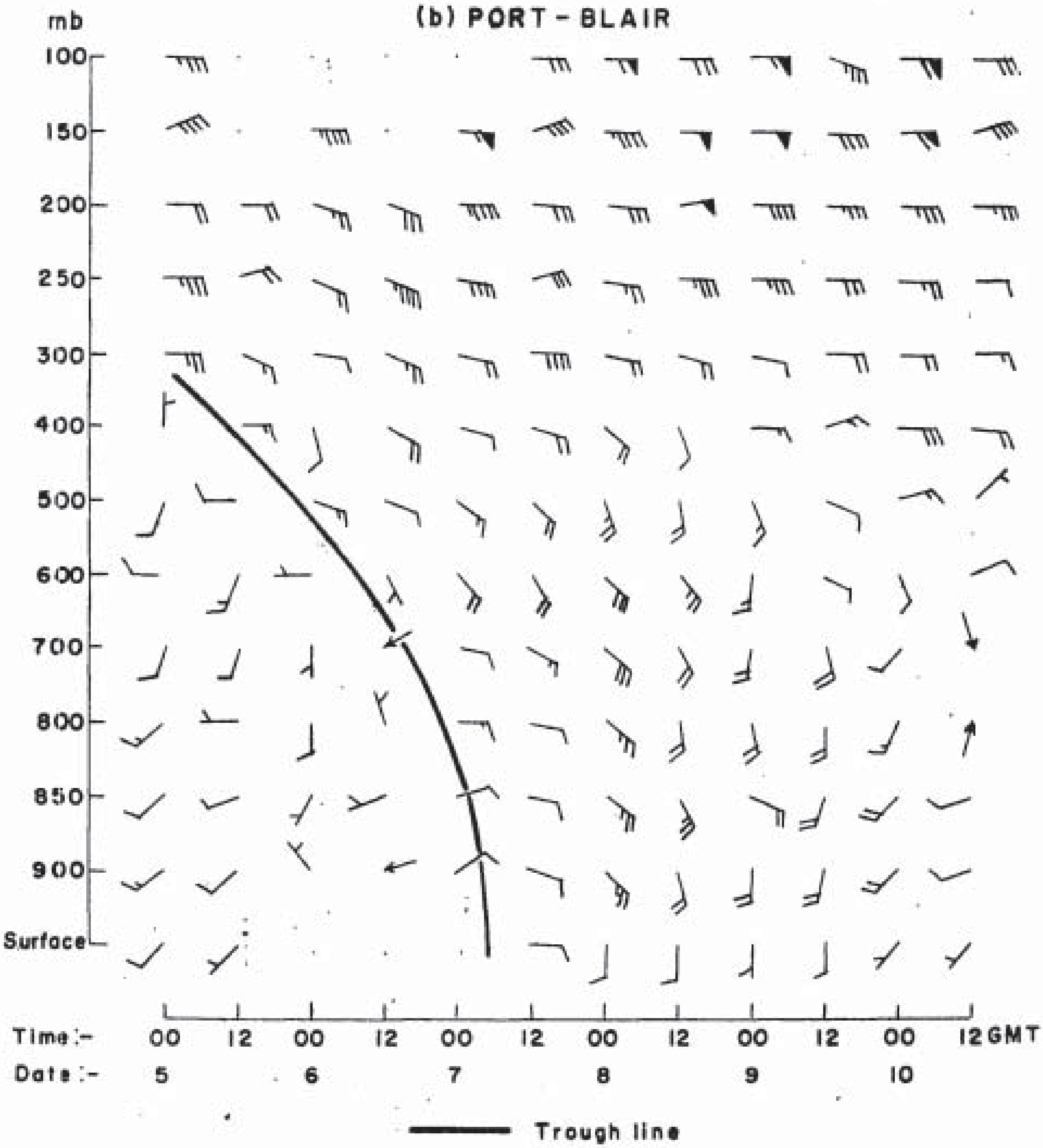


FIG. II·8 TIME SECTION CHART (5 – 10 MAY 1970)

(b) PORT – BLAIR



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