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INDIA METEOROLOGICAL DEPARTMENT

FORECASTING MANUAL

PART III

DISCUSSION OF TYPICAL SYNOPTIC WEATHER SITUATIONS

3.6 : SOUTHWEST MONSOON - TYPICAL SITUATIONS OVER WEST BENGAL AND ASSAM AND ADJACENT STATES

BY

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Part III - Discussion of Typical Synoptic Weather Situations

3.6 Southwest Monsoon - Typical Situations over West Bengal and Assam and adjacent states

by

V. Srinivasan, S. Raman and S. Mukherji

Contents

1. Introduction

Northeast India comprises of the states of Arunachal Pradesh, Assam, Meghalaya, Nagaland, Manipur, Mizoram, Tripura, West Bengal, Bihar and Orissa. Typical synoptic situations during the southwest monsoon season in Orissa and Bihar have already been discussed in the earlier FMU Reports Nos. III-3.2 and III-3.5 respectively. The remaining states will be dealt with in this report. These states are divided into five sub-divisions for meteorological purposes; they are:

i) Arunachal Pradesh

ii) Assam and Meghalaya

iii) Nagaland, Manipur, Mizoram and Tripura

iv) Sub-Himalayan West Bengal and

v) Gangetic West Bengal

Of these, all except Gangetic West Bengal are mountainous regions (Fig. 1.1), and weather there is strongly influenced by orography.

2. Southwest Monsoon over West Bengal, Assam and *adjacent States - General

2.1.1 The southwest monsoon advances normally into West Bengal and Assam and adjacent States, during the first week of June. The advance into south Assam and adjoining states takes place by the very end of May or in the beginning of June, and the advance over the rest of Assam and adjoining states and West Bengal is complete by about the end of the first week of June. However, in individual years, the date of advance of the monsoon varies widely from the normal date. An examination of the date for the past two decades shows that the advance of monsoon into West Bengal, Assam and adjacent states has occurred between the last few days of May and the first fortnight of June, in

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* The group of states consisting of Arunachal Pradesh, Assam, Meghalaya, Nagaland, Manipur, Mizoram and Tripura will be referred to as "Assam and adjacent States" in this report.

nearly 9% of the occasions. In extreme cases, the onset has been as early as 27 May or as late as 23 June.

2.1.2 The advance of the monsoon into West Bengal takes place either simultaneously as or within a few days of its advance into Assam and adjacent states. On a large majority of the occasions (nearly 75%), the lag is no more than 3 days; on 90% of the cases, it is less than a week.

2.1.3 Low pressure areas, depressions and cyclonic storms that form in the Bay of Bengal and move in a northerly/northeasterly track usher in the monsoon to West Bengal, Assam and adjacent States in a little over half the number of occasions. These disturbances cross coast into West Bengal or Bangla Desh from the Bay. Some of them may even reach Assam and adjacent States and Sub Himalayan West Bengal as weaker systems.

2.l.4 On some occasions, low pressure areas or upper air cyclonic circulations that form over land (i.e. over northeast India or Bangla Desh) have been responsible for the onset of the monsoon.

21.5 Yet another important synoptic system that appears to cause the advance of the monsoon, particularly in Assam and adjacent States and Sub Himalayan West Bengal, is the trough in middle latitude westerlies. Either the westerly trough itself may extend southwards into West Bengal, Assam and adjacent States or it may induce some weaker system over northeast India, which may serve to usher in the monsoon.

2.2 Rainfall

2.2.l The mean monthly rainfall and number of rainy days in West Bengal, Assam and adjacent States during the southwest monsoon season are given in Table 1. The table shows that southwest monsoon is the principal rainy season for these tables. However, unlike some other parts of the country, such as, Uttar Pradesh, Rajasthan, Madhya Pradesh, Gujarat State or Konkan, signifi-

cant rainfall amounts occur in the pre-monsoon season (March to May) also in West Bengal, Assam and adjacent States. Particularly in Assam and adjacent States, rainfall in the pre-monsoon months constitutes nearly a quarter (25%) of the annual total, whereas the monsoon rainfall constitutes 66% of the annual rainfall. Considering the whole country,rainfall during the monsoon as a percentage of the annual rainfall, is less than in Assam and adjacent States in only five meteorological sub-divisions - Bay Islands, Jammu and Kashmir, Coastal Andhra Pradesh, Rayalaseema and Tamil Nadu.

2.2.2 Rainfall in Assam and adjacent States during May is high (34 cm) and is comparable to the rainfall in June (48 cm). There is no sharp rise in rainfall as the monsoon sets in. We notice only a progressively increase from May to June as in the case of Kerala. During the monsoon season itself, rainfall is more in June and July than in the latter half of the season, in Assam and adjacent States and Sub Himalayan West Bengal, whereas in Gangetic West Bengal, July and August are the rainiest months. There is a decrease of rainfall in September in all the sub-divisions; but the rainfall during this month is still substantial (about 20% of the season's total). Significant decrease in rainfall comes only October with the withdrawal of the monsoon.

2.2.3 The co-efficient of variation of rainfall for the monsoon season as a whole is small (of the order of 20%) over West Bengal, Assam and adjacent States. Thus, in these states, the likelihood of large year-to-year variations in monsoon rainfall is very small.

2.2.4 The rainfall distribution over West Bengal, Assam and adjacent States month by month during the monsoon season is shown in Fig. 2.1. The salient features of the distribution are discussed below. Orography is found to be a significant factor in the distribution of rainfall.

TABLE - I

Mean Rainfall (cm) and number of rainy days in Assam and adjacent states and West Bengal

	Jun.	Jul.	Aug.	Sept.	Season's Total	Annual
Assam and adjacent states						
Rainfall (cm)	48	45	40	32	165	252
Rainfall as % of season's total	29	27	24	20		
No. of rainy days	18	19	17	14	68	114
Season's Total as % of Annual rainfall					66	
Sub-Himalayan West Bengal						
Rainfall (cm)	67	68	57	50	242	313
Rainfall as % of season's total	28	28	23	21		
No. of rainy days	18	19	18	15	70	99
Season's rain as % of Annual Rainfall					77	
Gangetic West Bengal						
Rainfall (cm)	24	32	32	21	109	143
Rainfall as % of season's total	22	29	29	20		
No. of rainy days	11	15	15	11	52	72
Season's rain as % of Annual rainfall					76	

(From "Memoirs of the India Meteorological Department" Vol .XXXI - Part III) (1962)

2.2.5 Gangetic West Bengal:

The rainfall in the month of June is about 20-30 cm over Gangetic West Bengal. I-; increases in July and August and becomes 30-35 cm. In September, it decreases and becomes about 20-¿}0 cm (as in June). There is not much variation of rainfall from district to district, as this area is a nearly uniform flat plain.

2.2.6 Assam and adjacent States:

The effect of orography over the distribution of rainfall is very pronounced in Assam and adjacent States. The role of the high mountain ranges in enhancing the rainfall on the windward side and suppressing it on the lee side is clearly evident from the diagrams. The major feature to be noted in the rainfall distribution over Assam and adjacent States is a pronounced east-west oriented rainfall maximum along the southern side of the Garo Hills and Khasi-Jaintia hills.

2.2.7 The Khasi-Jaintia hills are well-known for their very heavy rains; this area is one of the wettest places in the world. The following are the rainfall figures for Cherrapunji and Mawsynram - two well-known stations in Khasi-Jaintia hills.

TABLE - II

Rainfall in cm

	Rainfall in					Season's total (June to September)	Annual Total
	May	June	July	Aug.	Sept.		
Cherrapunji (Police Station)	124	264	236	180	1lO	790	1064
Cherrapunji Observatory	135	268	242	180	112	802	1087
Mawsynram Observatory	133	281	250	234	153	918	1141

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

2.2.8 Even May is a good rainy month for Assam and adjacent states. Rain fall increases in June with the onset of the monsoon. In fact, June appears to be the rainiest month, for, by July there is a slight decrease, particularly in south Assam and adjoining States. Rainfall progressively decreases in the second half of the monsoon season.

2.2.9 In view of the very large spatial variations in rainfall, any mean picture of rainfall for Assam and adjacent states as a whole, carries no meaning. The season's average varies from over 1000 cm in the southern slope of the Khasi-Jaintia hills to about 100 cm (1/10th the value) on the lee of the hills to the north. Comparative rainfall figures for some typical stations to bring out the magnitude of the mountain effect are given below:-

TABLE - III

Rainfall (cm)*

	Rainfall in					Seasonal total (June to September)	Annual total
	May	June	July	August	Sept.		
Windward - Mawsynram	133	281	250	234	153	918	1141
Leeward - Lanka (Nowgong Dist.)	11	22	18	20	20	80	124
Leeward - Maibong (Mikir and north Cacher Hill)	21	34	19	16	16	85	145
Lanka/Mawsynram Rainfall	0.08	0.08	0.07	0.09	0.13	0.09	0.1

(*From I.Met.D. Memoirs Vol.XXXI Part III)

2.2.10 Cherrapunji is well known as one of the wettest places in the world, with the annual rainfall exceeding 1000 cm. Mawsynram, only a few kms to the west of Cherrapunji and also at a little higher elevation, has a slightly higher mean rainfall. 75% to 80% of this rainfall occur during the monsoon season.

2.2.11 The orography of the area in relation to the prevailing winds is very favourable for the high rainfall. The prevailing low level moist winds from the Bay strike (almost at right angles) the Khasi hills which rise very steeply (reaching a height of about 1.5 km within a distance of above 10 kms). The location of Cherrapunji and Mawsynram overlooking the funnel shaped catchments opening to the south, is another favourable factor as the funnel shaped valley adds to the convergence produced in the air mass rushing into the valley from the south. The strength of the southerly component of the low level wind

striking the hills and the moisture content of the air mass may provide useful indicators of the intensity of rainfall on the southern slopes of the Garo-Khasi-Jaintia Hills.

2.2.12 Cherrapunji also holds the record for the highest 24 hrs rainfall in India, which is 103.6 cm. It is a matter of interest to know that in 1876 the annual rainfall at Cherrapunji has been 905", of which 366" fell in July alone. It has also been observed that at Cherrapunji, the early morning period (0100-0700 hrs IST) is more rainy than the afternoon (1200-1800 hrs IST).

2.2.13 The figures in Table III clearly bring out the order of difference in rainfall on either side of the Khasi-Jaintia hills. It is, therefore, necessary for the forecasters to be fully aware of such large variations in rainfall caused by orography, and to keep them in view while issuing heavy rainfall warnings for small areas.

2.2.14 As a matter of interest, the following rainfall figures are given to compare the relative magnitude of the orographic effects produced by Khasi-Jaintia hills and the Western Ghats.

TABLE - IV

Khasi-Jaintia Hills	Rainfall (cm.)	
	July	August
Mawsynram	250	234
Lanka	18	20
Ratio of Lanka/Mawsynram rainfall	0.07	0.09
Western Ghats		
Mahabaleshwar	255	176
Mhaswad (Satara Dist.)	5	5
Ratio of Mhaswad/Mahabaleshwar rainfall	0.02	0.03

(From "I.M.D. Memoirs Vol.XXXI Part III")

2.3 Heavy rainfall

2.3.1 West Bengal, Assam and adjacent states receive heavy rains during the monsoon season. The amounts are large and the frequency of occurrence of heavy rain is also high - particularly in Assam and adjacent states and sub-Himalayan West Bengal. The maximum frequency is over sub-Himalayan West Bengal and Khasi-Jaintia hills. Khasi-Jaintia hills is one of the three regions in India where rainfall amounts exceeding 75 cm in 24 hrs occur. The record 24 hr. rainfall at Cherrapunji is 103.6 cm on 14 June 1876. Rainfall of the order of 40 to 50 cm (in 24 hrs.) occur in the remaining portions of Assam and adjacent states and in sub-Himalayan West Bengal. In Gangetic West Bengal the magnitude of heavy falls is slightly less (30 to 50 cm).

2.3.2 Monthwise, Assam and adjacent states get very heavy rains more frequently in June than in the remaining months of the monsoon season. Although 'breaks' are more frequent in August, the frequency of very heavy rains (exceeding 25 cm) in August is just one-third of its value in June. However, studies on the frequency of floods have shown that August is the principal month for floods in Assam and adjacent states. In West Bengal also, during the first two months of the monsoon (June and July), very heavy rain is more frequent than in the subsequent two months.

2.4 Monsoon activity

2.4.1 The percentage frequency of occurrence of strong to vigorous, normal and weak* monsoon days in West Bengal, Assam and adjacent states is given in Table V.

2.4.2 The main features brought out by this table are:-

i) In Assam and adjacent states and sub-Himalayan West Bengal, strong to vigorous monsoon conditions prevail on 20% of the occasions in the first

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* For a definition of the terms "Strong", "Vigorous" etc. see Appendix II.

TABLE - V

Percentage frequency of occurrence of vigorous*, strong, normal and weak monsoon days over West Bengal and Assam and adjacent states (Based on data of 1964-68)

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
North Assam*	1	23	47	27	2	0	20	53	26	1	1	14	52	31	2	0	20	47	29	4	1	19	50	28	2
South Assam*	3	16	51	28	2	3	15	54	28	0	0	9	53	37	1	1	9	49	33	8	2	12	52	31	3
Sub Himalayan West Bengal	1	19	31	37	12	4	17	39	36	4	5	13	33	41	8	1	9	35	41	14	3	15	34	39	9
Gangetic West Bengal	3	13	38	23	23	4	10	44	40	2	2	16	43	34	5	5	10	33	42	10	4	12	39	35	10

* Met. sub-divisions as before 26 January 1972.

V = Vigorous
S = Strong
N = Normal
W = Weak with some rain
D = Weak without any rain

half of the monsoon season (June and July). In the latter half, the frequency decreases except in the case of North Assam, where another increase in activity is seen in September. In Gangetic West Bengal, the activity is nearly uniform throughout the season.

ii) Perfectly dry days are rare in these sub-divisions. Orography in the case of sub-Himalayan West Bengal, Assam and adjacent states and the presence of the monsoon trough on most of the days in Gangetic West Bengal, are responsible for the absence of dry days.

iii) In Assam and adjacent states normal monsoon occurs in nearly half the number of days. Weak monsoon is relatively less common.

iv) In Gangetic West Bengal, weak monsoon and normal monsoon conditions prevail in nearly the same number of days in the mid-monsoon months of July and August. However, earlier and later in the season, a weak monsoon is more common than a normal monsoon in West Bengal.

2.5 Thunderstorms

2.5.1 Thunderstorms form an important and significant feature of weather over West Bengal, Assam and adjacent states during the monsoon months, though they may not be as violent, or associated with severe squalls, as in the pre-monsoon period. In these areas, the thunderstorm frequency is quite high even in the monsoon season; and rainfall is accompanied by thunder on almost half the number of days. Thunderstorms are only slightly less in July than in the other three months.

2.6 Pressure

2.6.1 The seasonal monsoon trough is the most common feature over West Bengal, Assam and adjacent states on the surface chart. In the mean charts, the axis of the monsoon trough is over Gangetic West Bengal at the sea level as well as in the lower troposphere; at 0.9 km asl, it passes close to Allahabad and Asansol in July and August. The trough oscillates across a fairly large distance on individual days. Due to the proximity of the trough line the pressure gradient

is generally slack over northeast India.

2.6.2 However, when a deep depression or a cyclonic storm develops in the trough there is steep gradient in the field of the disturbance. Also, when the monsoon trough shifts towards the foot hills of the Himalayas, there is an organised south to north pressure gradient over the whole of northeast India, which may be of moderate intensity.

2.7 Upper Winds

2.7.1 The vertical profiles of monthly mean upper winds of Calcutta and Gauhati for April to October are given in Fig. 2.2. Calcutta may be taken to be representative of conditions over Gangetic West Bengal and Gauhati representative of conditions over Assam and sub-Himalayan West Bengal.

2.7.2 Over Calcutta, the winds in the lower and middle troposphere are light southerlies and also unsteady except in the lowest levels (below 1.0 km). In the upper troposphere, the winds are steady easterlies and their speed increases with height. The changes in the wind regime at the beginning and the end of the monsoon season are also marked in the upper troposphere.

2.7.3 Over Gauhati, the winds are light throughout the lower and mid-troposphere. Only above 300 mb level, moderate easterlies prevail; the mean speed of the easterlies at Gauhati is less than at Calcutta. Similarly, the easterlies are also seen only for a shorter period (at the height of the monsoon, in July and August) at Gauhati.

2.7.4 The small speeds and the unsteadiness of winds in the lower and mid-troposphere over West Bengal, Assam and adjacent states are due to the frequent north-south oscillations of the axis of the monsoon trough, and the formation of low pressure areas with their movement across the North Bay and northeast India. In the upper troposphere, however, the easterlies are stable.

2.7.5 Though the mean winds in the lower troposphere are weak over West

Bengal, Assam and adjacent states, on individual occasions, moderate to strong winds reaching at times upto 40/50 knots are possible. Such high speed winds usually occur with

i) an intense low pressure system over the head Bay, when strong easterlies prevail over West Bengal, Assam and adjacent states and

ii) the seasonal monsoon trough lying close to the foot hills, when moderate to strong southwest/westerlies may prevail.

2.8 Upper Air Temperatures and Humidity

2.8.1 The chief features of temperature and humidity distribution over West Bengal, Assam and adjacent states are discussed in this sub-section. The mean tephigrams of Calcutta and Gauhati for the mid-monsoon month of July are given in Fig. 2.3(a and b). The tephigrams for May are also incorporated to bring out the changes that occur with the onset of the monsoon. Gauhati is representative of conditions in Assam and sub-Himalayan West Bengal and Calcutta represents the conditions over Gangetic West Bengal.

2.8.2 Gauhati:

'i) There is an appreciable warming up of the entire troposphere from April to June, the warming being more (6°C to 8°C) in the mid-and upper troposphere. There is also a large increase in humidity particularly from May to June.

ii) The temperature remains nearly the same during the monsoon period, except that September is slightly cooler than the other monsoon months, in the mid-and upper troposphere.

iii) The moisture content reaches a maximum during July and August. In the lower layers, the mixing ratios are of the order of 16-20 gm/kg - a very high value. In fact, Gauhati shows the highest mean precipitable water content, for the whole of India in the monsoon months.

iv) During the monsoon season, the lapse rate above 700 mb is nearly equal to saturated adiabatic lapse rate.

2.8.3 Calcutta:

i) Calcutta also shows a progressive warming from April to June at all levels (in the troposphere) particularly above 700 mb, the maximum warming (7-8°C) being at 300 mb level. The temperature remains nearly the same throughout the whole of the monsoon period, except in September, when it falls slightly (by about 1°-2°C) at all levels.

ii) There is an increase in moisture content at all levels (below 500 mb) from April to June and the increase from May to June is considerable; the increase continues and reaches a maximum in July-August. Again by September, the moisture content begins to show the reverse trend.

iii) Gauhati is slightly warmer than Calcutta above 700 mb level. There is a general north-south temperature gradient at all levels over northeast India, with warm air to the north. However, the gradient is quite slack in the lower troposphere. Only in the upper troposphere they reach substantial values. For instance, the temperature difference between Gauhati and Vishakhapatnam is about 1.5°C at 700 mb and 6°C at 200 mb. The major portion of the gradient is concentrated to the south of Calcutta. The temperature difference about 4°C between Calcutta and Vishakhapatnam (in a distance of about 4° latitude) 150 mb level would produce a thermal wind of about 17 kts from the east between 200 and 100 mb levels. The increase in the observed mean values of wind speed between these levels in the area is about 21 kts.

2.8.4 The mean tephigrams of Calcutta and Gauhati for active/vigorous, normal and weak monsoon days are given in Fig. 2.4. The diagrams are based on data for the years 1968-70 (after W.B.R.T. instruments were introduced at these stations). These diagrams bring out the following features:

i) Both at Calcutta and Gauhati, there is very little change in dry-bulb temperatures throughout the entire troposphere, irrespective of the monsoon activity. This feature has been noticed in the other parts of the country

also, as pointed out in some of the earlier FMU Reports on Southwest Monsoon

ii) In the moisture field, there is not much difference between active to vigorous and normal monsoon days, throughout the troposphere in the case of Gauhati, and in the lower troposphere in the case of Calcutta. During weak monsoon, the humidity is less than that prevailing during a normal monsoon, particularly above 800 mb.

iii) It is a point worth noting that in the lowest levels (i.e. upto about 800 mb) there is no significant change either in the dry-bulb temperature or the dew point at Gauhati or at Calcutta, whatever be the monsoon activity.

2.8.5 A few typical tephigrams of Gauhati and Calcutta for individual occasions are also given in Fig. 2.5 a and b to bring out these points.

3. Synoptic Situations associated with Monsoon Activity over West Bengal, Assam and adjacent states

3.1 Types of synoptic systems

3.1.1 The types of synoptic situations noticed in association with increased rainfall in West Bengal and Assam and adjacent states are:-

i) Depression

ii) Low pressure area (surface and/or upper air)

iii) Seasonal monsoon trough

iv) North-south oriented trough in monsoon westerlies

v) East-west oriented trough (other than the seasonal monsoon trough)

3.1.2 These features have been found either over or close to West Bengal, Assam and adjacent states, when there was an increase in monsoon activity. Sometimes, a trough in middle latitude westerlies was also additionally present to the north of these sub-divisions in the middle and upper troposphere; a few of them extended southwards upto northeast India. However, the troughs in middle latitude westerlies have not been specifically mentioned as a separate item, because along with these troughs, one or the other of the items mentioned above (i.e.

depressions, etc.) ~~were~~ was also present simultaneously in practically all the cases.

3.2 General characteristics of synoptic systems affecting West Bengal, Assam and adjacent states

In the following paragraphs we shall discuss a few salient characteristics of the above mentioned synoptic systems.

(a) Monsoon Depression:

3.2.1 During the monsoon season, depressions form over North Bay of Bengal and move in a westnorthwesterly direction. There are typical synoptic condition: under which a depression may form over the head Bay of Bengal. They are:

i) A low pressure system from the east reaching the Bay, either as a surface system (in the isobaric or isallobaric field) or as an upper air system (lo or trough)

ii) Intensification of an existing mid-troposphere system over the Head Bay and its gradual build-up downwards.

iii) A north-south trough from Orissa and Bihar Plateau moving eastwards to nort Bay, resulting in the formation of a depression

iv) Initial development of an upper air perturbation in the mid-or upper troposphere, under the influence of a middle latitude system in westerlies moving further north.

3.2.2 One or more of the above conditions may contribute to the formation of a depression over the North Bay and adjoining land areas. However, in all cases prior to the formation of the depression, the monsoon trough shifts to the head Bay of Bengal and the depression forms at its eastern end. A favourable superposition of an upper tropospheric system (such as a trough or a wind maxima) over the low level monsoon trough is also noticed. A large majority of the depressions move inland across the north Orissa coast and adjoining coastal West Bengal. As will be seen from Fig. 3.1 which depicts the centres of monsoon depression in every degree-square, a substantial number of depressions moves

across the southern districts of Gangetic West Bengal. The main area of rainfall in a monsoon depression is close to and on the southern side of the track. As such, the southern districts of Gangetic West Bengal (especially 24 Parganas, Midnapur, Bankura and Purulia) are most affected by the monsoon depressions. The monthly mean rainfall in these districts between July and September is also slightly higher than in the districts further north in Gangetic West Bengal.

3.2.3 Towards the end of the season (in September) though depressions may form at more southerly latitudes than in July and August, some of them move in northwesterly/northerly direction and affect West Bengal and Assam and adjacent states.

3.2.4 Of the five meteorological sub-divisions in West Bengal, Assam and adjacent states it is only Gangetic West Bengal that is largely affected by monsoon depressions; only a few depressions - particularly at the beginning and end of the monsoon - affect sub-Himalayan West Bengal and Assam and adjacent states.

3.2.5 During the mid-monsoon period (July and August), vigorous or strong monsoon occurs over Gangetic West Bengal, when a depression is over the sub-division. When it is over North Bay north of 19°N or over north Orissa, the monsoon is only normal in Gangetic West Bengal; on such occasions the southern districts (24 paraganas, Midnapur, Hoogly, Bankura and Purulia) alone get substantial rainfall and the other districts of West Bengal usually do not have any significant amounts. When the depression is to the south of Lat. 19°N, Gangetic West Bengal is not at all affected and monsoon remains weak there.

3.2.6 During July and August, the monsoon becomes strong in south Assam and adjoining states only when the depression is over Bangla Desh or the adjoining parts of Gangetic West Bengal; such cases are few and far between. Normal monsoon, however, prevails with a depression over the Bay north of 19°N and east of 87°E as well as over Gangetic West Bengal. Depressions beyond this area do not affect monsoon activity over south Assam and adjoining states.

3.2.7 Very occasionally, especially during the height of the monsoon, depressions may form over land (in Gangetic West Bengal and Bangla Desh); however, their number is very small compared to those that form over North Bay.

3.2.8 In some depressions, particularly those in September, heavy rainfall is not necessarily confined to the southwestern sector. It occurs in the other sectors also. In such cases, although the depression may move westnorthwestwards, still the monsoon will become active over the whole of Gangetic West Bengal.

3.2.9 Another feature peculiar to Gangetic West Bengal, which is not noticed in the other sub-divisions over which monsoon depressions move, is the occurrence of rainfall to the rear of the depression centre, when the southwest/southerly winds are very strong. Such strong southwesterly/southerlies from the North Bay reaching coastal West Bengal in the rear of the depression bring copious rainfall to the coastal districts. Experience indicates that the rainfall on such occasions may be more showery compared to steady type of rain in the southwest sector of depression. This point has been highlighted in some of the case histories discussed later (vide para 4.9, 5.11).

(b) Low Pressure Area:

3.2.10 Low pressure areas may be divided into two categories:

i) those that are seen on the surface isobaric charts as well as on upper air charts and

ii) those that are seen only on the upper air charts

The latter are also referred to as "upper air cyclonic circulations", while the term 'low pressure area' is usually confined to the former category.

3.2.11 Generally, only one closed isobar (at 2 mb interval) is noticed around a low pressure area. Sometimes, it may be only an odd-valued isobar. The low pressure areas generally extend upto the mid-troposphere. Upper air cyclonic circulation may be seen either in the lower or mid-tropospheric level, ~~in~~ or in both

the levels, but not on the surface chart.

3.2.12 Low pressure areas form under similar synoptic situations as in the case of depressions (vide para 3.2.1). However, their movement is not as regular as that of a monsoon depression.

3.2.13 Low pressure areas form over North Bay as well over the land areas of Gangetic West Bengal and Bangla Desh, in June, July and August. They are few in September. In August, there is a great preponderance of formation over land than over the sea, as compared to June and July (when they form evenly over land as well as over sea). Low pressure areas found over Assam and sub-Himalayan West Bengal are mainly the remnants of depressions.

3.2.14 Low pressure areas are associated with active and normal monsoon activity on about an equal number of occasions.

(c) Monsoon Trough:

3.2.15 The seasonal monsoon trough is usually ill-defined at the beginning of the monsoon season. When the monsoon is established over the whole country, the trough becomes a prominent feature of the synoptic chart on every day. Towards the end of the season, the western end of the trough becomes diffuse, but the eastern end can be noticed on the charts.

3.2.16 The position of the monsoon trough varies from head Bay in the south to the sub-montane regions of the Himalayas in the north, through nearly 7 degrees of latitude. When the trough is at its extreme northern position, along the foot-hills, rainfall activity is mainly confined to sub-Himalayan West Bengal, North Assam and adjoing states. But rainfall may extend southwards to Gangetic West Bengal, South Assam and adjoining states, if a north-south trough or a large amplitude westerly trough is also simultaneously present.

3.2.17 When a low or a depression forms over the head Bay of Bengal, the eastern end of the axis of the monsoon trough shifts southwards. It remains in its

southerly position till the depression/low moves fairly far to the west; later the eastern end of the trough begins to shift north. While the eastern end of the trough with or without the embedded low/depression, is to the south of the normal position, rainfall is confined to the coastal districts of West Bengal. The other portions viz. northern districts of Gangetic West Bengal, sub-Himalayan West Bengal and Assam and adjacent states usually experience weak monsoon conditions - and occasionally even dry weather.

3.2.18 Gangetic West Bengal, South Assam and adjoining states get active monsoon due to the trough, when the trough shifts rapidly north or south across the area or when the trough lies over the area prior to the formation of a low/depression over land.

(d) North-South Trough in monsoon westerlies:

3.2.19 North-south trough sometimes develops in monsoon westerlies in the lower/mid-tropospheric levels when the axis of the seasonal monsoon trough shifts north, to the foot-hills. The north-south trough may sometimes develop as far west as West Madhya Pradesh and travel east upto Bangla Desh, Assam and adjacent states. At times, there is no regular eastward movement. More often, it is found over Bihar Plateau, Orissa and Gangetic West Bengal. Sometimes it extends south into the head Bay of Bengal and a depression forms there. During the mid-monsoon months, a north-south oriented trough axis is a favourable condition for producing active monsoon conditions in South Assam and adjoining states. It becomes very much less frequent by September. In the case of North Assam and adjoining states and sub-Himalayan West Bengal, the rainfall due to the seasonal monsoon trough gets further enhanced due to the presence of the north-south trough over these areas.

(e) East-West Oriented Trough, other than the Seasonal Monsoon Trough:

3.2.20 In addition to the seasonal monsoon trough and the north-south oriented trough in monsoon westerlies, sometimes minor east-west oriented troughs

are noticed, particularly over Assam and sub-Himalayan West Bengal, which cause normal or active monsoon conditions. They are seen only in the lower troposphere. Rarely do they extend above 700 mb; most often they are seen only below 850 mb. When such a minor trough is present over Assam and sub-Himalayan West Bengal, the seasonal monsoon trough remains in its normal or south of normal position, often extending into North Bay.

3.2.21 When the seasonal monsoon trough lies over North Bay and neighbourhood and is well-marked, it can be delineated unambiguously. At times, the seasonal monsoon trough in the south is not so well-marked and a doubt may arise whether the trough over Assam is the eastern end of the seasonal trough or the one that is extending into the Bay is the seasonal trough. This difficulty in locating the axis of the seasonal trough on some occasions has also been discussed earlier in para 3.6.10 of FMU Rep. No.III-3.5.

3.2.22 Though the east-west oriented minor trough activates the monsoon, the rainfall amounts may not be so high as with the main monsoon trough.

3.2.23 Two examples of the east-west oriented trough are given in Fig.3.2 (a) and (b). In these figures, the east-west oriented trough as well as the seasonal monsoon trough are marked. The rainfall amounts have also been plotted on these charts. On 7 July 1962, the seasonal monsoon trough is well-marked and can be unambiguously delineated, whereas on 16 July 1962, there can be a doubt as to which of the two trough lines is the eastern portion of the seasonal monsoon trough.

3.3 Frequency Distribution of Synoptic Situations

3.3.1 Table VI gives the percentage frequency of the various synoptic situations associated with active to vigorous and normal monsoon activity in the meteorological sub-divisions in West Bengal, Assam and adjacent states.

TABLE - VI

Percentage frequency of synoptic situations associated with Active and normal monsoon over West Bengal and Assam and adjacent states (based on data of 1964–68)

	North Assam*								South Assam*								sub-Himalayan West Bengal								Gangetic West Bengal							
	June		July		Aug.		Sept.		June		July		Aug.		Sept.		June		July		Aug.		Sept.		June		July		Aug.		Sept.	
	A	N	A	N	A	N	A	N	A	N	A	N	A	N	A	N	A	N	A	N	A	N	A	N	A	N	A	N	A	N	A	N
Monsoon trough	22	45	65	61	61	68	30	32	7	25	21	35	15	35	20	32	19	33	56	68	70	60	33	35	0	14	18	26	11	31	0	21
Depression	0	3	3	5	0	1	10	5	3	5	7	12	7	7	20	5	0	0	3	3	0	2	0	9	22	7	18	19	21	18	36	25
Low	14	10	0	5	9	12	10	21	18	13	7	6	7	25	27	21	16	22	3	7	7	23	33	26	52	27	18	14	43	34	64	35
Upper air circulation	9	15	0	2	13	4	7	11	14	11	0	2	7	5	13	11	19	11	0	3	0	2	20	8	22	24	9	4	4	3	0	0
N/S oriented trough	33	13	19	8	13	4	20	11	39	20	54	17	57	15	0	11	26	28	38	8	15	9	7	13	4	19	33	34	21	13	0	15
E/W oriented trough	22	13	10	10	0	5	20	18	19	19	4	6	0	2	20	18	17	6	0	3	0	0	7	9	0	7	0	0	0	0	0	4
Misc.	0	1	3	9	4	6	3	2	0	7	7	22	7	11	0	2	3	0	0	8	8	4	0	0	0	2	4	3	0	1	0	0

* Meteorological sub-division as before 26 Jan. 1972.

3.3.2 From the data presented in Table VI, we may draw the following inferences on the synoptic situations causing monsoon activity in the different sub-divisions:

3.3.3 North Assam and adjoining areas:

i) The seasonal monsoon trough and the north-south trough account for nearly 75% to 85% of the active monsoon days in northern parts of Assam and adjoining areas during the mid-monsoon months of July and August, and about 50% in June and September. Rainfall on such occasions may be further enhanced by the presence of a trough in the middle latitude westerlies.

ii) Low pressure areas (surface and upper air) are next in importance to the monsoon trough and they affect this area in June, August and September on about 20% of the occasions; they are almost nil in July.

iii) Depressions affecting the area are very few and they occur mostly in September.

3.3.4 South Assam and adjoining areas:

i) Depressions and lows (surface or upper air) are the systems responsible for 60% of the occasions of active monsoon in southern parts of Assam and adjoining areas in September. At the height of the monsoon, however, as the monsoon depressions and lows form over North Bay and generally move west-northwest, they do not affect southern parts of Assam and adjoining areas. However, a few lows or depressions form over the land (over Gangetic West Bengal or Bangla Desh) and these cause active to vigorous monsoon conditions in south Assam and adjoining areas.

ii) A north-south oriented trough in monsoon westerlies is a very significant synoptic feature in causing rains over southern parts of Assam and adjoining areas in the mid-monsoon months and to a slightly less extent in June. Such troughs are rare in September.

iii) The seasonal monsoon trough causes active monsoon on only about 15-20% of the occasions in July to September. It is not significant in June. As in

the case of Gangetic West Bengal, the seasonal monsoon trough is usually found over south Assam and adjoining areas only during its northward or southward oscillation and it remains over the sub-division only for a short period (not more than 1 or 2 days).

iv) East-west oriented trough affects these areas only in June and September.

v) The seasonal monsoon trough overlies south Assam and adjoining states when its eastern end shifts to the north of the mean position. Similarly north-south trough can form only when the seasonal monsoon trough is towards foot-hills of Himalayas. As south Assam and adjoining states get rainfall predominantly only under such conditions during the mid-monsoon months, a shift of the seasonal trough northwards is a favourable factor for increased monsoon activity in these areas.

3.3.5 Sub-Himalayan West Bengal:

i) This region is similar to North Assam and Meghalaya. During July and August (i) the seasonal monsoon trough and (ii) the north-south trough represent, by and large, (85% to 95% of the occasions), the only synoptic features leading to strong to vigorous monsoon conditions in sub-Himalayan West Bengal. On some occasions along with the seasonal monsoon trough, a north-south oriented trough in the monsoon westerlies may be simultaneously present or a trough in middle latitude westerlies (in the middle or upper troposphere) may be affecting the area. When these additional features are also present, the rainfall is heavier. In June and September, the monsoon trough and the north-south trough are found responsible for active monsoon on nearly half the number of occasions.

ii) Depressions affect this sub-division very rarely. Even those that have a northerly track from the Bay, weaken off by the time they approach sub-Himalayan West Bengal. Low pressure areas are also rare in the mid-monsoon period. Only in June and September, low pressure areas (surface or upper air) affect sub-Himalayan West Bengal and cause active monsoon on about one-

third to half the number of occasions.

3.3.6 Gangetic West Bengal:

i) Depressions and low pressure areas (surface and upper air) are the only two systems which cause active to vigorous monsoon in Gangetic West Bengal at the beginning and at the end of the season (June and September).

ii) During the height of monsoon (July/August), however, the first five synoptic systems mentioned in Table VI affect this sub-division. Depressions and lows (surface and upper air) constitute about 50-70% of the number of synoptic situations on active monsoon days. North-south oriented trough affects on 20% to 30% of occasions.

iii) East-west oriented trough rarely affects this sub-division. The seasonal monsoon trough is usually associated with an active monsoon, when it rapidly moves north or south across this sub-division.

3.4 The effect of disturbances moving to the north of India, on weather in West Bengal & Assam and adjacent states

3.4.1 We have seen how the monsoon activity over north Assam and adjoining areas and sub-Himalayan West Bengal increases with the northward shift of the monsoon trough to the foot-hills of the Eastern Himalayas. But, there are variations in the degree of activity, and these are to some extent dependent on the synoptic situations prevailing further north over Tibet and its adjoining areas. An analysis of the features over this area vis-a-vis the monsoon activity over North Assam and adjoining areas and sub-Himalayan West Bengal during July and August of 1965-68, has been made and the results are shown in the form of a table.

TABLE - VII

Percentage frequency of monsoon activity in North Assam* and Sub-Himalayan West Bengal in association with lows and highs to the north of Tibet and different positions of Monsoon Trough (July and August 1965-1968)

Position of Monsoon Trough	Synoptic situation to the north of Tibet	Monsoon activity in North Assam* and sub-Himalayan West Bengal		
		Weak	Normal	Strong
1) Close to the foot-Hills of Himalayas	Low/Trough	13	49	38
	High/Ridge	20	58	22
2) Over North Assam and sub-Himalayan West Bengal	Low/Trough	13	71	15
	High/Ridge	19	62	19
3) South of 25°N	Low/Trough	45	42	13
	High/Ridge	53	39	8

* Sub-division before 26 Jan., 1972.

3.4.2 The Table gives the percentage frequency of days of weak, normal and strong monsoon activity over North Assam and adjoining areas and sub-Himalayan West Bengal in association with (i) lows (or troughs) and highs (or ridges) to the north of Tibet and neighbouring areas and (ii) a monsoon trough along different latitudinal belts. The table shows that a strong monsoon is most frequent (38%) with a monsoon trough to the north and a low further north. Under these synoptic conditions, a weak monsoon in North Assam and adjoining areas and sub-Himalayan West Bengal is uncommon (13% of the total number of occasions). When the monsoon trough is a little to the south of the foot-hills, i.e., over sub-Himalayan West Bengal and North Assam, the frequency of strong monsoon is slightly less, both with a low or a high to the north. On these occasions, the frequency of weak monsoon conditions also is small. But, when the monsoon trough shifts far south, a weak monsoon predominates, irrespective of the presence of a low or high to the north; the monsoon is rarely strong on such occasions.

3.4.3 When the surface low to the north of Tibet is well-marked, a trough in the middle latitude westerlies is generally present over this area. This trough may be often seen extending southwards as far as India in the middle and upper troposphere. An examination of the upper air charts for a limited period showed that when the westerly trough was present and the surface conditions over North Assam and sub-Himalayan West Bengal were favourable for an active monsoon, the rainfall in these sub-divisions was very heavy; but when the westerly trough was not present, even though the monsoon was active, the rainfall amounts were not high.

3.4.4 This analysis of conditions to the north of India brings out the dependence of monsoon activity over sub-Himalayan West Bengal, North Assam and adjoining areas on conditions over Tibet and areas north of it. In the following 9 sections (section 4 to 12), typical cases of synoptic situations and the associated monsoon activity over West Bengal and Assam and adjacent States are discussed.

4. Deep Depression from Northwest Bay to Southeast Uttar Pradesh, causing strong monsoon in Gangetic West Bengal - 24 to 30 July 1965

4.1 On the morning of 24 July 1965, the axis of the seasonal monsoon trough extended from Punjab-Haryana to the Bihar Plains, and thence southeastwards into North Bay of Bengal. There was a pressure fall of about 3 mb over the north Bay while over Assam and adjacent states it was rising slightly. The departure was about 1 mb (negative) over North Bay and adjoining Bangla Desh, while it was generally positive over the rest of the country.

4.2 On the next day also (25th) pressures were falling by 2 to 3 mb over south Assam and adjoining states, Bangla Desh and Northeast Bay, and an extended low pressure area formed over North Bay, Gangetic West Bengal and adjoining parts of Bangla Desh. In the upper air, the circulation was noticed upto 400 mb. The monsoon was strong along the Arakan coast, where heavy to very heavy rainfall was reported. The continued pressure fall over North Bay and adjoining areas,

and the gradual changes in the upper winds around the head Bay indicated that the circulation was becoming more marked. The strong cyclonic shear of winds over the North and adjoining Central Bay, as well as heavy rain along the Arakan coast - all these features suggested possible intensification of the low pressure area into a depression.

4.3 The low pressure area concentrated into a depression by the 26th morning and was centred near 21°N 89.5°E (Fig. 4.1). The circulation extended to about 400 mb level with a southwestward tilt with height above 700 mb (Fig. 4.2). With the formation of a depression close to the coast, the monsoon strengthened in Gangetic West Bengal and an isolated heavy fall of 8 cm was reported from Sandheads. The rainfall was mainly over Bihar Plateau, Orissa and the southern districts of West Bengal, while in Assam and adjacent states and the northern districts of West Bengal, where easterlies prevailed in the lower and mid-troposphere, the monsoon was weak. The 24 hour pressure changes, as well as the strong easterly flow over northeast India in the lower and middle troposphere, suggested that the depression might take the usual westnorthwesterly course.

4.4 Moving slowly westnorthwestwards, the depression deepened and was centred on the 27th morning close to Sagar Island, which reported an easterly wind of 30 kt (unusually gusty) and a pressure of 990.6 mb (nearly 9 mb below normal) (Fig. 4.3). The associated cyclonic circulation extended to 400 mb - with a southward slope with height, towards the colder air (Fig. 4.4). Lower tropospheric winds over Calcutta reached 40 knots, and a uniformly strong, easterly current prevailed on this day over northeast India, Uttar Pradesh and Rajasthan in the lower and mid-troposphere. The cross-section along a line joining Gauhati, Calcutta and Visakhapatnam brings out the slope of the system and the cold air to the south of the depression (Fig. 4.5). The corresponding tephigrams are given in Fig. 4.6. Note the extreme dryness and stability over Gauhati and the dry weather in Assam and adjacent states and sub-Himalayan West Bengal. The deep depression caused widespread rainfall on this day (27th) in

Orissa, Bihar Plateau and southern districts of Gangetic West Bengal with a few heavy/very heavy falls in Orissa. By way of contrast, Assam and adjacent states, the northern districts of West Bengal, Bihar Plains and Uttar Pradesh, where strong easterlies prevailed, were nearly dry. The pressure changes and the strong easterly flow pattern referred to above suggested a continued westnorthwest/ northwesterly movement.

4.5 The deep depression crossed coast during the evening of 27th and was centred near Chakulia on 28th morning (Fig. 4.7). The associated cyclonic circulation continued to extend to 400 mb (Fig. 4.8). In the rear of the deep depression, there was a steep pressure gradient over the North Bay where winds of 30-40 knots were reported. With the inland movement of the depression, the eastern end of the axis of the monsoon trough shifted northwards to Gangetic West Bengal and Bangla Desh. The strong southerlies/south westerlies together with the shift of the axis of the trough across the area caused fairly widespread rainfall over coastal areas of West Bengal and Bangla Desh which was to the rear of the depression. A few heavy falls (7-11 cm) were reported from this area. This feature of heavy rainfall in the rear of the depression is not very common; it is often peculiar to Gangetic West Bengal and the adjoining areas. It is not usually observed, for instance, further west over Madhya Pradesh, Bihar or even over Orissa. As the eastern end of the monsoon trough shifted north, there was an increase in rainfall over southern parts of Assam and adjoining states. The monsoon continued to be weak in sub-Himalayan West Bengal and northern parts of Assam. Pressures rose rapidly in the rear of the deep depression, and the significant pressure falls (though of small magnitude) were over Bihar Plateau. This indicated a northwesterly movement of the deep depression.

4.6 The deep depression moved northwestwards to West Bihar and adjoining Uttar Pradesh on the 29th morning. Thereafter, it rapidly weakened into a low pressure area. The eastern end of the axis of the monsoon trough shifted further north and was roughly along 24°N over West Bengal and Assam and adjacent states.

The southwesterly winds over coastal West Bengal and Bangla Desh decreased in speed (the pressure difference between Sagar Island and Akyab, which was about 10 mb on 28th, was reduced to about 5 mb on 29th).

4.7 As the depression moved away and weakened, there was a further decrease in rainfall in Gangetic West Bengal, except in the districts close to Bihar. But, as the monsoon trough was moving north, the rainfall increased in sub-Himalayan West Bengal and Assam and adjacent states; consequently the monsoon became strong in sub-Himalayan West Bengal and southern parts of Assam and adjoining states.

4.8 During the next 24 hours, the low weakened further and the eastern end of the axis of the seasonal trough moved to the foot-hills by the 30th morning. As a result, the monsoon strengthened further to the north - it was vigorous in sub-Himalayan West Bengal and continued to be strong in southern parts of Assam and adjoining states. The rainfall decreased further in Gangetic West Bengal.

4.9 The main features of this case may be summarised as follows:-

i) This sequence of charts brings out the spell of rainfall over Gangetic West Bengal in association with the formation of a monsoon depression and its westnorthwesterly/northwesterly movement. As the depression track was over a more northerly latitude, strong monsoon conditions prevailed for a day over Gangetic West Bengal. If the track lay further to the south, across north Orissa, the belt of weather may not extend beyond the coastal districts of West Bengal.

ii) As the deep depression formed and moved westnorthwestwards, the weather improved in areas well to the north of the depression, (i.e. sub-Himalayan West Bengal and Assam and adjacent states)and generally weak monsoon conditions prevailed there.

iii) The pronounced dry weather in Assam and adjacent states and the stability of the airmass over the area (shown by Gauhati tephigrams) when the deep

depression was in the Bay are noteworthy features.

iv) After the depression moved inland, the eastern end of the axis of the monsoon trough moved progressively northwards across Gangetic West Bengal and adjoining states, and reached the foot-hills of the Himalayas on 30th. With this movement, the weather rapidly deteriorated in sub-Himalayan West Bengal, and Assam and adjacent states and the monsoon naturally strengthened there. Simultaneously, in the south, the rainfall decreased in Gangetic West Bengal.

v) Although the weather generally improves in the rear of a monsoon depression, the northward shift of the axis of the trough and the strong pressure gradient, prolonged the spell of rainfall in Gangetic West Bengal for a day, even though the depression had moved inland. Such strong pressure gradients causing strong to vigorous monsoon over the sea-area in association with the depressions is a feature to be taken note of, while issuing marine forecasts.

5. Land Depression over Gangetic West Bengal moving in a westerly direction - 30 August to 6 Sept.1970

5.1 On the morning of 30 August 1970, the axis of the seasonal monsoon trough ran from northeast Rajasthan to south Assam and adjoining states across south Uttar Pradesh and Bihar Plains. Over northeast India, the axis was roughly along 25°N and was well-marked. There was strong cyclonic shear to the south of the axis over northeast India in the lower troposphere (the shear was about 15 knots across one degree latitude in Gangetic West Bengal). Pressures were generally rising over the whole country, while there was a slight fall over the north and central Bay, suggesting that the trough over northeast India might shift south.

5.2 During the next 24 hrs, the trough shifted rapidly southwards and on 31st it passed through northeast Madhya Pradesh, coastal West Bengal and thence into northeast angle of the Bay at 900 m asl. A feeble cyclonic circulation could be seen over coastal West Bengal and the head Bay in the lower and middle troposphere (Fig. 5.1). Pressures were falling over the whole country, and the

falls were relatively more pronounced over North Bay, Orissa, Gangetic West Bengal, Bangla Desh and adjoining areas (Fig. 5.2). As the trough shifted southwards and a cyclonic circulation formed over Gangetic West Bengal, rapid changes took place in the weather over northeast India. In North Assam and adjoining states, where the monsoon was strong on 30th, rainfall almost ceased. Over Gangetic West Bengal where the weather was dry on 30th, rainfall increased considerably and the monsoon became active; Calcutta reported 10 cm of rain.

5.3 On 1st September, the eastern end of the axis of the seasonal trough moved further south, and the upper air cyclonic circulation also persisted over coastal West Bengal and adjoining North Bay. There was further general fall of pressure over most of the country. The rainfall over northeast India on this day was also to the south of the axis of the trough; monsoon continued to be active in Gangetic West Bengal and weak to normal in the north (in Assam and adjacent states and sub-Himalayan West Bengal).

5.4 During the next 24 hrs., there was relatively more pressure fall over North Bay, coastal West Bengal and adjoining areas. As a result, the system over coastal West Bengal intensified into a depression centred near Chakulia on the morning of 2nd (Fig. 5.3). The associated cyclonic circulation extended upto 500 mb level (Fig. 5.4), which was sloping southwestwards with height (towards the cold air side). The circulation extended as far west as Nagpur. The monsoon further strengthened and became vigorous in Gangetic West Bengal where heavy to very heavy rains upto 13 cm were reported. Monsoon was weak in north Bengal and Assam and adjacent states.

5.5 The continued pressure falls on the 12 GMT chart of 2nd in the area of the depression with rising pressure all around, was indicative of deepening of the depression, although it was over land. The depression moved northwest, deepened and lay with its centre between Ranchi and Jamshedpur on the 3rd morning. The maximum pressure departure at the centre was -9 mb as against -7 mb on the

on the previous day. The associated cyclonic circulation extended to 300 mb without any significant tilt with height. The eastern end of the axis of trough shifted slightly north and was across Gangetic West Bengal, Bangla Desh and south Assam and adjoining states. The pressure gradient over North and Central Bay was quite strong, and surface winds with speeds upto 40 kts were reported over the area. The monsoon continued to be vigorous over Gangetic West Bengal with a few heavy to very heavy falls. Over northeast India to the north of 24°N, the monsoon was quite weak with only a few light falls.

5.6 The deep depression moved westnorthwestwards to northeast Madhya Pradesh; its centre was between Pendra and Ambikapur on 4th morning. Though the depression moved westwards, the eastern end of the axis of the monsoon trough did not move any further north, but remained over Gangetic West Bengal and Northeast Bay of Bengal. The pressure gradient also continued to be strong over North and Central Bay, and winds were still upto 40 knots over these areas.

5.7 Though heavy rainfall extended westwards to the Bihar Plateau with the westward movement of the depression, and the pressure rose heavily over Gangetic West Bengal in the rear of the depression, Gangetic West Bengal continued to have vigorous monsoon conditions, with a few very heavy falls of 20-25 cm in the southern parts of the sub-division. The monsoon was generally weak over the rest of the area.

5.8 The deep depression moved further west to the central parts of Madhya Pradesh. On the 5th morning it was centred near Narsinghpur (Figs.5.5 and 5.6). The pressure rose further over Gangetic West Bengal and the gradient over North and Central Bay of Bengal slackened. However, the eastern end of axis of the seasonal trough continued to be over coastal West Bengal and adjoining Northeast Bay. As a result, the monsoon continued to be vigorous over Gangetic West Bengal for the fourth day in succession, though the deep depression had moved quite far to the west. The monsoon continued weak over sub-Himalayan West Bengal and

Assam and adjacent states where there was hardly any rain.

5.9 By 6th morning, the deep depression moved further westwards to extreme West Madhya Pradesh and the adjoining Gujarat Region. The eastern end of the axis of the trough also became less marked as another low was moving westwards across Burma. As a result, weak winds with col type circulation prevailed over Bangla Desh and the adjoining areas of West Bengal and Assam and adjacent states. The rainfall decreased over Gangetic West Bengal, although monsoon was still strong there; Sub-Himalayan West Bengal and Assam and adjacent states continued to have almost dry weather.

5.10 By the 7th rainfall very rapidly decreased and the monsoon became weak over whole of West Bengal and Assam and adjacent states.

5.11 The following are the important features of weather over West Bengal and Assam and adjacent states during the period 30 August to 6 September, 1970:-

i) Formation of a depression over the land area and its intensification

ii) Continued monsoon activity in Gangetic West Bengal, due to the presence of the axis of monsoon trough over the area and a strong pressure gradient over North Bay, even after the depression had moved far to the west. The monsoon was strong to vigorous for six days continuously, which is a rare occurrence. The heavy rains flooded vast areas in the districts of Midnapur, Birbhum, Burdwan, 24 Parganas, Howrah and Hooghly as well as Calcutta city proper. The rainfall over Gangetic West Bengal during this spell (31st August to 6th September) was nearly 60% above normal for the week, and nearly twice the mean rainfall for the sub-division for the month of September.

iii) Weak monsoon with almost dry weather prevailed in the northern sector of the deep depression i.e. North Assam and adjoining areas and the northern districts of West Bengal.

5.12 A few salient features noticed in this sequence of charts discussed in this section are:-

i) During the period the axis of the seasonal trough was well-marked and slightly south of the seasonal position. There were embedded vortices in it and the general monsoon activity over the country was good. The trough also extended east upto south China Sea. Charts for 3 September are given as typical of the period (Fig. 5.7 and 5.8). The satellite picture for the same day (Fig. 5.9(a))clearly brings out the extensive zonal clouding mainly close to and to the south of the trough line with little or no clouding to the north.

ii) On account of the above feature, the eastern end of the seasonal monsoon trough did not shift north after the deep depression moved inland. Additionally, a fresh low was also approaching the Bay across Burma.

iii) The deep depression formed initially in the upper air (as a cyclonic circulation) and was seen only subsequently on the surface isobaric chart. It formed over North Bay and adjoining Gangetic West Bengal and there was no clear evidence of any low pressure system from the east travelling westwards and leading to the formation of the depression. However, extended area charts suggested that a deep westerly trough in the upper troposphere moving east penetrated southwards upto Assam and adjacent states and Bangla Desh and Northeast Bay across East Tibet and adjoining China on 30th, leading to the initial formation of the upper low. The linking of the clouding over the mid-latitudes with the clouding over northeast India, caused by the southward extension of the westerly trough is illustrated by the satellite picture for 30th (see Fig. 5.9b). Thus, the effect of the westerly trough appeared to be very significant for the formation of the monsoon depression over North Bay and Gangetic West Bengal.

iv) A sample day's (3 Sept. 0000Z) tephigrams of Gauhati and Calcutta during the period show the dryness and stability of the air over sub-Himalayan West Bengal and Assam and adjacent states,and the highly humid airmass over

Gangetic West Bengal with an almost saturated adiabatic lapse rate (Fig.5.10). Such large contrasts in the airmass within a distance of 400 to 500 km are interesting. The tephigrams of Calcutta for 1st and 2nd evening, when the depression was forming within 100 km west of Calcutta, show a deep, moist layer with and nearly saturated adiabatic lapse rate extending from the surface well into the middle troposphere (500 mb to 350 mb) and relatively drier air above.

6. Depression from North Bay of Bengal moving northnortheastwards to Assam and ushering the monsoon into West Bengal and Assam and adjacent states - 3 to 9 June 1963

6.1 Depressions of the monsoon season usually move in a westnorthwest/northwesterly direction. However, those that form at the very beginning of the monsoon season usually take a northerly course and travel even upto Assam and sub-Himalayan West Bengal, bringing the monsoon to these areas. In this section we will discuss a case of this type.

6.2 On the morning of 3 June 1963, the southwest monsoon had advanced into east-Central Bay of Bengal and the seasonal trough extended from Punjab-Haryana to the North Bay across North Orissa on the surface chart. At 700 mb, a low developed over North Bay (which was not present on the previous day). A low was also present over North and adjoining Central Bay in the middle troposphere, which is a seasonal feature. Thus, a low pressure system (either as a trough or a low) was present over the North Bay in the entire lower troposphere and extended upto the mid-troposphere.

6.3 On the next morning (4th) the cyclonic circulation over North and adjoining Central Bay became marked. On the surface chart, a feeble low could also be located over the area where only a trough was present earlier. Pressures were falling more over the areas when compared with the adjoining area. The weather was mostly dry over northeast India on this day.

6.4 During the next 24 hours, there was further development of the cyclonic circulation, and on the 5th morning, the low pressure area over the Northwest and adjoining West Central Bay became well-marked, extending upto about 400 mb, with a southward slope with height (towards the colder air) in the middle troposphere. The pressure departures were -4 mb over the area and pressures were generally falling there; it was slightly rising in the neighbouring areas. This appeared to be an indication of a possible intensification of the system. Weather continued mainly dry over northeast India, outside south Assam and adjoining states.

6.5 By the morning of 6th, the low pressure area concentrated into a depression with its centre near 19.5°N 88.5°E (Fig. 6.1). The cyclonic circulation in the upper air extended upto 300 mb level with a southward slope with height (towards cold air) (Fig. 6.2). Pressure changes were about -4 mb near the centre of the depression and pressure falls extended to Bangla Desh and adjoining West Bengal. Over the surrounding areas, pressures continued rising. The maximum pressure departure was about -6 mb. On this day, a few thunderstorms were reported from Gangetic West Bengal with light to moderate rainfall. Fairly widespread thunderstorms also occurred in south Assam and adjoining states, though the associated rainfall was generally light. The small pressure falls extending to Bangla Desh and Gangetic West Bengal on 6th morning (referred to already) were followed by a more organised pattern of pressure falls of 2-3 mb over the area by the evening of 6th; this indicated a northerly track for the depression.

6.6 The depression moved northnortheastwards, crossed West Bengal - Bangla Desh coast during the night of 6th and was centred close to Satkhira on 7th morning (Fig. 6.3). The pressure departure at the centre was about 6-8 mb (negative). In the meantime, a trough in westerlies to the north of the country developed large amplitude over Tibet. On the 6th, it was extending from central Mongolia southwestwards almost upto East Uttar Pradesh across East Tibet. By 7th, the northern portion of the westerly trough moved eastwards while the

southern portion over Tibet and India persisted with only a slight eastward movement (Fig. 6.4). With the northward movement of the depression, rainfall became fairly widespread in West Bengal and south Assam and adjoining states, while it was only scattered in north Assam and adjoining areas.

6.7 The depression moved in a northnortheasterly direction and slightly weakened and was centred on 8th morning, to the south of Dhubri. The pressure departure at the centre was only about 5-6 mb (negative). Pressures were generally falling along the foot-hills of Himalayas, while they were heavily rising over Gangetic West Bengal and North Bay. Upper air data over northeast India was meagre on this day; but available observations suggested that the circulation associated with the depression had become considerably less marked and merged with the westerly trough at the higher levels, which was persisting over Tibet and adjoining northeast India. The 24 hrs. pressure tendencies and the location of the depression with reference to the westerly trough suggested a continued northerly track. Under the influence of the depression, monsoon advanced into West Bengal and Assam and adjacent states where fairly widespread rainfall occurred, with a few heavy to very heavy amounts, Cherrapunji reported a very heavy fall of 40 cm. By the evening, the depression weakened into a low pressure area as it moved further northnortheastwards towards the Himalayas.

6.8 By the next morning (9th) the low pressure area became unimportant and the eastern end of the monsoon trough was over sub-Himalayan West Bengal and north Assam. Pressures rose generally over whole of northeast India and rather heavily over sub-Himalayan West Bengal and Assam and adjacent states. As the depression moved northwards and weakened, rainfall decreased in Gangetic West Bengal. However, over sub-Himalayan West Bengal, and Assam and adjacent states the monsoon activity continued to be strong to vigorous and heavy to very heavy falls of 12 to 18 cm were reported.

6.9 The salient features of the situation discussed in this section are:-

i) The depression is a typical case of a disturbance that forms in the Bay ahead of the advancing southwest monsoon current. These disturbances generally take a northerly/northeasterly track and usher the monsoon into West Bengal and Assam and adjacent states. The tracks of these early June depressions, in advance of the monsoon, are quite different from the common westnorthwesterly track of monsoon depressions later in the season.

ii) The westerly trough that moved across Tibet and extended into Uttar Pradesh and northeast India exerted much influence over the direction of movement of the depression.

iii) In the initial stages of formation of the depression, the fall of pressure at the centre, with pressure rising around, was a good indication of the intensification of the depression. Under such situations, forecasters should be on their guard and should not be misled by the rising pressure over the coastal areas, while the systems may be actually intensifying out at sea.

iv) The depression, while over the sea, showed a southward slope with height towards the colder air. However, after crossing inland it came under the influence of the westerly trough and the upper air circulation merged with the trough system. The rapid weakening of upper air circulation was very conspicuous between the 7th and 8th; the surface system also rapidly weakened 24 hours after the upper air circulation had weakened.

v) Initially, the rainfall was accompanied by thunderstorm, whereas subsequently the thunderstorm activity decreased. Gauhati tephigram brings out clearly the increase in the stability (from unstable to neutral conditions) as the monsoon advanced into the area (two typical tephigrams of Gauhati are shown as an example in Fig. 6.5).

vi) During this spell, rainfall was generally more in sub-Himalayan West Bengal and Assam and adjacent states than in Gangetic West Bengal. Orography, and the westerly trough, possibly enhanced the rainfall in Sub-Himalayan West Bengal and Assam and adjacent states. On the other hand, Gangetic West Bengal, although it experienced active monsoon for a day, did not get heavy rains, because the sub-division was to the west of the depression track.

7. "Land Low" over Bangla Desh and Gangetic West Bengal - 31 July to 4 August, 1965

7.1 Towards the end of July 1965, a deep depression from the Bay of Bengal moved northwestwards to the western parts of Bihar where it weakened into a low by 29th July 1965 (see Sec. 4). The low became unimportant during the course of the next two days. While pressures were rising markedly over Orissa, Bihar and Gangetic West Bengal on 29th and 30th, in the wake of the northwestward movement of the deep depression and its weakening, a well-marked isallobaric low was travelling westwards across central Burma and it reached Bangla Desh on 31st morning, when the 24 hr. pressure changes were about -4 mb. On this day, the axis of the seasonal monsoon trough lay across southeast Uttar Pradesh and central parts of Bihar State and Bangla Desh and the major area of rainfall in northeast India and Bangla Desh was along and near this trough line.

7.2 By 1st August morning, the monsoon trough became well-marked over Bangla Desh and adjoining Gangetic West Bengal, where there was a further pressure fall by 1-2 mb (Fig. 7.1). Over this area the trough line was inclined towards the southwest with height, as inferred by the winds at Calcutta, which were westerly/northwesterly in the lower troposphere changing to light southeasterly in the mid-troposphere (Fig. 7.2). Available upper winds suggested that a low may also be present in the trough at some levels. The significant rainfall amounts were mainly in and near the trough line over the Bihar Plains, north Bengal and Bangla Desh on this day.

7.3 During the course of the day (i.e. 1st August), there was further development over Bangla Desh and the adjoining areas and a well-marked low pressure area formed over the southern parts of Bangla Desh on 2nd morning (Fig. 7.3). Pressures were falling slightly over the area of the low while they were generally rising in adjacent areas, which indicated the low being one of small extent but well-marked. The pressure departure was about -4 mb at the centre of the low. The low was well-marked in the upper air also, and extended upto 6.0 km with a southwestward slope with height (towards the cold air) (Fig. 7.4).

7.4 Under the influence of the low, rainfall considerably increased over Gangetic West Bengal; heavy to very heavy rains occurred in the southwest sector of the low, over coastal West Bengal and adjoining north Orissa, with amounts ranging from 8 cm to 14 cm at a number of stations. The monsoon was vigorous in Gangetic West Bengal. There was a decrease of rainfall in sub-Himalayan West Bengal and Bihar Plains.

7.5 The pressure changes on the evening of 2nd were suggestive of a northward movement of the low (~~see Fig. 7.5~~).

7.6 By the 3rd morning the low moved slowly northwest, and was over central portions of West Bengal and adjoining Bangla Desh, with its central region between Berhampore and Malda (Fig. 7.5). In the upper air, the circulation became less marked (Fig. 7.6). Pressures were generally rising over the whole country. The monsoon was strong in Gangetic West Bengal on this day, and a few stations reported falls upto 6 cm. There were some heavy falls in the southern parts of Bangla Desh. Relatively, sub-Himalayan West Bengal, and Assam and adjacent states did not have much rain; the monsoon was only normal.

7.7 During the next 24 hours, the low weakened and merged with the seasonal trough and on 4th morning the monsoon trough extended from the sub-montane districts of Uttar Pradesh and Bihar to south Assam and adjoining states. There

was also a feeble north-south oriented trough (perhaps the remnant of the weakened low) over West Bengal and Bangla Desh, with its axis roughly along 89°E in the lower troposphere. The flow pattern thus tended to become more like a 'break' situation. With the weakening of the low, there was a general decrease of rainfall over West Bengal, and the monsoon became normal in Gangetic West Bengal and weak in sub-Himalayan West Bengal. Assam and adjacent states continued to have normal monsoon.

7.8 For the subsequent 2 or 3 days, the eastern half of the monsoon trough remained well north of its normal position with a north-south trough over West Bengal and Bangla Desh in the lower troposphere leading to strong monsoon conditions in sub-Himalayan West Bengal and Assam and adjacent states.

7.9 The important points brought out in this case were:-

i) The low pressure area which formed over Bangla Desh on 2nd, could be traced earlier as a well-marked isallobaric low travelling westward across north Burma to Bangla Desh. In these areas, where upper wind data are very meagre and irregular, pressure changes are often very helpful in tracking these low pressure systems.

ii) With the formation of the low and its slow northwestward movement, there was an increase in monsoon activity in Gangetic West Bengal. Strong to vigorous monsoon conditions prevailed over the sub-division on the 2nd and 3rd, and widespread rainfall with a few heavy to very heavy falls occurred. Calcutta tephigrams for these days show a very deep layer (reaching ~~500~~ 600 mb or more) of almost saturated air (Fig. 7.7).

iii) As the low moved further towards sub-Himalayan West Bengal and north Assam rainfall considerably decreased in Gangetic West Bengal on the 4th. The monsoon trough shifted to the foot-hills of the Himalayas and a north-south trough was present in the monsoon westerlies on 4th. This led to an increase in rainfall in Assam and adjacent states where the monsoon strengthened by 5th. It is a point to note that though the axis of the monsoon

trough was towards the foot-hills on 4th and 5th, sub-Himalayan West Bengal did not get much rain, whereas Assam and adjacent states experienced strong monsoon conditions. This is due to the location of the north-south trough in the lower tropospheric westerlies along 89-90°E.

iv) The low had a slope towards the south (towards cold air) on 2nd and the rainfall was generally more and also heavy to the left of the track of the low.

v) Between 4 and 8 August, a well-marked low pressure system moved eastwards, north of Tibet. In the middle and upper troposphere, a trough moved eastwards across Tibet during the same period. These features in the middle latitudes initiated the northward shift of the axis of the seasonal trough, and the spell of heavy rains along the Eastern Himalayas.

8. Strong to vigorous monsoon conditions in West Bengal and Assam and adjacent states during a "Break"

8.1 The seasonal monsoon trough often oscillates in a north-south direction across Gangetic West Bengal. When it is far to the south (i.e. south of 20°N) easterlies prevail over Gangetic West Bengal and the monsoon is weak. When the trough overlies Gangetic West Bengal, rainfall increases there and monsoon becomes normal or even strong.

8.2 When the trough moves further north and lies close to the foot-hills, the monsoon becomes strong to vigorous over north Assam and adjoining areas and sub-Himalayan West Bengal, while rainfall decreases in Gangetic West Bengal. An extreme case of this type is the 'break monsoon'* condition when the trough persists along the foot-hills for a few days. The general concept is that rainfall during the 'break' is confined to the sub-montane districts of the Himalayas, and the plains are mainly dry. This is usually so in Uttar Pradesh and the central parts of the country. But, further to the east, over northeast India, we find that while rainfall is widespread and copious along and near the hills, quite often

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* Refer to FMU Rep. No. IV-18.3 "Some aspects of the 'Break' in the Indian South-west Monsoon during July and August."

light to moderate rainfall extends well to south of 25°N, even during the 'break' periods. This feature is reflected in Figs. 4 and 5 of FMU Rep. No. IV-18.3.

8.3 A typical case of 'break monsoon' has been given in the above-mentioned Forecasting Manual report. Here, we shall discuss another case which affected West Bengal and Assam and adjacent states. Though the case to be discussed was not called a 'break' in the departmental weather reports, because rainfall activity did not completely cease over the plains, the synoptic conditions were very similar to those noticed during a 'break' in the monsoon.

8.4 During the period 2-4 July 1967, a low pressure area (which was the remnant of a depression from Northwest Bay of Bengal) moved to north Madhya Pradesh and weakened. In its wake, the axis of the monsoon trough shifted progressively northwards and by the 6th morning, the eastern half (east of Long 80°E) lay close to the foot-hills of the Himalayas. As the trough moved north across Gangetic West Bengal, strong monsoon activity prevailed over the sub-division on the 4th and subsequently, with further northward shift of the trough, rainfall decreased in Gangetic West Bengal. Normal monsoon prevailed over Assam and adjacent states and sub-Himalayan West Bengal on these days (4th to 6th).

8.5 On 7th, the monsoon trough continued to be close to the foot of the Himalayas along its entire length to the east of 80°E(Fig. 8.1). The south-north pressure gradient in northeast India (as measured by the pressure difference between Sagar Island and Baghdogra) also increased from 3 mb on 6th to nearly 6 mb on 7th. In the lower troposphere, the westerlies over north India strengthened and reached upto 40-50 knots and there were also indications of a feeble north-south oriented trough line over sub-Himalayan West Bengal (Fig.8.2). These features of the surface and upper air conditions were typical of 'break' monsoon conditions. As a result of these changes in the synoptic conditions, the monsoon became strong to vogorous in Assam and adjacent states. Pasighat

reported 39 cm of rain and Agartala 17 cm. It was normal in sub-Himalayan West Bengal and weak in Gangetic West Bengal.

3.6 The synoptic features remained the same on the 8th as on the previous day, except for a slight pressure rise over Assam and adjacent states. Additionally a trough in the upper tropospheric westerlies moved from western Tibet eastwards, became more marked and extended well southwards (Fig. 8.3). It was noticed from 500 mb to 200 mb, and its axis ran from central Tibet to east Uttar Pradesh. The heavy rains, because the monsoon trough lay close to the foot-hills, were further enhanced in sub-Himalayan West Bengal and adjoining Assam by the approach of a westerly trough. The monsoon became strong to vigorous in sub-Himalayan West Bengal and north Assam. Kalimpong recorded 17 cm and Darjeeling 16 cm (Fig. 8.3).

8.7 During the next 24 hours the westerly trough remained stationary, and also extended upto north Orissa on 9th morning (Fig. 8.4). Due to rain and low clouds, pibal observations were very meagre over northeast India. But, the available observations indicated light easterlies appearing over north Assam and sub-Himalayan West Bengal. As a result of these developments - viz.

i) the upper westerly trough and its extension southwards and

ii) slight shift of the monsoon trough southwards, the rainfall extended southwards also and whole of Assam and adjacent states and West Bengal experienced strong to vigorous monsoon conditions. Many stations recorded heavy to very heavy rains and Cooch-Behar (in sub-Himalayan West Bengal) recorded 36 cm. It is a point of interest to note that on this day the rainfall decreased in the hills, and the stations which reported heavy rains in West Bengal and adjoining Assam and Meghalaya were mainly between 24°N and 26°N. This was due to the slight southward shift of the axis of the seasonal trough.

8.8 On this day (9th) there was a relatively larger fall of pressure over

North Bay and Arakan coast, and rainfall also increased over Arakan coast (Fig. 8.5). These features, together with the slight southward shift of the trough, indicated that the 'break' may terminate.

8.9 During the next two days (10th and 11th) the circulation and pressure patterns changed considerably over northeast India and North Bay. A mid-tropospheric circulation appeared over northeast Bay on the 10th morning; by 11th it became more marked and also moved slightly west (Figs. 8.6 and 8.7). On the surface chart (for 11th), the pressure field became flat over northeast India and a general trough system with lows embedded in it, was established there. The pressure changes also took a definite pattern with large rise over the whole of northeast India and a slight fall over North Bay. The lower tropospheric winds weakened. The westerly trough also became less marked over northeast India. Thus, at the surface as well as in the upper air, the pressure and wind patterns were returning back to the normal during these two days. As a result, a general decrease in rainfall began on 10th when only sub-Himalayan West Bengal had strong monsoon and by 11th even here the monsoon activity decreased. The whole of Assam and adjacent states and West Bengal had only weak to normal activity.

8.10 The APT pictures for the period were of poor quality and are not reproduced here. But, they showed an occluded system centred near 50°N 80°E with well-marked cloud bands extending southwards to Tibet. This cloud band was associated with the westerly trough referred to in the earlier paragraphs.

8.11 The situation discussed is illustrative of a case of strong to vigorous monsoon in sub-Himalayan West Bengal and Assam and adjacent states associated with the shift of the axis of the monsoon trough towards the foot-hills. There was also the added influence of a system in middle latitude westerlies. During this period, monsoon was generally weak over most of the remaining parts of the country. The following are the noteworthy points in the present case:-

i) The eastern part of the axis of the monsoon trough shifted progressively northwards to north Assam and sub-Himalayan West Bengal, as a depression from the Bay of Bengal moved westwards inland to north Madhya Pradesh and there was no fresh development over the Bay. The trough continued to be close to the foot-hills till a fresh low (in the middle troposphere) began to develop over the head Bay on the 10th.

ii) During this period (8th-10th), a trough in middle latitude westerlies also moved across Tibet. When it came over Central Tibet, it developed a large amplitude and extended well into northeast India and adjoining Uttar Pradesh. The northern portion of the trough moved away across Tibet and adjoining China by 11th-12th, while the southern portion became progressively less marked over northeast India without any movement eastwards.

ii) The extended charts were helpful in identifying the trough, and following its movement and intensity. Simultaneous with the upper trough, an intense surface low also moved eastwards, north of Tibet. Many stations in Tibet reported rain and heavy clouding during the period. Thus even surface charts may be, on some occasions, helpful in inferring the passage of disturbances in westerlies, north of India.

iv) Although the axis of the seasonal monsoon trough was north of 25°N, well close to the foot-hills during the period 7th to 10th, just as the deep westerly trough affected the area, the rainbelt extended southwards to Gangetic West Bengal (and even upto south Orissa).

v) Under the combined influence of the shift of the axis of the monsoon trough to the north, and the passage of the westerly trough, very heavy rains ranging from 15 cm to 40 cm occurred in north Assam and adjoining areas and sub-Himalayan West Bengal on four consecutive days - 7th to 10th.

vi) There were also spells of increased rain in Gangetic West Bengal, south Assam and adjoining states as the monsoon trough shifted north and south across these sub-divisions.

vii) When the monsoon trough was close to the foot-hills, the north-south pressure gradient over northeast India was strong. It was as much as 6 mb in 5 degrees latitude and lower tropospheric westerlies were also strong, reaching 40-50 knots. There was also some evidence of speed convergence in the westerlies due to weakening of the winds downstream.

9. Seasonal monsoon trough shifting north to foot-hills of Eastern Himalayas but causing only subdued monsoon activity - 12 to 15 August, 1967

9.1 In the previous section, we saw how the monsoon activity increased over north Assam and adjoining areas and sub-Himalayan West Bengal in association with the shift of the monsoon trough to the foot-hills of the Eastern Himalayas. Although rainfall invariably increases over these sub-divisions whenever the monsoon trough shifts north, there are a few occasions when the monsoon may not strengthen. The axis of the seasonal trough may shift towards the foot-hills in both cases; but there are some other synoptic features which are different and distinguish the two cases.

9.2 These will be highlighted in the course of the following discussion of a case of subdued monsoon activity which occurred in north Assam and sub-Himalayan West Bengal during the period 13-15 August, 1967.

9.3 A low pressure area which formed over Gangetic West Bengal and adjoining Bihar Plateau on 10 August 1967 moved slowly westnorthwestwards and lay on 12th over northeast Madhya Pradesh and southeast Uttar Pradesh (Fig. 9.1), where it became less marked. The axis of the monsoon trough was south of its normal position. At 900 m it was located across North Bay of Bengal and the extreme southern parts of Gangetic West Bengal, and thereafter westnorthwestwards to north Rajasthan (Fig. 9.2). In the lower troposphere, the Bay current which was entering south Assam and adjoining states and Gangetic West Bengal as a southerly stream, branched into two - one branch going over north Assam as a southwest/westerly current and the other over sub-Himalayan West Bengal and Bihar as an

east/southeasterly current. This type of difluent flow led to a difluent wind field over northwest Assam, sub-Himalayan West Bengal and adjoining Bihar Plains, where rainfall was scattered and mostly light. Monsoon was weak in West Bengal and south Assam and adjoining states on this day and normal over north Assam.

9.4 By the 13th morning the low pressure area moved westnorthwestwards to southwest Uttar Pradesh, and the eastern half of the monsoon trough shifted rapidly northwards (Fig. 9.3). Its axis at 900 m passed through central Uttar Pradesh, Bihar Plains, sub-Himalayan West Bengal and further eastwards along the foot-hills of the Himalayas (Fig. 9.4). As a result of the northward shift, the winds over south Assam and adjoining states, Gangetic West Bengal and Bihar Plateau changed to southwest from southeast/south. However, they were only light to moderate and the difluence in the wind field was less marked. Although the low had a southward tilt with height (towards the cold air), the monsoon trough to the east of 85°E showed no such tilt. The monsoon continued to be weak in West Bengal and was normal in Assam and adjacent states. In north Assam and adjoining areas rainfall became fairly widespread as against isolated on 12th, but the highest amount recorded was only 5 cm at Pasighat. Over sub-Himalayan West Bengal, it was scattered and the highest amount was also only 2 cm at Jalpaiguri.

9.5 The synoptic conditions over northeast India, continued to be the same on 14th as on the previous day, with the eastern end of the trough close to foot-hills over north Assam and adjoining areas and sub-Himalayan West Bengal. The lower tropospheric westerlies over northeast India were also weak (mostly 5-10 knots). There was considerable rise in surface pressure over the whole country and pressure departures were all positive, with lower values towards the foot of the Himalayas. With the northern position of the trough, there was a slight increase in rainfall over north Assam and adjoining areas and sub-Himalayan West Bengal; weather became dry over Gangetic West Bengal and only isolated rain occurred in south Assam. and adjoining states.

9.6 In the weak westerly wind field, a north-south trough developed over Gangetic West Bengal in the lower troposphere by 14th and became well-marked by the next morning (15th) extending into Northeast Bay (Fig. 9.5). The monsoon trough on the surface chart also shifted south to the North Bay, although in the upper air it remained close to the foot-hills of the Himalayas (Fig.9.6). Apparently due to the north-south trough, there was an increase in rainfall in Gangetic West Bengal (from dry weather to normal monsoon). Monsoon continued to be weak to normal in Assam and adjacent states and sub-Himalayan West Bengal. The highest amounts of rainfall recorded on this day were 7 cm at Pasighat and 5 cm at Balurghat.

9.7 The north-south trough intensified later and the situation changed completely which we will not discuss, as it does not have a direct bearing on the present discussion.

9.8 An examination of the extended charts shows a well-marked high over Mongolia on 14th with a ridge extending southwards upto southeast Tibet (Fig. 9.7). The 'high' moved slowly eastwards and the ridge continued to extend upto southeast Tibet till the 15th. In the upper air also, Tibet and adjoining areas were dominated by a 'high' during this period.

9.9 The satellite picture for 14th is given in Fig. 9.8; it shows two extra-tropical cloud systems over Central Asia, with an almost clear area in between (over Tibet, West and Central China and Mongolia). The cloudless area corresponds to the regime of the 'high'.

9.10 In the present case, the monsoon trough shifted north in the rear of a low pressure area moving westwards to West Uttar Pradesh from Gangetic West Bengal. As the monsoon trough shifted north, there was an increase in rainfall in sub-Himalayan West Bengal and north Assam and adjoining areas and a decrease in the south. However, the rainfall along the sub-montane districts

was mostly light to moderate with a few rather heavy falls. The usual heavy to very heavy rains, which are normally associated with the northward shift of the trough, were absent. As mentioned above, we note a significant feature to the north of India in the present case. The synoptic system to the north (over Tibet and China) was one of a pronounced anticyclone. The northward position of the monsoon trough in the lower troposphere was not accompanied by favourable middle and upper tropospheric conditions. This was responsible for the subdued monsoon activity along the foot-hills.

9.11 Comparing the present situation with the July 1967 case discussed in Sec. 8, when there was very heavy rain along the foot-hills in association with the northward shift of the axis of the monsoon trough, a number of contrasting features are noticed. These are indicated in Table VIII.

10. Eastern end of the Monsoon Trough shifting north in the rear of a Depression - 13 to 18 August,1969

10.1 On 13 August, 1969, a deep depression lay over the North Bay of Bengal with centre near 21°N and 89.5°E (Fig. 10.1). The associated cyclonic circulation extended to 500 mb with a slight southward tilt with height above 700 mb (towards the cold air side) (Fig. 10.2). Pressure changes suggested a westnorthwestward movement of the depression. Pressures were slightly rising over northeast India to the north of 25°N. Under the influence of the depression, the monsoon became active over Gangetic West Bengal (it was weak on the 11th and normal on the 12th); Sandheads reported 12 cm of rain on 13th. The upper winds over north Assam and sub-Himalayan West Bengal were weak northeast/easterlies (curving anticyclonically) in the lower troposphere. In the speed field also, there was anticyclonic shear over sub-Himalayan West Bengal and north Assam. Monsoon, therefore, remained weak over these sub-divisions. However, the winds over south Assam and adjoining states were southeasterly 25 knots, in the lower troposphere, being still within the grip of the depression. But the monsoon was weak there also, as the area was to the rear of the depression. By the same

TABLE - VIII

S.No.	Synoptic features	8-10 July 1967 (Sec. 8)	13-15 August 1967 (Sec. 9)
1.	Monsoon activity over north Assam and adjoining areas and sub-Himalayan West Bengal	Strong to vigorous	Weak to normal
2.	Maximum rainfall (in 24 hrs.)	15-40 cm	5-7 cm
3.	Surface pressure gradient over northeast India	Upto 6 mb/5 deg. lat.	1 mb/5 deg. lat.
4.	Lower tropospheric westerlies	40-50 kt.	5-15 kt.
5.	North-south trough in lower troposphere	Present	Appeared only towards the end.
6.	Features over and to north of eastern Tibet		
	i) Surface	Intense low	Extension of a well-marked high from Mangolia to southeastern Tibet.
	ii) Upper troposphere	Large amplitude middle latitude westerly trough extending to northeast India	Prominent high.
7.	Mean Tephigrams of Gauhati (Fig. 9.9)	Higher moisture content at all the levels in the lower and mid-troposphere, compared to August 67 case.	Slightly higher temperatures in the lower troposphere, compared to July 1967 case.

evening, the winds over north Assam began to veer towards east/southeast.

10.2 By the 14th morning, the deep depression crossed coast and was centred about 100 km westnorthwest of Balasore. While pressures were falling briskly in the western sector of the depression, there was a marked rise (4-6 mb) in the east, particularly over Bangla Desh, Assam and adjacent states. As the depression moved westnorthwest, rainfall increased in Orissa and decreased over Gangetic West Bengal . There were no heavy falls in Gangetic West Bengal where monsoon was normal. The change in the wind pattern over Assam and adjacent states which started by 13th evening continued further. The replacement of the previous anticyclonic northeasterly stream (in the lower and middle troposphere) over north Assam by a cyclonic southeasterly flow during the period of 24 hours. brought about a sudden increase of rainfall over that area; widespread rain with a few heavy falls of 7-9 cm was reported and the monsoon became strong. The area of heavy rain was confined to the eastern parts of north Assam and adjoining areas where the wind shift was marked during the preceding 12 hours. In south Assam and adjoining areas also, there was an increase in monsoon activity (from weak to normal). The monsoon, however, continued to be weak in sub-Himalayan West Bengal.

10.3 As mentioned earlier, winds over Assam and adjacent states had veered to southeasterlies by the 14th morning. The veering continued during the day and by the evening (of 14th), the winds over the whole of Assam and adjacent states became south/southwesterly indicating that the eastern end of the axis of the monsoon trough had shifted to the foot hills over north Assam and adjoining areas in the upper air, although on the surface chart it was still not possible to place the eastern end of the trough over north Assam. In this connection, it may be mentioned that pressures over West Bengal, Bangla Desh, Assam and adjacent states were rapidly rising and were not favourable for a northward shift of the monsoon trough.

10.4 The deep depression moved northwestwards and was centred near Sidhi on the 15th morning (Fig. 10.3). The pressure rise immediately behind the deep depression was again marked and was about 4-8 mb over Gangetic West Bengal. Pressure departures from normal were positive over the whole of northeast India and of the order of 4-5 mb. The eastern portion of the monsoon trough was now passing through Gangetic West Bengal to northeast Assam. The southerlies over Gangetic West Bengal and south Assam and adjoining areas in the lower troposphere were relatively stronger than the southwesterlies over north Assam (Fig. 10.4). But this convergence in the wind field due to downstream weakening of the wind was counter balanced by the increasing anticyclonic curvature. Presumably as a result of this, the monsoon activity decreased in north Assam and adjoining areas and it was only normal. It was also normal in sub-Himalayan West Bengal, south Assam and adjoining areas. With a further westward movement of the deep depression, the rainfall continued to decrease over Gangetic West Bengal.

10.5 By the 16th, the depression moved away to northwest Madhya Pradesh and the eastern half of the monsoon trough shifted well to the north (which could be noticed in the surface chart as well as in the upper wind charts)(Figs. 10.5 and 10.6). Its axis at 0.9 km passed across Bihar Plains to the foot hills of the Himalayas in north Assam. The southerlies over Gangetic West Bengal and south Assam and adjoining areas veered and southwest/west winds prevailed over the entire northeast India in the lower and middle troposphere. The monsoon was normal over the area outside Gangetic West Bengal where it became weak.

10.6 The eastern half of the monsoon trough remained close to the foot-hills on 17th (Fig. 10.7). There was also a strengthening of winds over northeast India south of Lat. 25°N leading to greater cyclonic shear to the north of Lat. 25°N.(Fig. 10.8). These resulted in the monsoon becoming vigorous over north Assam and adjoining areas and strong over sub-Himalayan West Bengal; Pasighat recorded 23 cm of rain and Jalpaiguri 14 cm. It was only normal in

Gangetic West Bengal, south Assam and adjoining areas.

10.7 By the 18th morning the eastern end of the axis of the seasonal trough began moving southwards (Fig. 10.9). It was roughly along 25°N over northeast India, where it persisted till the 19th. The shift of the axis of the monsoon trough to the Eastern Himalayas was shortlived; hardly after two days it again moved south on account of a land low over Bangla Desh and adjoining Gangetic West Bengal. With the southward shift of the axis, there was a decrease in rainfall towards the foot-hills of the Eastern Himalayas and an increase in the south. Rainfall considerably increased in south Assam and adjoining areas and the monsoon became strong to vigorous on the 18th and 19th. In Gangetic West Bengal it became strong on the 19th. Though rainfall decreased, still the monsoon continued active in sub-Himalayan West Bengal, north Assam and adjoining areas on 18th and 19th. By 20th monsoon became weak to normal in sub-Himalayan West Bengal and Assam and adjacent states.

10.8 The synoptic and upper air conditions to the north over Tibet and China are also of interest in relation to the monsoon activity over Assam and adjacent states and sub-Himalayan West Bengal. During this period (13th-18th) an extra-tropical low with its associated frontal system moved eastwards to the north of Tibet. A trough in the middle latitude westerlies moved (north of 40°N) to central China and it extended southwards to extreme northeast Tibet by 15th evening and further south to north Assam and adjacent areas and adjoining north Burma by 16th (Fig. 10.10). The southern end of the trough persisted over these areas for the next two days, while the northern portion moved eastwards. This trough apparently contributed to the strong/vigorous monsoon activity over Assam and adjacent states on 17th and 18th, when very heavy falls upto 23 cm occurred. It is of interest to note that though the eastern end of the axis of the monsoon trough shifted to foot-hills even by 16th morning, heavy falls commenced only when the effect of the westerly trough was also superposed. Besides, the rain was heavier in the eastern portions of Assam and adjoining

areas compared to west Assam and sub-Himalayan West Bengal on 17th and 18th.

10.9 The satellite pictures for the period show the movement of the cloud belt associated with the extratropical system and its extension to Assam and adjacent states on the 16th, when it joined up with the clouds associated with the monsoon trough. After the westerly systems moved away, the cloudiness due to the monsoon trough alone was present. This moved southwards and extended into Northeast Bay and Arakan coast as seen from the Nimbus pictures for 18th (Fig. 10.11).

10.10 The salient features of this sequence may be summarised as follows:-

i) Prior to the formation of a depression over the North Bay, the monsoon trough shifted south and upper winds became easterly over West Bengal and Assam and adjacent states. As the system intensified into a deep depression on 13th, the easterlies became more organised and strengthened. This led to an improvement in weather over north Assam and adjoining areas and sub-Himalayan West Bengal where the monsoon became weak. Under the influence of the deep depression, the monsoon was strong in Gangetic West Bengal for one day (13th), although there was substantial rainfall on the following day also.

ii) As the deep depression moved inland on 14th, the winds over Assam and adjacent states veered steadily to south/southwest and ultimately west. The rainfall also increased progressively over sub-Himalayan West Bengal and Assam and adjacent states, whereas it decreased over Gangetic West Bengal. The northward movement of the monsoon trough was first noticed in the upper air above 850 mb; subsequently, it was clearly noticed in the lower levels and on the surface chart. With the northward movement of the monsoon trough, there was a northward displacement of the area of heavy clouding on 13th and 14th (as seen from the APT pictures).

iii) As the depression moved away northwestwards, the eastern part of the monsoon trough moved north close to the foot-hills by 16th. With this, the

the monsoon activity over sub-Himalayan West Bengal, north Assam and adjoining areas increased.

iv) During this period, a trough in the middle latitude westerlies extended from central China to northeast Assam, and contributed to the enhancement of the monsoon activity over Assam and adjacent states with heavy to very heavy falls upto 23 cm.

11. Movement of a North-South Trough across Northeast India causing Strong Monsoon Activity over Gangetic West Bengal - 23 to 27 August, 1966

11.1 In Section 6.2 of FMU Rep. No.III-3.2 the case of a trough in the monsoon westerlies during a 'break' monsoon period, which caused substantial rainfall over Orissa, was discussed. A brief reference to the same system, is made here because it also affected West Bengal and Assam and adjoining states.

11.2 'Break' monsoon conditions were prevailing over the country during the period 23-27 August 1966. With the monsoon trough lying close to the foot of the Himalayas, the winds in the lower and middle troposphere were mainly southwest to west and were 20-30 kt strong over northeast India on the 23rd (Figs.11.1 and 11.2). A north-south oriented trough in the monsoon westerlies was seen over the extreme eastern parts of Madhya Pradesh and neighbourhood. This extended upto 500 mb. Note the fall of pressure of 2-3 mb over the area right upto Bangla Desh. An examination of the extended charts shows a deep trough in the middle latitude westerlies extending into the Indian region across Tibet at 500 and 300 mb (Fig. 11.3). The monsoon was strong to vigorous over sub-Himalayan West Bengal and Assam and adjacent states, whereas it was weak over Gangetic West Bengal.

11.3 The north-south trough moved eastwards to West Bengal on 24th (Fig.11.4). The 24 hr. pressure changes are significant in relation to the movement of the trough. There was a rise of pressure by 2-3 mb in the rear of the trough over Bihar and east Uttar Pradesh and a slight fall ahead of it over Assam and

adjacent states. As the trough moved to West Bengal, rainfall increased over Gangetic West Bengal and the monsoon became strong there; many stations reported 2-4 cm of rain. Over the remaining sub-divisions, the monsoon continued to be generally strong/vigorous.

11.4 During the next 24 hours, the north-south trough moved further east to Bangla Desh. By 25th morning, its axis in the lower troposphere was roughly along 90°E. The trough in the middle latitude westerlies moved away eastwards beyond 100°E (although the north-south trough over the Indian region persisted) (Fig. 11.5). To the rear of the north-south trough, rainfall decreased abruptly over Gangetic West Bengal where it became isolated (~~refer to 200 mb level chart of Fig. 11.5~~). Rainfall also decreased over sub-Himalayan West Bengal, though it was still vigorous; but in the areas ahead of the trough, rainfall continued. Thus monsoon was generally active over Assam and adjacent states.

11.5 On 26th the north-south trough moved further eastwards to Assam and adjacent states and the adjoining Burma (Fig. 11.6). It was seen only below 700 mb. In the absence of the influence of the middle latitude westerly trough, rainfall decreased considerably over Assam and adjoining areas where the monsoon became normal. In the other sub-divisions also the monsoon activity decreased. A noteworthy development during the next 24 hours was the extension of the north-south trough into the northeast and adjoining East Central Bay.

11.6 Although the monsoon trough continued to be near the foot-hills on 27th, the trough in the Bay became more marked and rainfall decreased further over all the sub-divisions except sub-Himalayan West Bengal.

11.7 With further development in the Bay, the north-south trough could not be identified.

The chief points to be noted in this case are:-

i) Typical 'break' monsoon conditions coupled with the presence of a middle latitude westerly trough, extending into the northeastern parts of the country in the middle and upper troposphere, caused strong to vigorous monsoon condition over north Assam and adjoining areas and sub-Himalayan West Bengal upto 25th.

ii) The north-south oriented trough in the monsoon westerlies in the lower and middle troposphere, that lay over extreme East Madhya Pradesh on 23rd, moved eastwards to Assam and adjacent states by the 26th. The belt of significant rainfall also moved progressively eastward along with this trough, resulting in strong monsoon conditions over Gangetic West Bengal for a day (24th).

iii) As the middle latitude westerly trough as well as the north-south trough moved away eastwards, there was marked decrease of rainfall over northeast India, even though the monsoon trough remained near the foot-hills.

iv) The monsoon westerlies which were about 20-30 kt in the earlier part of the period decreased to 5-10 kt later. With this, a general weakening of the monsoon set in over northeast India.

v) In the final stages, the north-south trough extended into the Bay. In some cases, it has been noticed that an extension of eastward moving troughs into the Bay often results in the formation of a low or depression over that area.

12. Weak Monsoon

12.1 Weak monsoon conditions prevail over West Bengal and Assam and adjacent states when none of the synoptic systems discussed in sub-Sec. 3.1 affects these sub-divisions. As seen from Table V, the monsoon is weak over Assam and adjacent states on about a third of the days and on nearly half the number of days in West Bengal. In Assam and adjacent states, weak monsoon conditions occur on slightly less number of days in June and July than in the other months. They are less in July and August in Gangetic West Bengal and in July in sub-Himalayan West Bengal.

12.2 Two common synoptic situations associated with weak monsoon conditions over West Bengal and Assam and adjacent states are:-

i) When a depression or low is to the south of 20°N over Bay or over south Orissa and strong easterlies prevail over northeast India, West Bengal and Assam and adjacent states may have weak monsoon. It the depression is over north Orissa or North Bay north of 20°N, weak monsoon may be confined to Assam and adjacent states and northern districts of West Bengal only.

ii) When the axis of the seasonal trough has moved to the foot-hills and no north-south oriented trough or a trough in middle latitude westerlies extending into northeast India is present ~~in the monsoon westerlies~~, Gangetic West Bengal and south Assam and adjoining states may have weak monsoon, while monsoon is strong to vigorous in sub-Himalayan West Bengal, north Assam and adjoining areas.

12.3 Instances of weak monsoon conditions have already been referred to, while discussing *case histories* in Sec. 4 to 11. A few instances of weak monsoon conditions, to which we have made reference, are listed in Table IX.

13. Conclusions

13.1 In this report we have dealt with the synoptic situations over the five meteorological sub-divisions (i) Arunachal Pradesh, (ii) Assam and Meghalaya, (iii) Nagaland, Manipur, Mizoram and Tripura, (iv) sub-Himalayan West Bengal and (v) Gangetic West Bengal during the southwest monsoon. From the point of view of climatology and synoptic meteorology, Arunachal Pradesh and north Assam and sub-Himalayan West Bengal may be considered to be very similar to each other.

13.2 Orography plays an important role in sub-Himalayan West Bengal and Assam and adjacent states. It produces large variations in weather over short distances and also contributes to excessive rainfall on the windward side of the mountain ranges. Khasi-Jaintia hills is one of the wettest places in the whole world. The average annual rainfall at some places in this area is over 1000 cm. Rainfall

TABLE - IX

Instances of Weak Monsoon Conditions

S.No.	Date	Rainfall distribution	Synoptic Situation	Reference
1	25-27 July,1965	Monsoon weak over Assam and adjacent states and sub-Himalayan West Bengal and normal/strong over Gangetic West Bengal	A low pressure area formed over North Bay of Bengal on 25th, intensified progressively into a deep depression by 27th and crossed coast the same evening. Later it moved away northwestwards. Weak monsoon conditions prevailed over areas well to the north of the depression, in the field of the easterlies.	Sec. 4
2	2-6 Sept.1970	Weak monsoon with almost dry weather in north Assam and adjoining areas and sub-Himalayan West Bengal; strong to vigorous monsoon in Gangetic West Bengal	A deep land depression forming on 2nd over Gangetic West Bengal moved away westnorthwestwards; but the axis of the monsoon trough continued to be in a southerly position over coastal West Bengal and northeast Bay. Sub-Himalayan West Bengal, Assam and adjacent states being on the northern sector of the depression and to the north of the monsoon trough later, had weak monsoon.	Sec. 5
3	6-7 July,1967	Monsoon weak over Gangetic West Bengal, but normal or active over the other sub-divisions	Typical 'break' monsoon conditions.	Sec. 8
4	16-18 Aug.1969	Monsoon weak over Gangetic West Bengal and normal to vigorous in the other sub-divisions	As the deep depression moved away northwestwards, the eastern half of the monsoon trough shifted to the foot-hills and westerlies strengthened south of 25°N.	Sec. 10
5	26 Aug. 1966	Monsoon weak over Gangetic West Bengal; but normal or strong over the other sub-divisions.	Continued 'break' monsoon conditions with a north-south trough having moved eastwards to Assam and adjacent states by 26th. A middle latitude westerly trough also had moved away eastwards.	Sec. 11

of the order of 50 to 100 cm in 24 hours has occurred in sub-Himalayan West Bengal and Assam and adjacent states. Weak monsoon conditions prevail in Assam and adjacent states on only 25%-30% of the days, in the months of June and July.

13.3 Thunderstorm is a very significant feature of weather over West Bengal and Assam and adjacent states during the monsoon months. Rainfall is accompanied by thunder on almost half the number of days. High moisture content in the atmosphere is another feature of West Bengal and Assam and adjacent states. Even on weak monsoon days, the humidity in the lowest levels (800 mb and below) is high.

13.4 The most common synoptic feature causing strong to vigorous monsoon in north Assam and adjoining areas and sub-Himalayan West Bengal is the presence of the seasonal monsoon trough over these sub-divisions or close to the foot-hills. The activity is further enhanced when simultaneously a trough in mid-latitude westerlies (in the mid or upper troposphere) or a north-south oriented trough in monsoon westerlies (in lower or mid-troposphere) affects the area. The monsoon trough causes rainfall in Gangetic West Bengal and south Assam and adjoining states also, particularly when it oscillates north-south across these sub-divisions.

13.5 A north-south oriented trough in the monsoon westerlies is a significant synoptic situation leading to increased monsoon activity in Gangetic West Bengal, south Assam and adjoining areas. These troughs moving from west to east, sometimes extend into north Bay, leading to the formation of depressions.

13.6 A monsoon depression generally affects only Gangetic West Bengal, especially the southern districts. Over the remaining parts of Gangetic West Bengal and in Assam and adjacent states, weather improves when a depression is present over north Bay or Orissa. Monsoon activity in Gangetic West Bengal (as a whole) is usually normal when the depression is over north Bay or when over north Orissa. Only when the depression is over Gangetic West Bengal or Bangla

Desh, monsoon becomes strong in the whole of Gangetic West Bengal. South Assam and adjoining areas may sometimes get heavier rainfall (usually normal monsoon) when the depression is over north Bay to the east of 87°E or over Gangetic West Bengal or Bangla Desh. Though heavy rainfall is usually confined to the south-west sector of a monsoon depression, in the case of Gangetic West Bengal, significant rainfall occurs along coastal West Bengal in the rear of the depression also (particularly deep depressions).

13.7 Low pressure areas form over north Bay as well as over Gangetic West Bengal and Bangla Desh. Land lows are more common than land depressions. They (land lows) cause active or normal monsoon activity (in about equal number of occasions) in Gangetic West Bengal and to a less extent in south Assam and adjoining areas.

13.8 Troughs in the middle latitude westerlies in the mid and upper troposphere have a great influence on monsoon activity over northeast India. These troughs have been noticed not only on occasions of typical 'breaks' but also on other occasions. Sometimes, such troughs extending well south, cause monsoon activity even in Gangetic West Bengal. The influence of the westerly troughs over the upper tropospheric easterlies over Gangetic West Bengal and north Bay by way of inducing troughs in upper easterlies, or a cyclonic circulation in the mid-troposphere over north Bay, has also been noticed. These, in their turn, may result in the formation of a low or a depression over north Bay or Gangetic West Bengal.

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DIAGRAMS

FIG. 1·1 RELIEF MAP

OF

WEST BENGAL & ASSAM & ADJACENT STATES

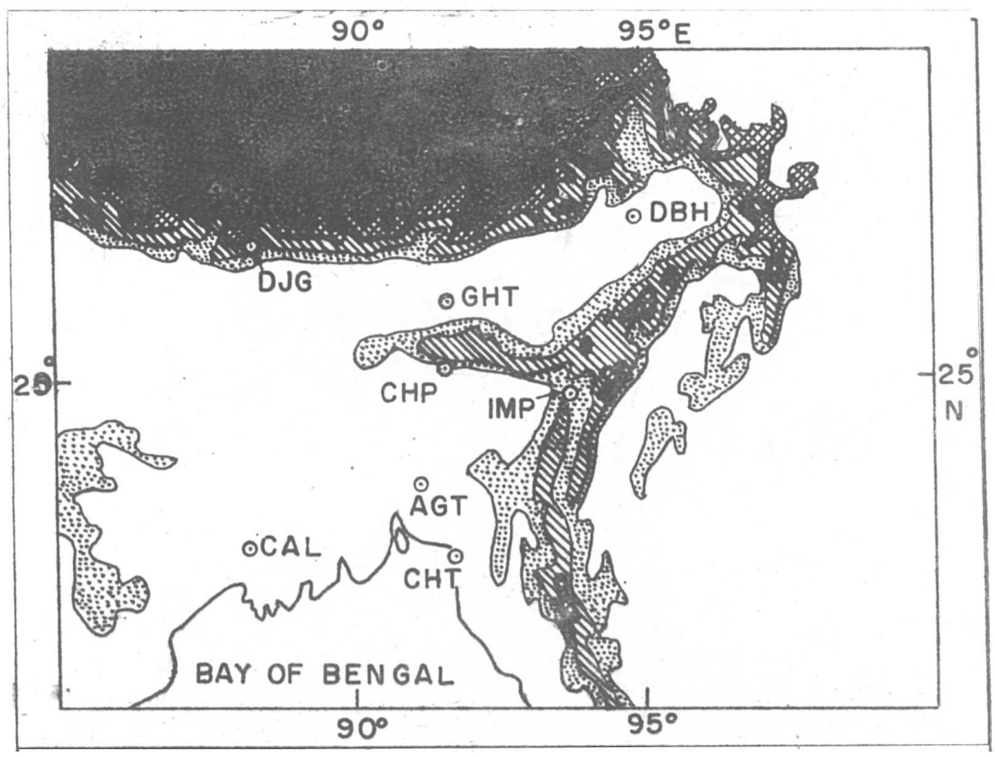
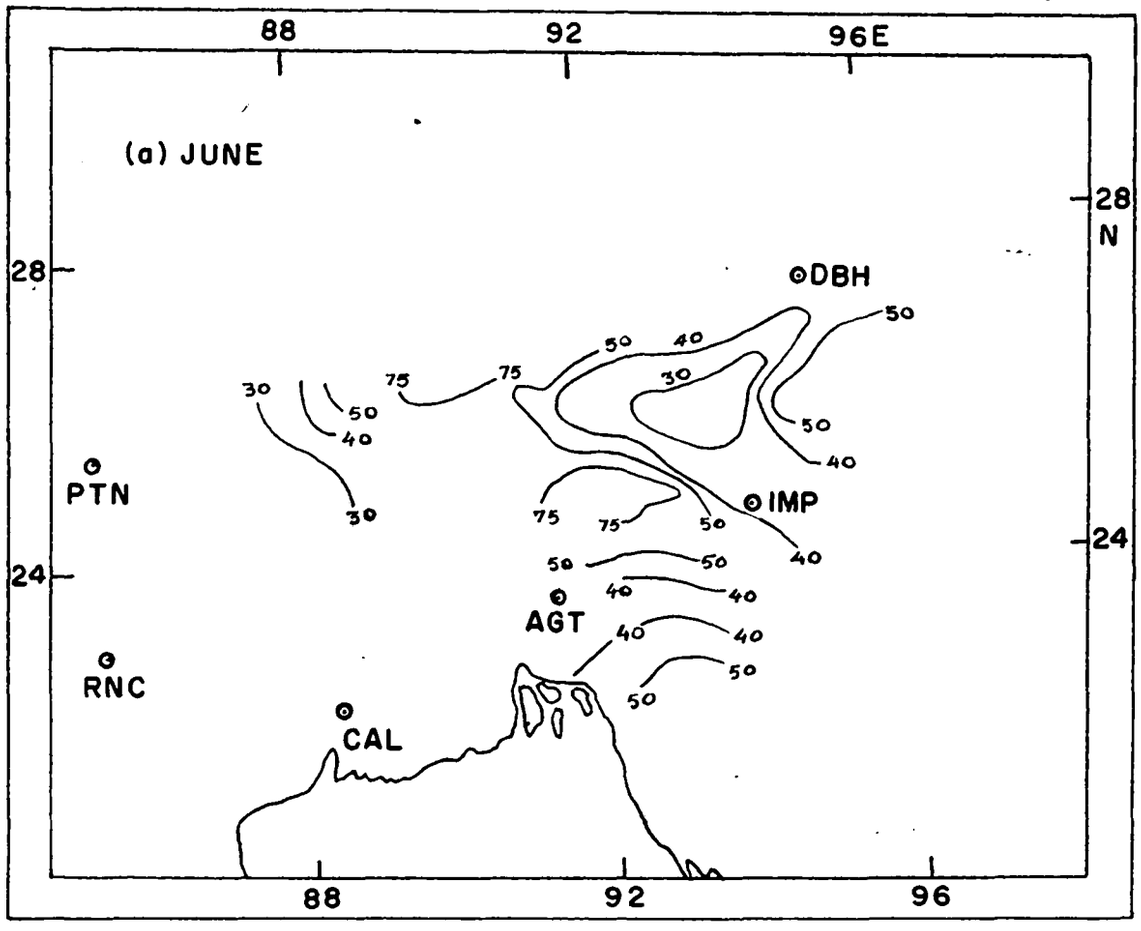


FIG. 2·1 MONTHLY MEAN RAINFALL (cm) OVER WEST BENGAL AND ASSAM AND ADJACENT STATES



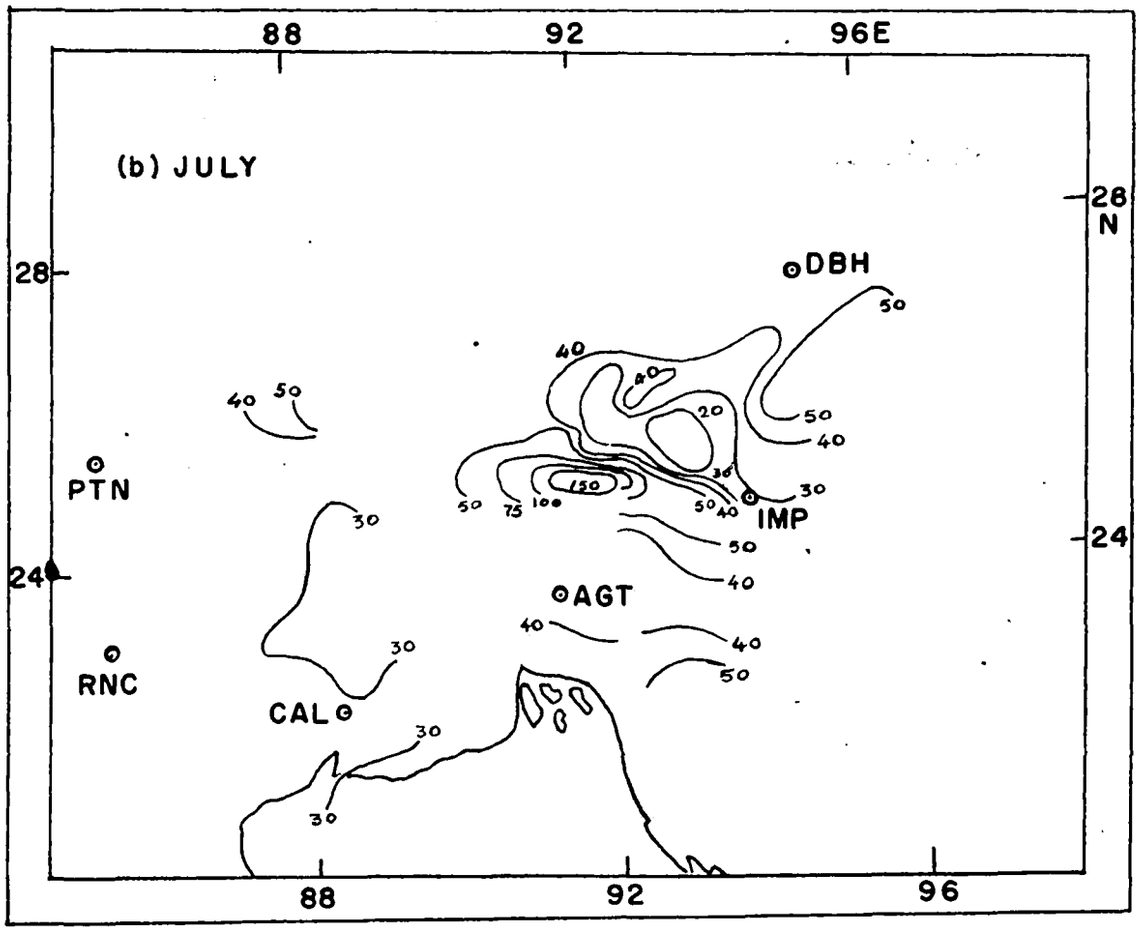
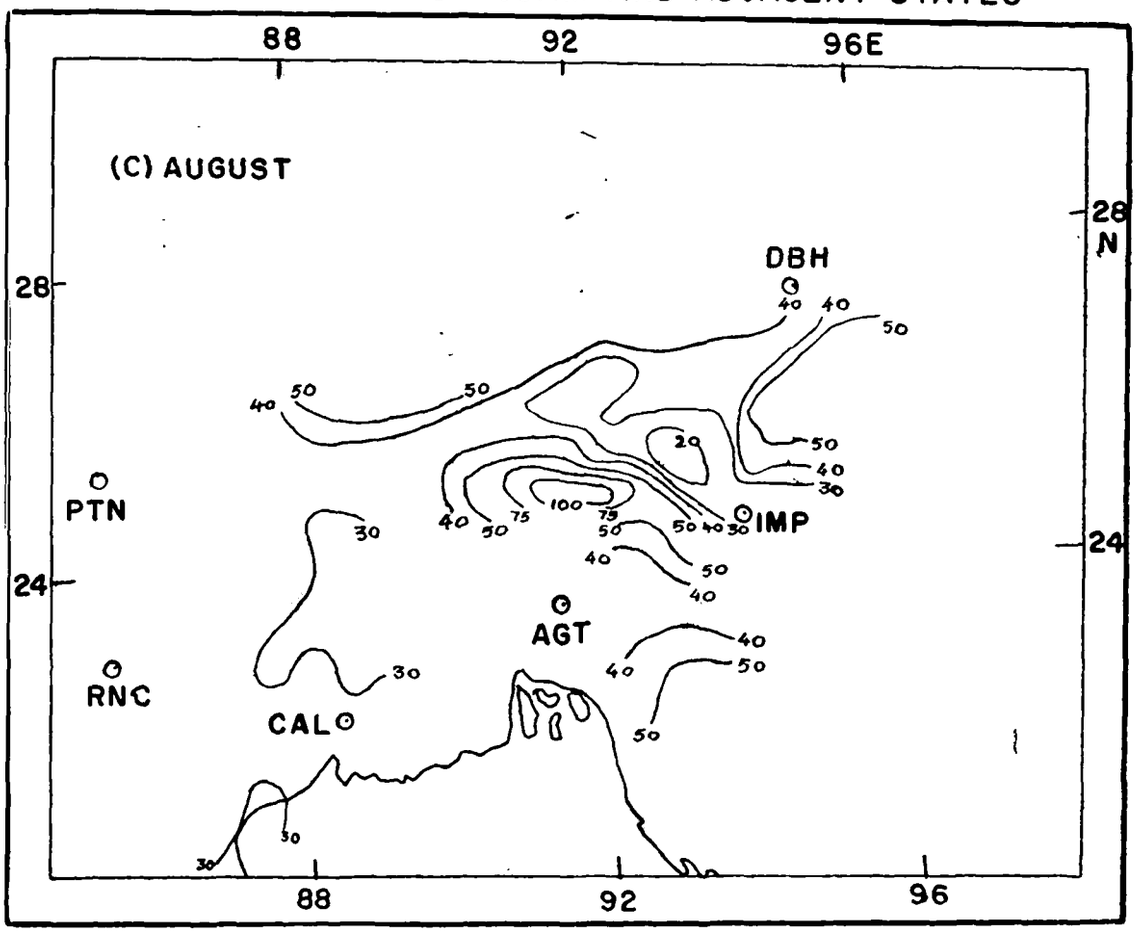


FIG. 2·1 MONTHLY MEAN RAINFALL (cm) OVER WEST BENGAL AND ASSAM AND ADJACENT STATES



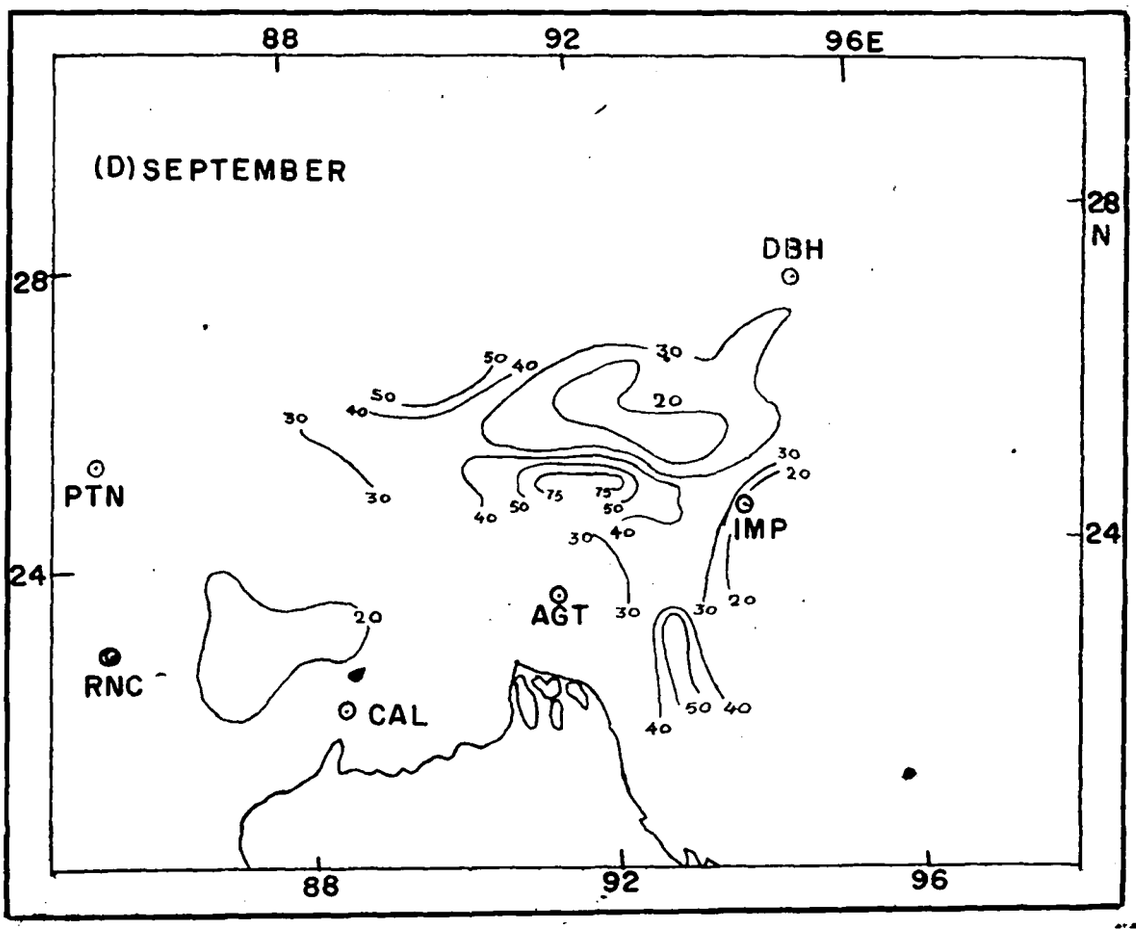


FIG.2·2 VERTICAL PROFILE OF MONTHLY MEAN UPPER WINDS (12GMT)

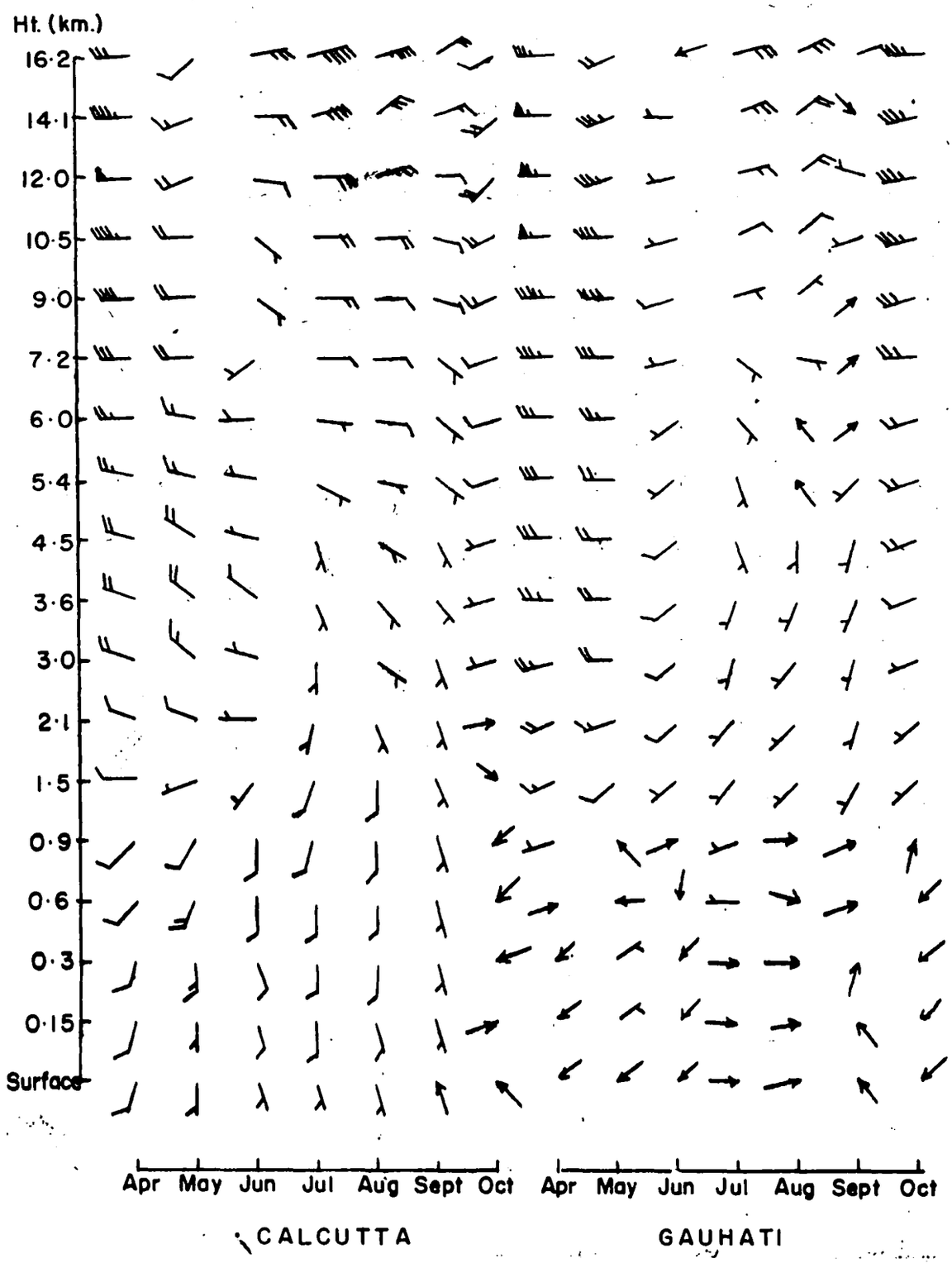


FIG. 2·3 (a) MEAN TEPHIGRAMS OF CALCUTTA (00 GMT)

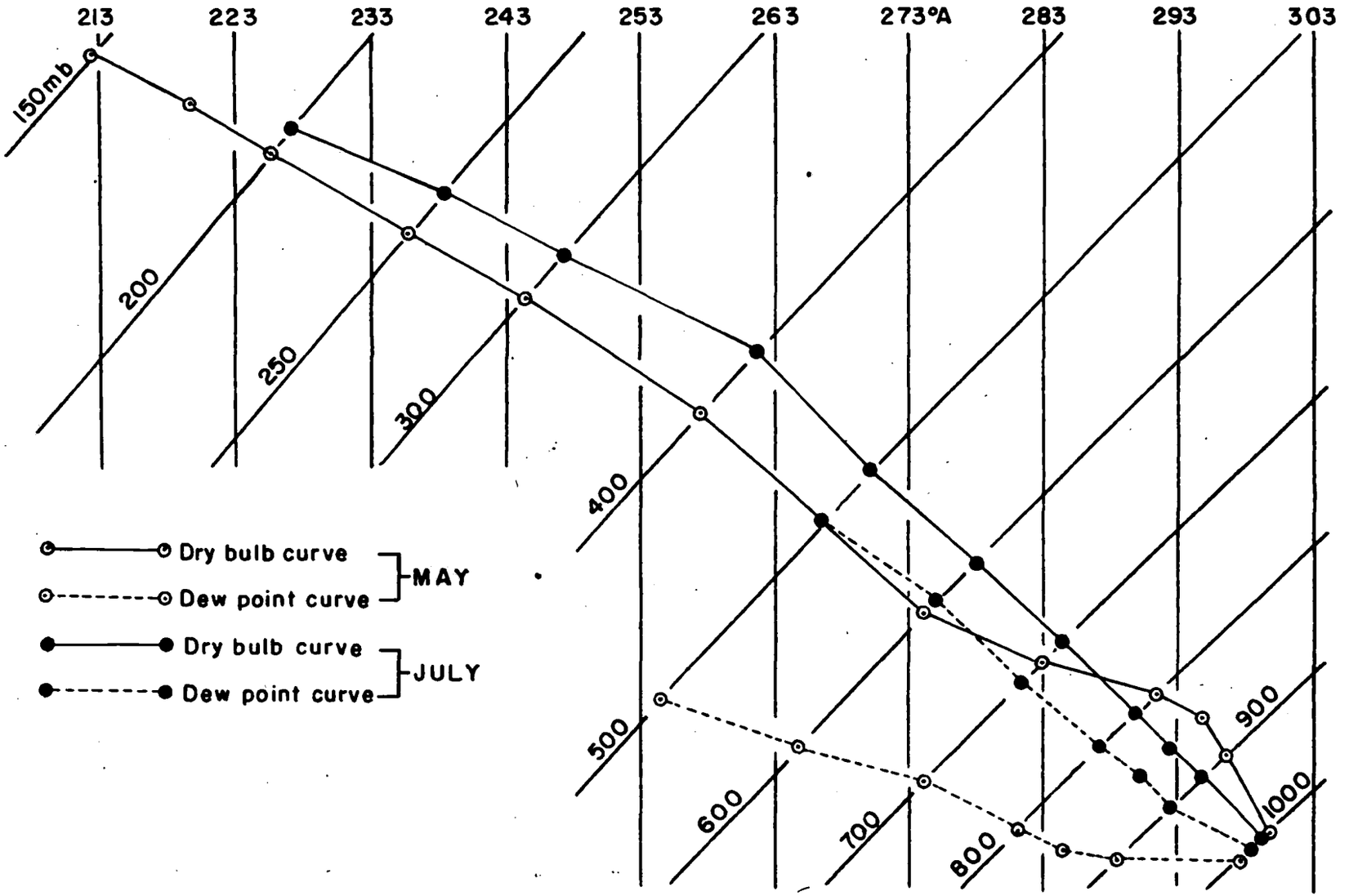


FIG. 2·3 (b) MEAN TEPHIGRAMS OF GAUHATI (00 GMT)

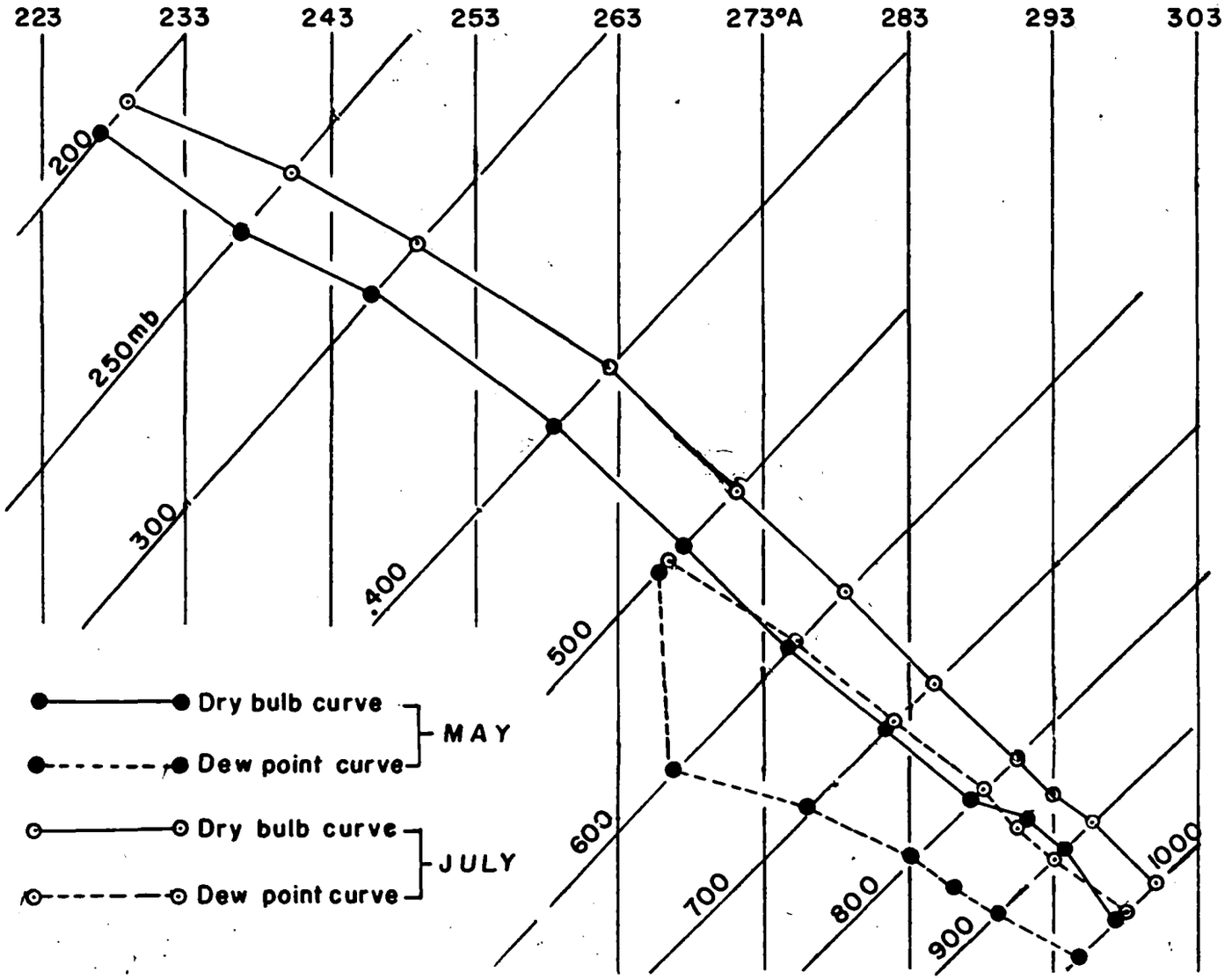


FIG. 2·4 (a) MEAN TEPHIGRAMS OF CALCUTTA (00GMT) (JUL. AND AUG.: 68-69)

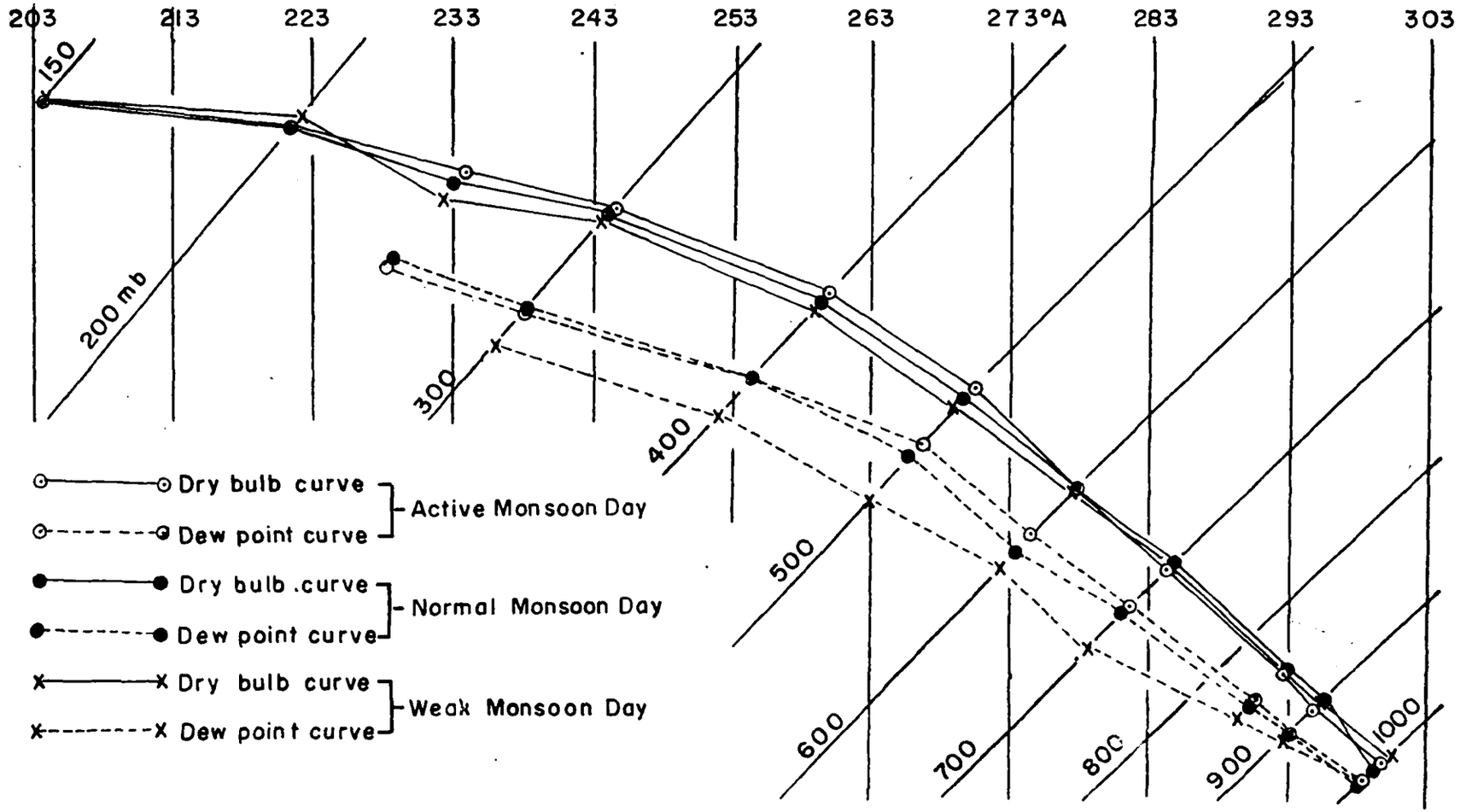


FIG. 2·4 (b) MEAN TEPHIGRAMS FOR GAUHATI (JUL. AND AUG. : 68 - 69)

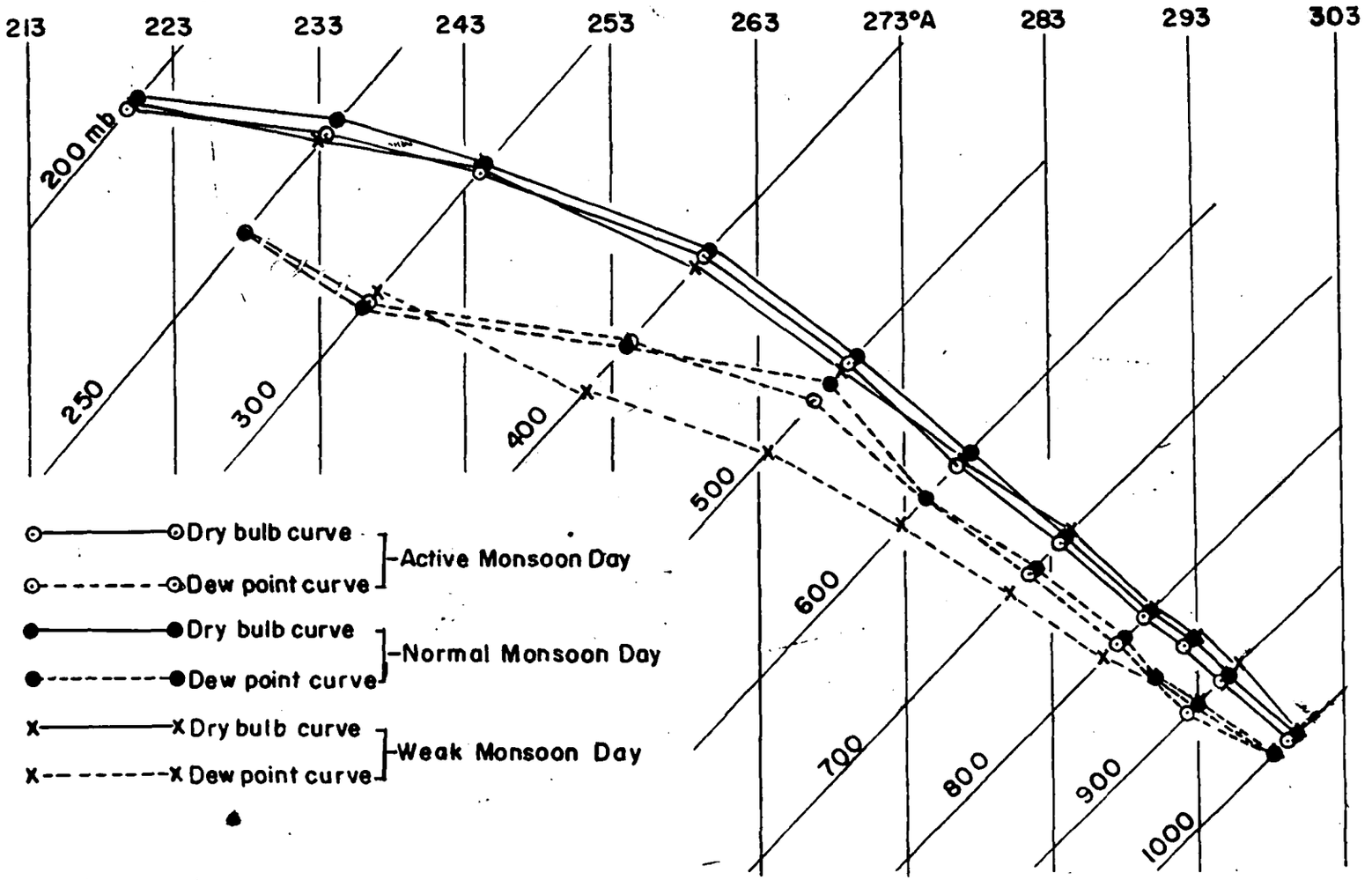


FIG. 2·5(a) TYPICAL TEPHIGRAMS OF CALCUTTA (00GMT)

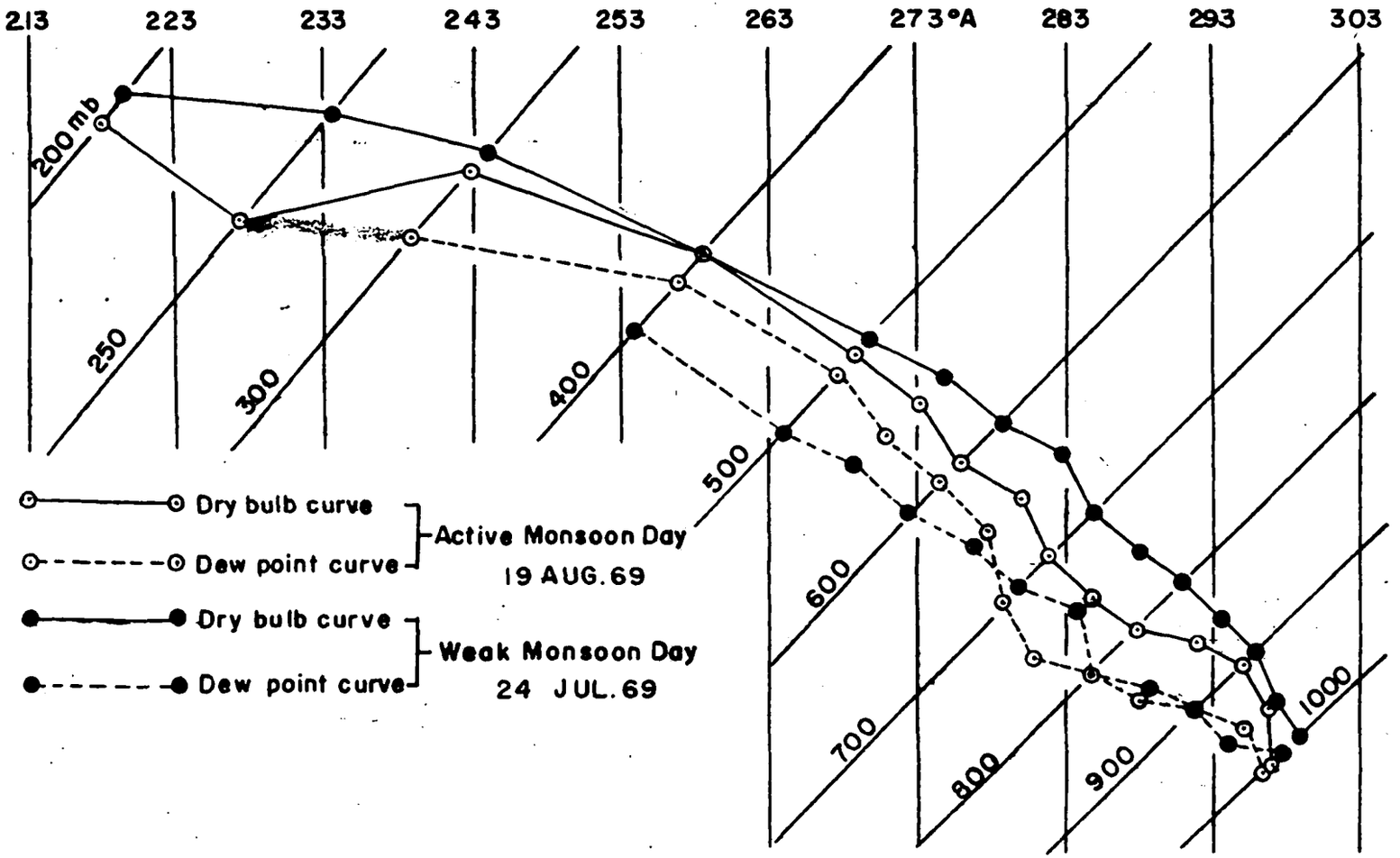


FIG. 2·5 (b) TYPICAL TEPHIGRAMS OF GAUHATI

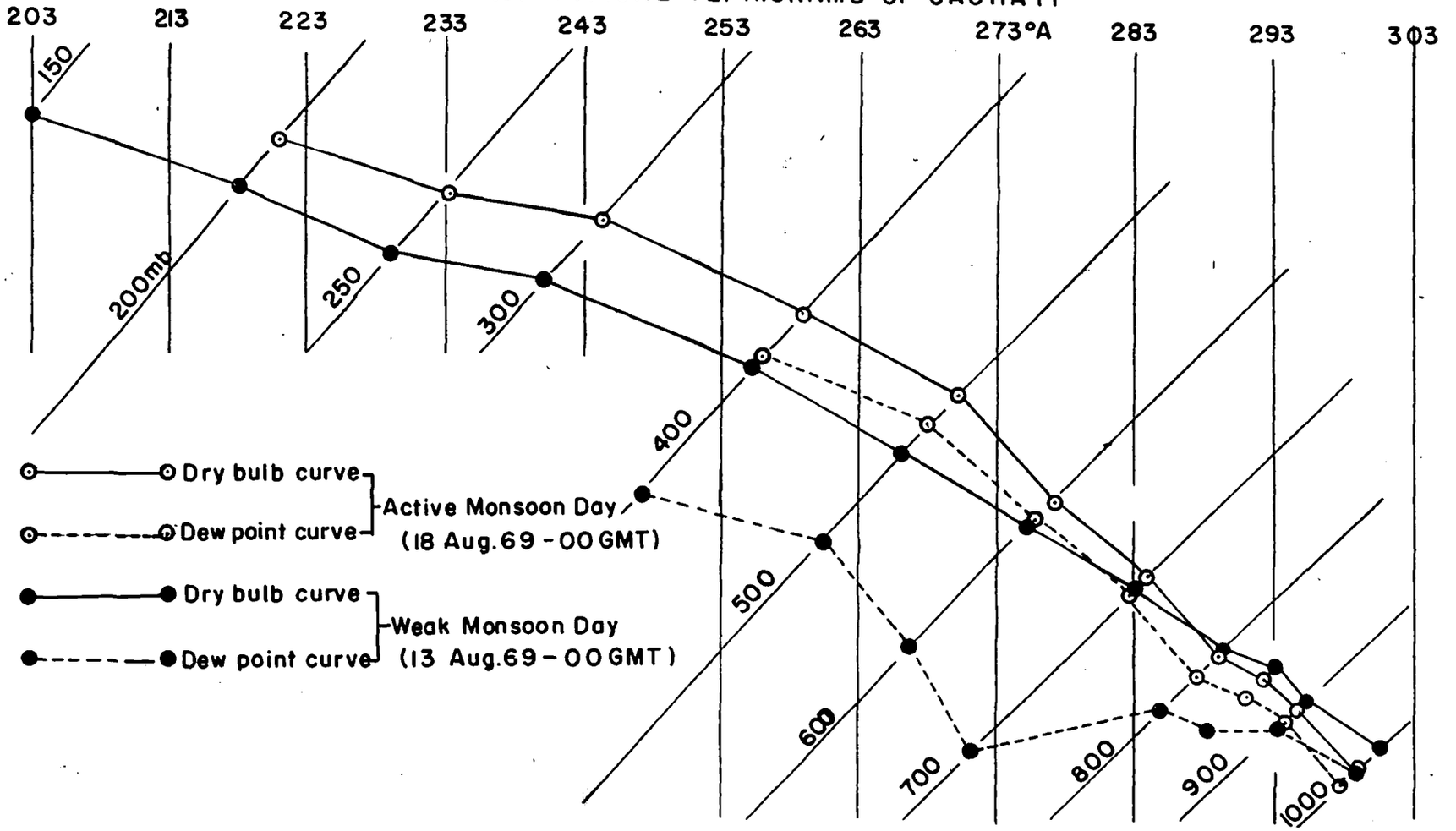


FIG. 3·1 AVERAGE NUMBER OF DEPRESSION CENTRES IN EACH DEGREE SQUARE (based on data of 1891 - 1969)

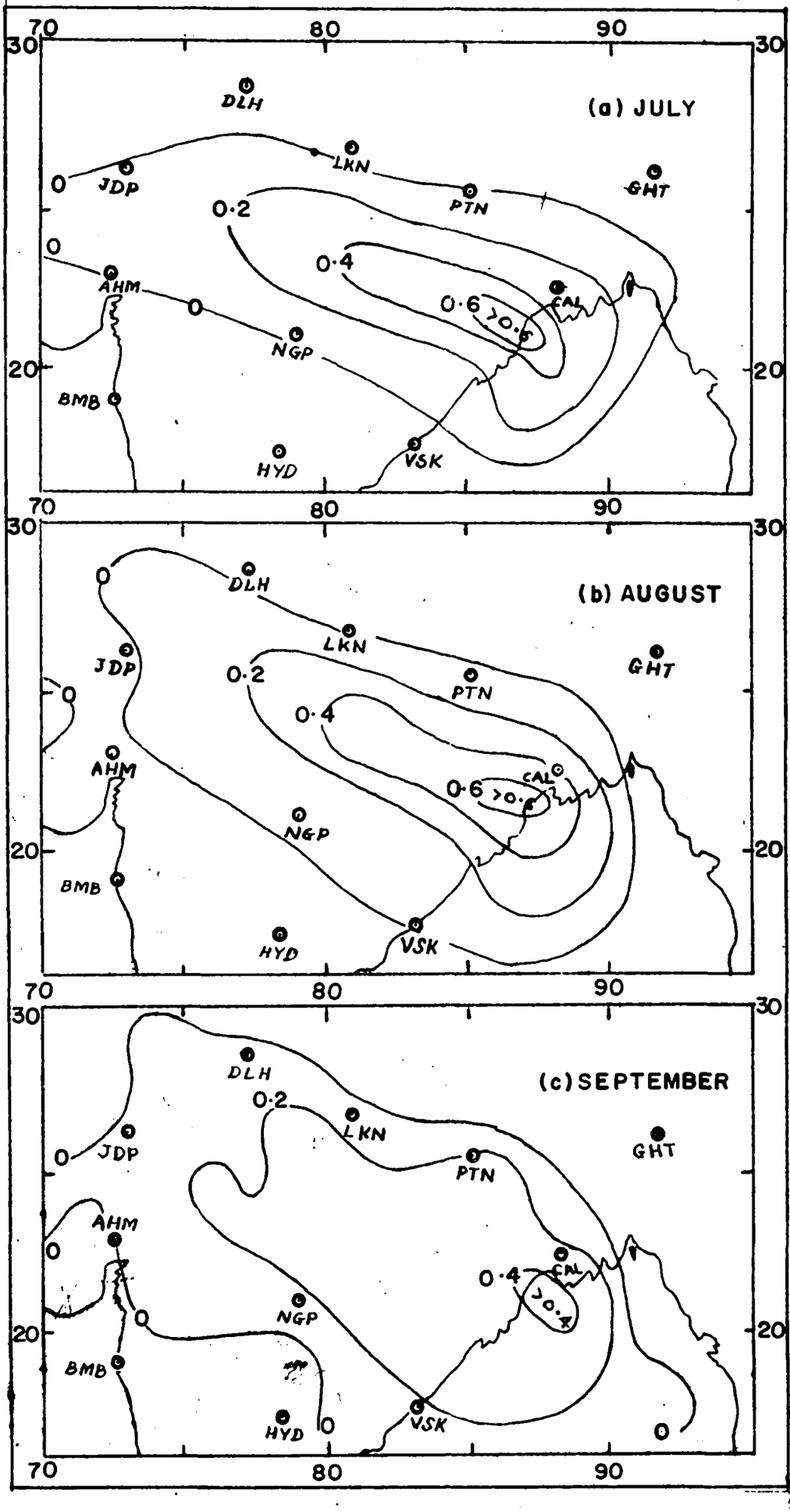


FIG. 3·2 UPPER AIR CHARTS 00GMT

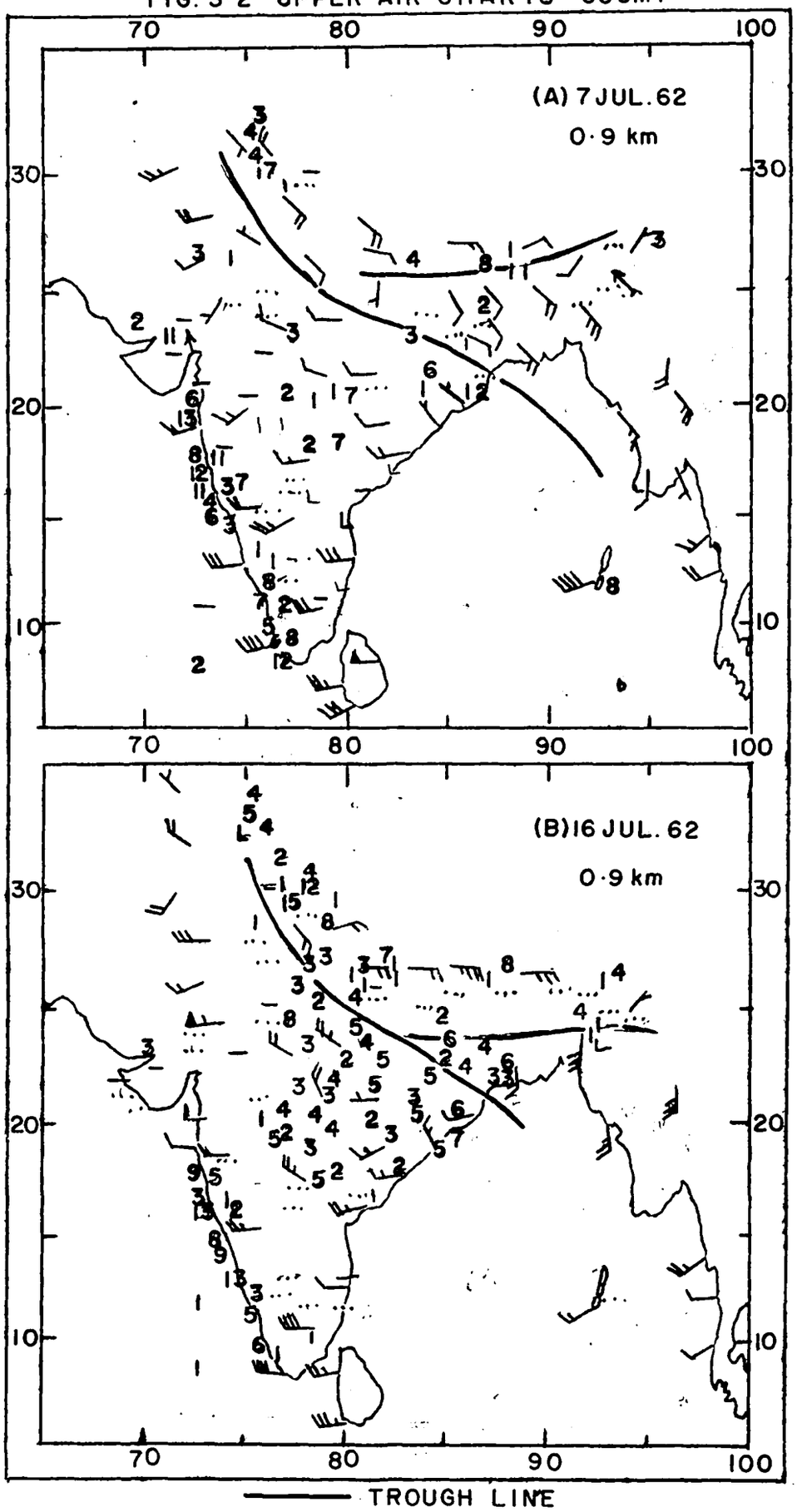


FIG. 4·1 SYNOPTIC CHARTS 0300 GMT 26 JUL. 65

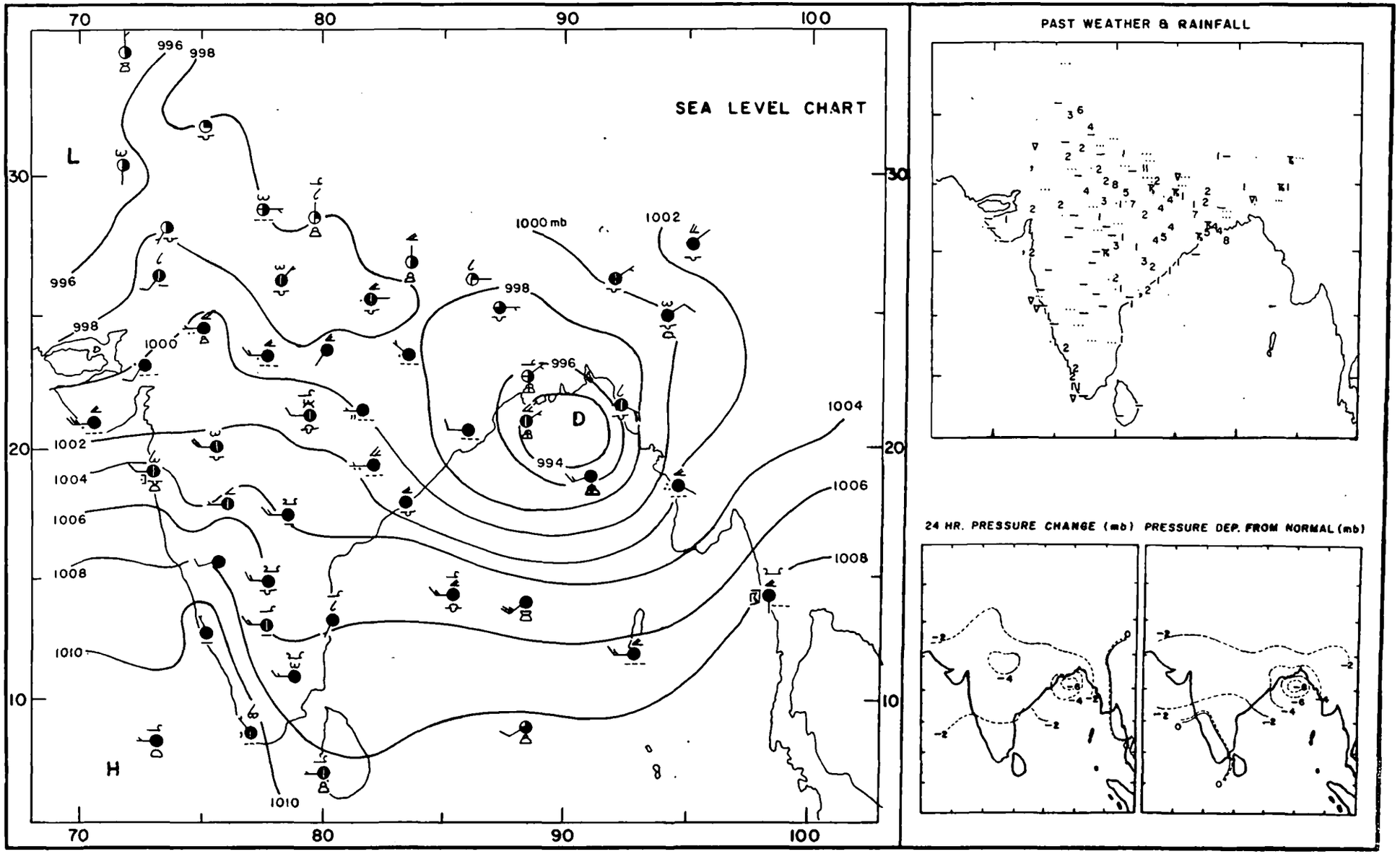
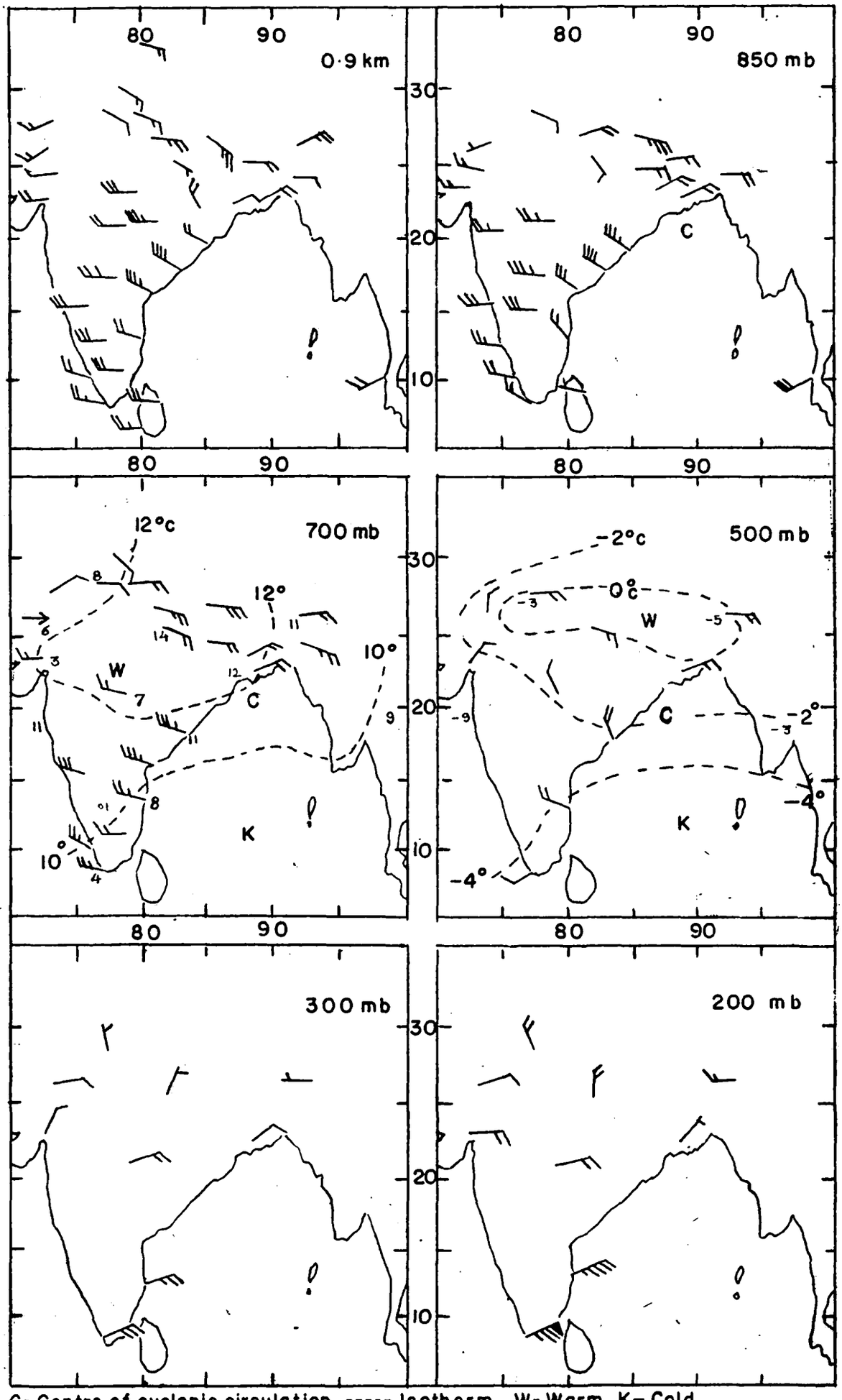


FIG. 4·2 UPPER WINDS 26 JUL. 65 00 GMT



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

Plotted figures $T_d T_d$

FIG. 4·3 SYNOPTIC CHARTS 0300 GMT 27 JUL. 65

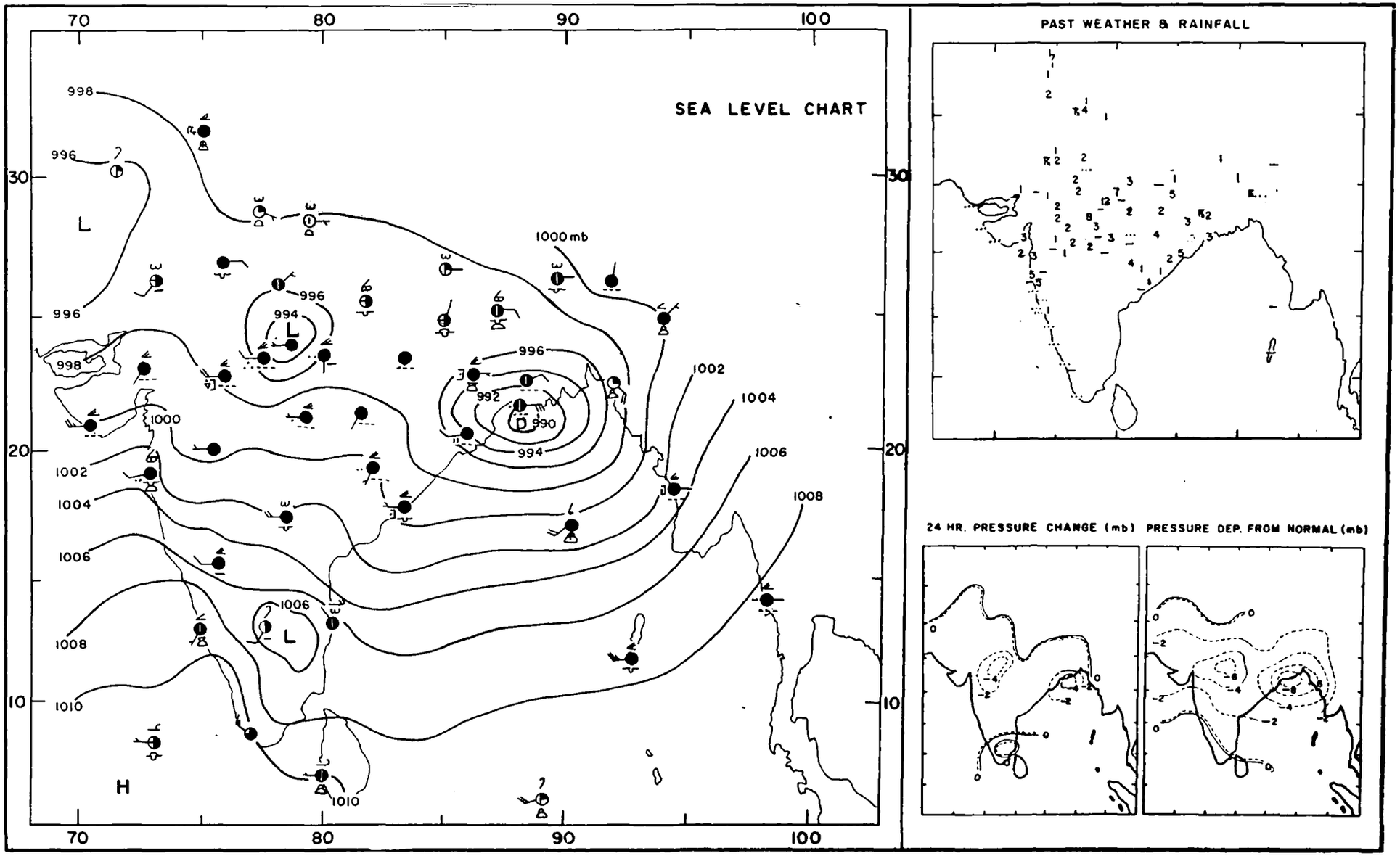
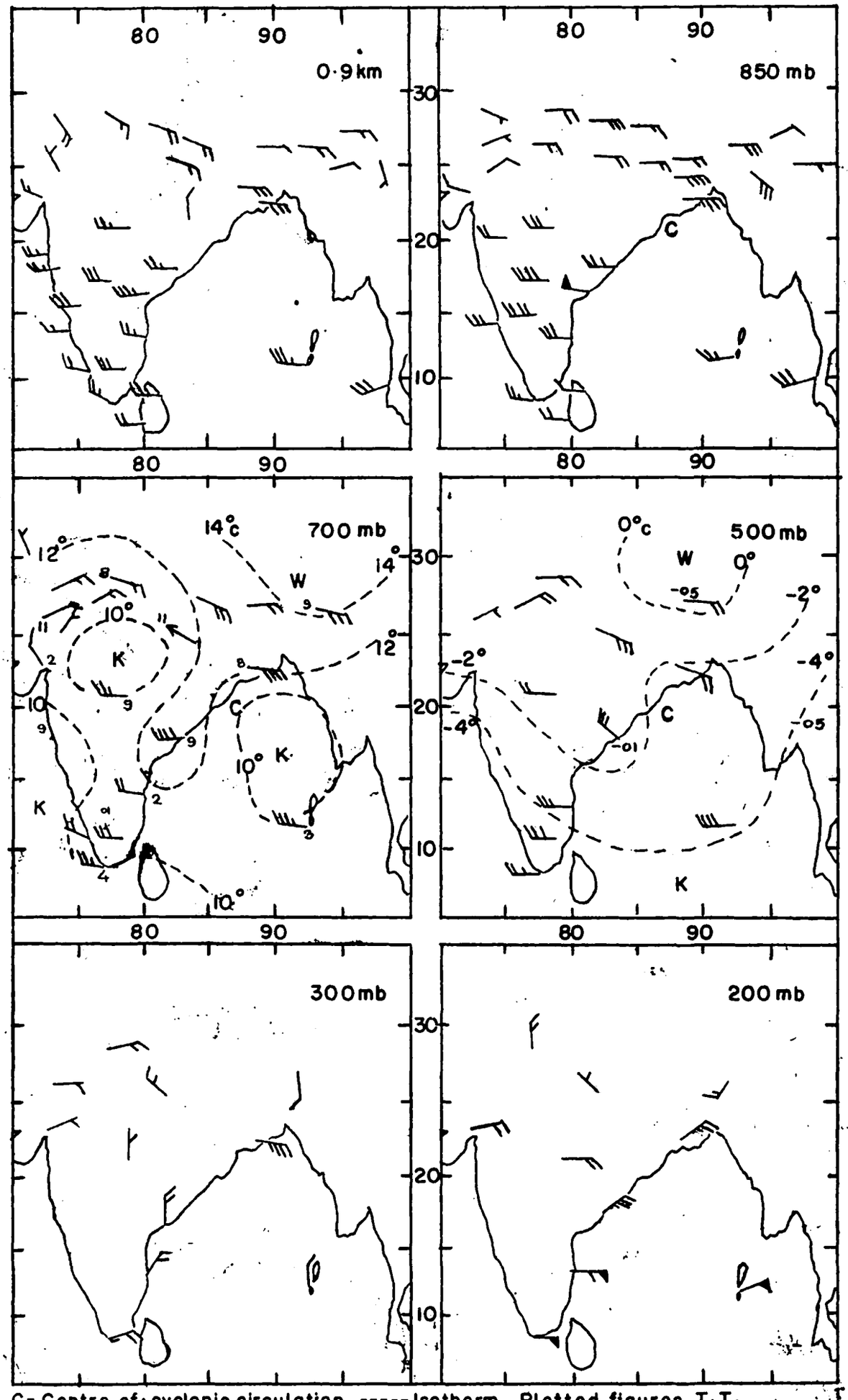
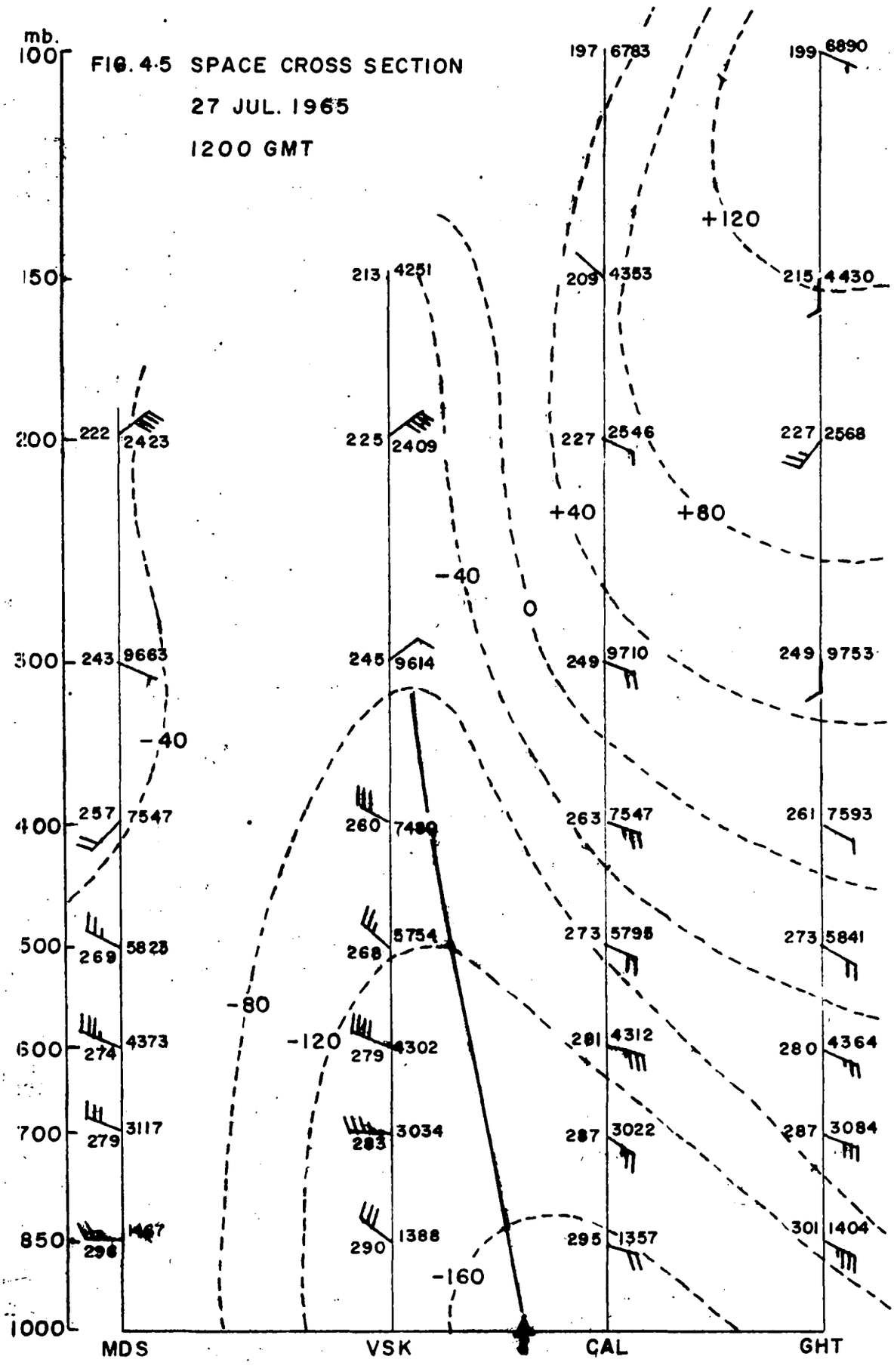


FIG. 4·4 UPPER WINDS 27 JUL. 65 00 GMT



C- Centre of cyclonic circulation ----- Isotherm Plotted figures T_d T_d

W- Warm K-Cold



—— Slope of axis of depression

------ Isopleths (in gpm) of departures from normal height values of Standard Atmosphere for Asian Tropics [P.R. Pisharoty - IJMG.-(1959)]

FIG. 4·6 TEPHIGRAMS OF CALCUTTA, GAUHATI AND VISHAKHAPATNAM-27JUL.65-00GMT

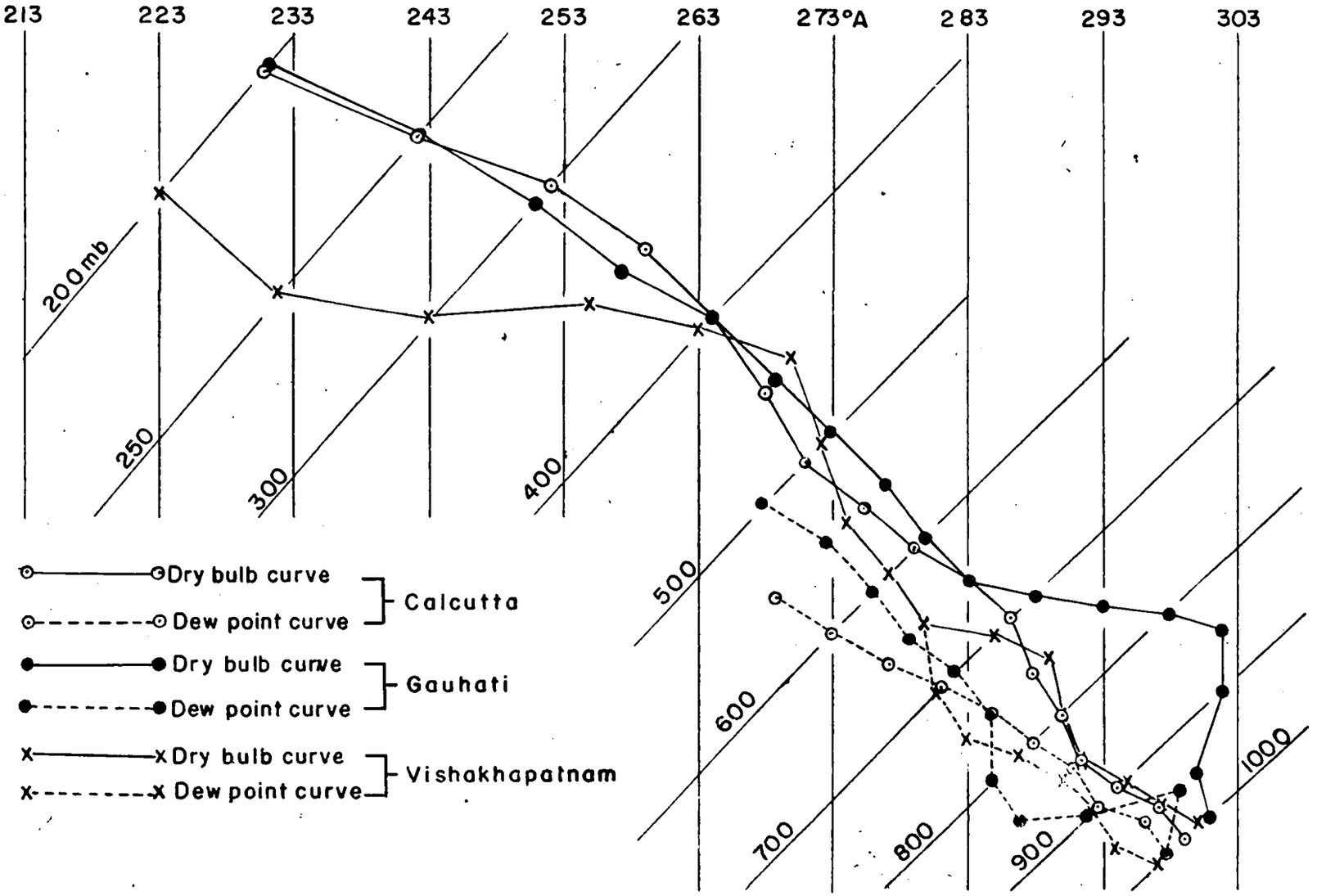


FIG. 4·7 SYNOPTIC CHARTS 0300 GMT 28 JUL. 65

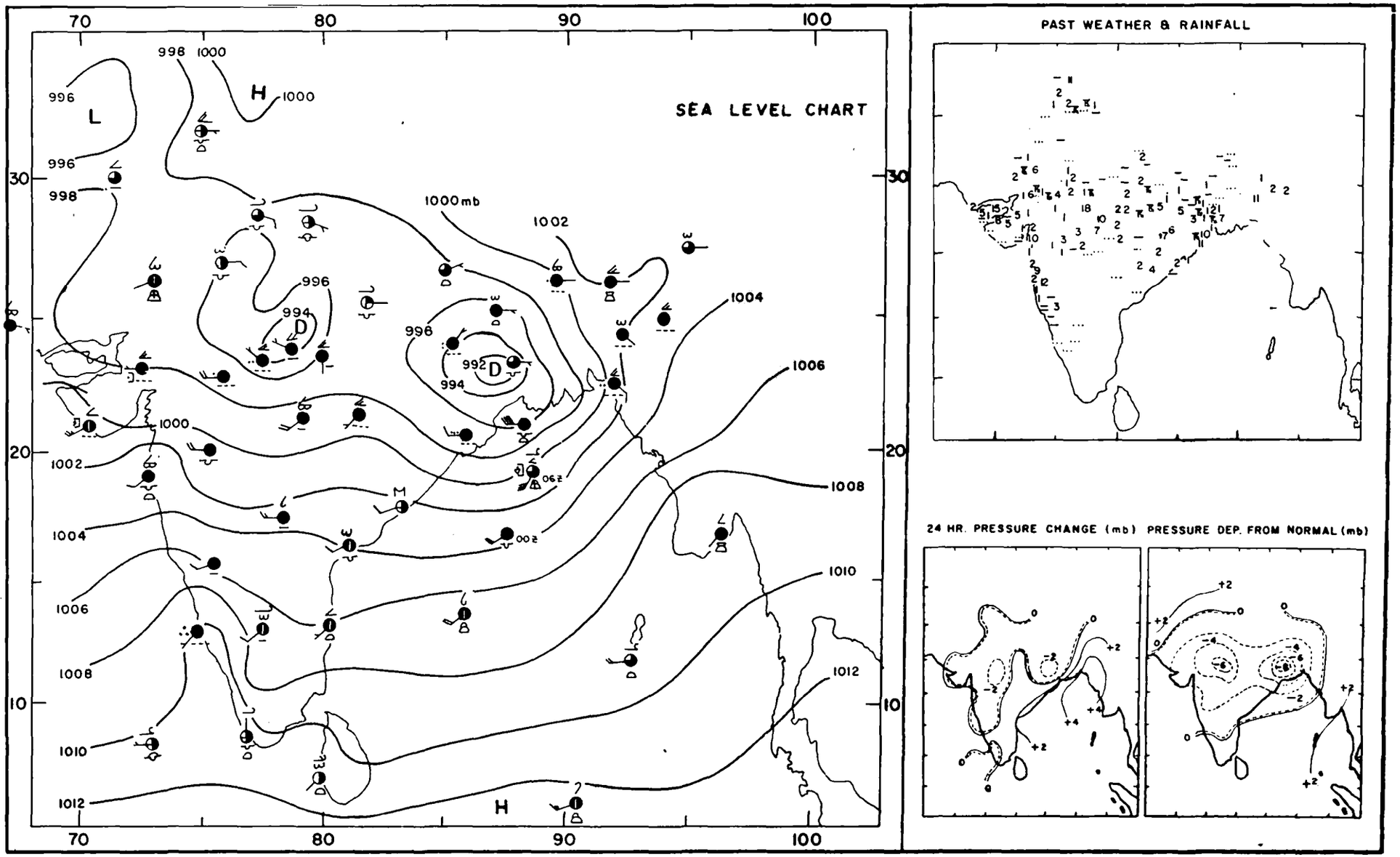
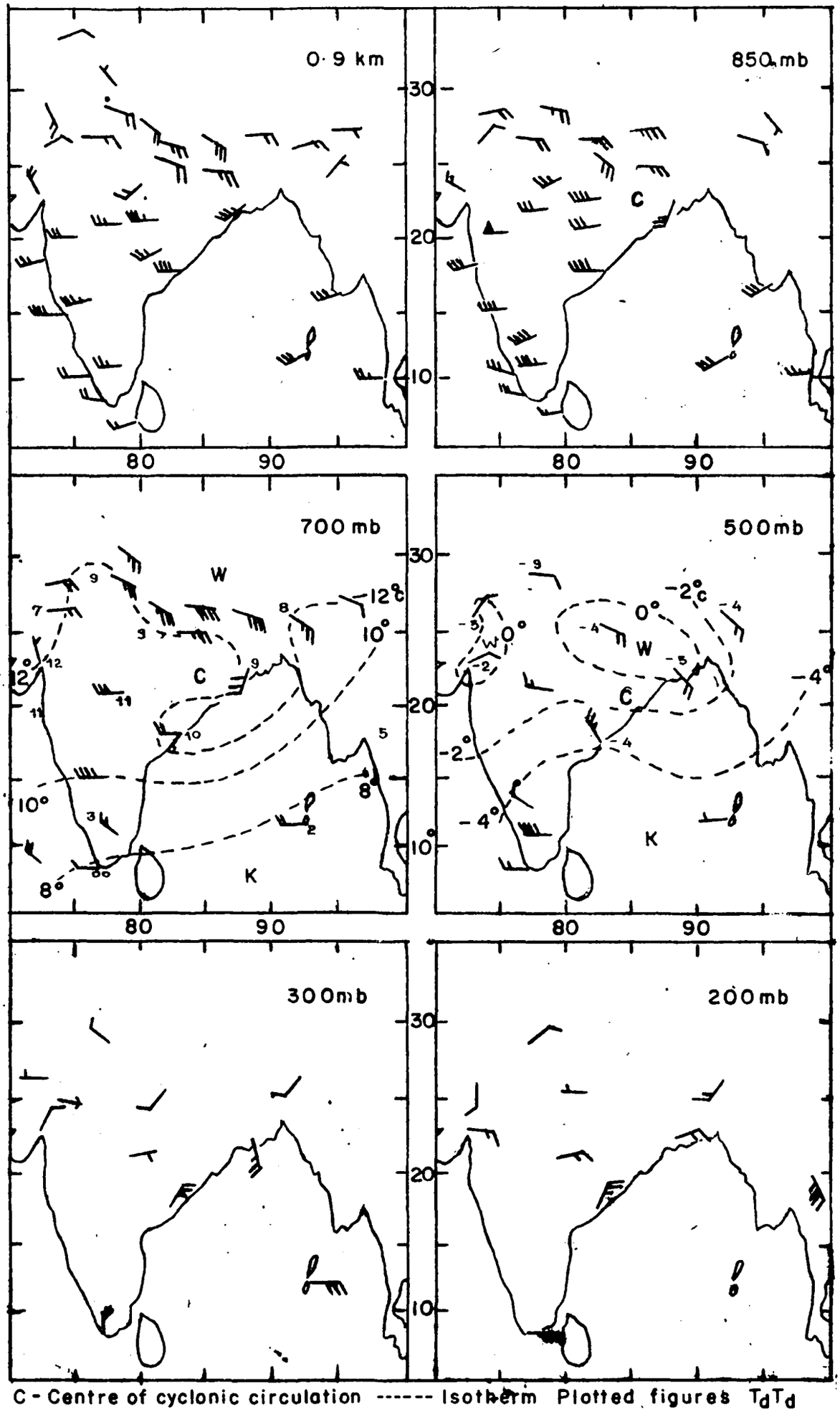


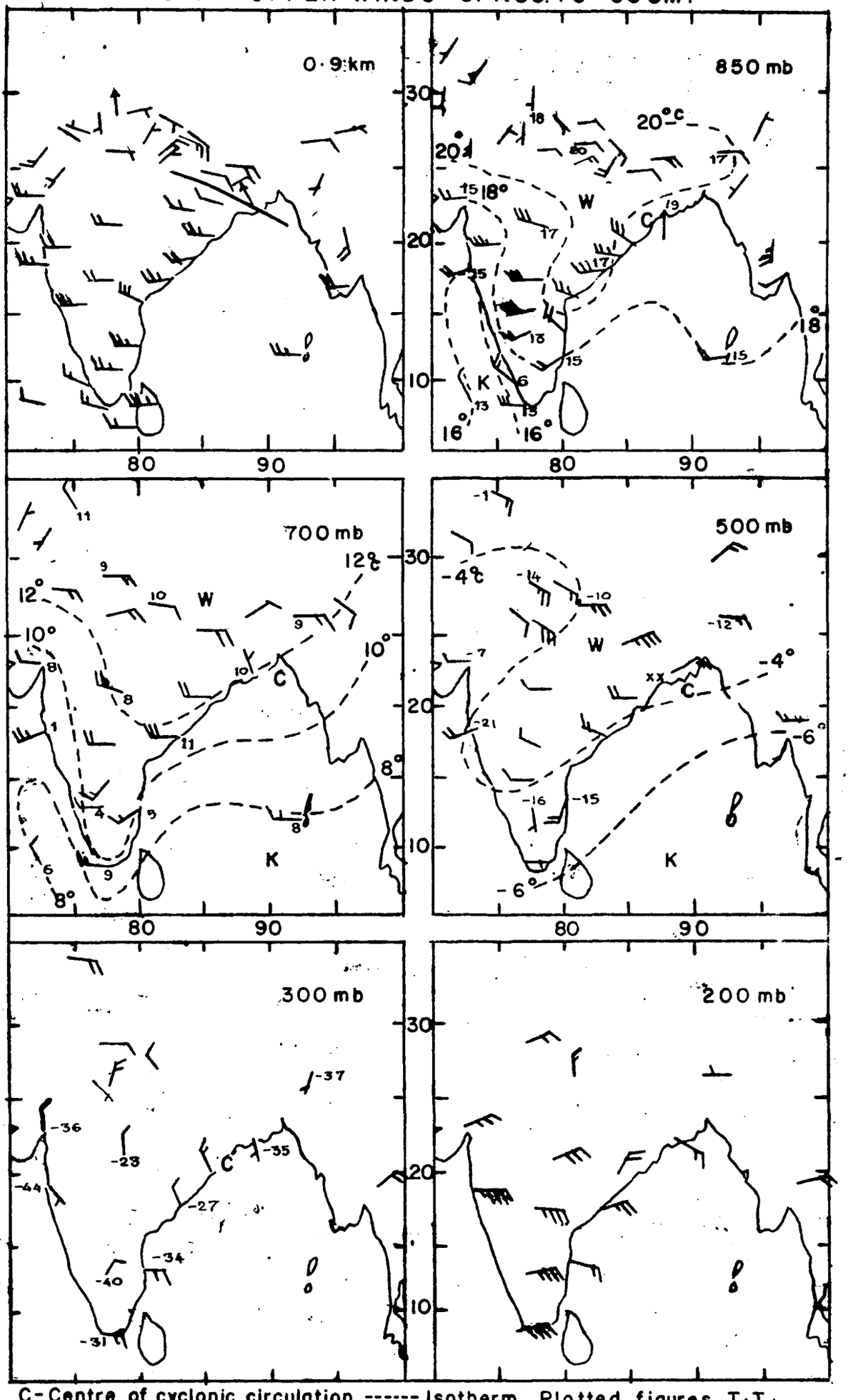
FIG. 4·8 UPPER WINDS 28 JUL. 65 00 GMT



C - Centre of cyclonic circulation ------ Isotherm Plotted figures $T_d T_d$

W - Warm K - Cold

FIG. 5·1 UPPER WINDS 31 AUG. 70 00GMT



C - Centre of cyclonic circulation ------ Isotherm Plotted figures $T_d T_d$

W - Warm K - Cold —— Trough line

FIG. 5·2 SYNOPTIC CHARTS 0300 GMT 31 AUG. 70

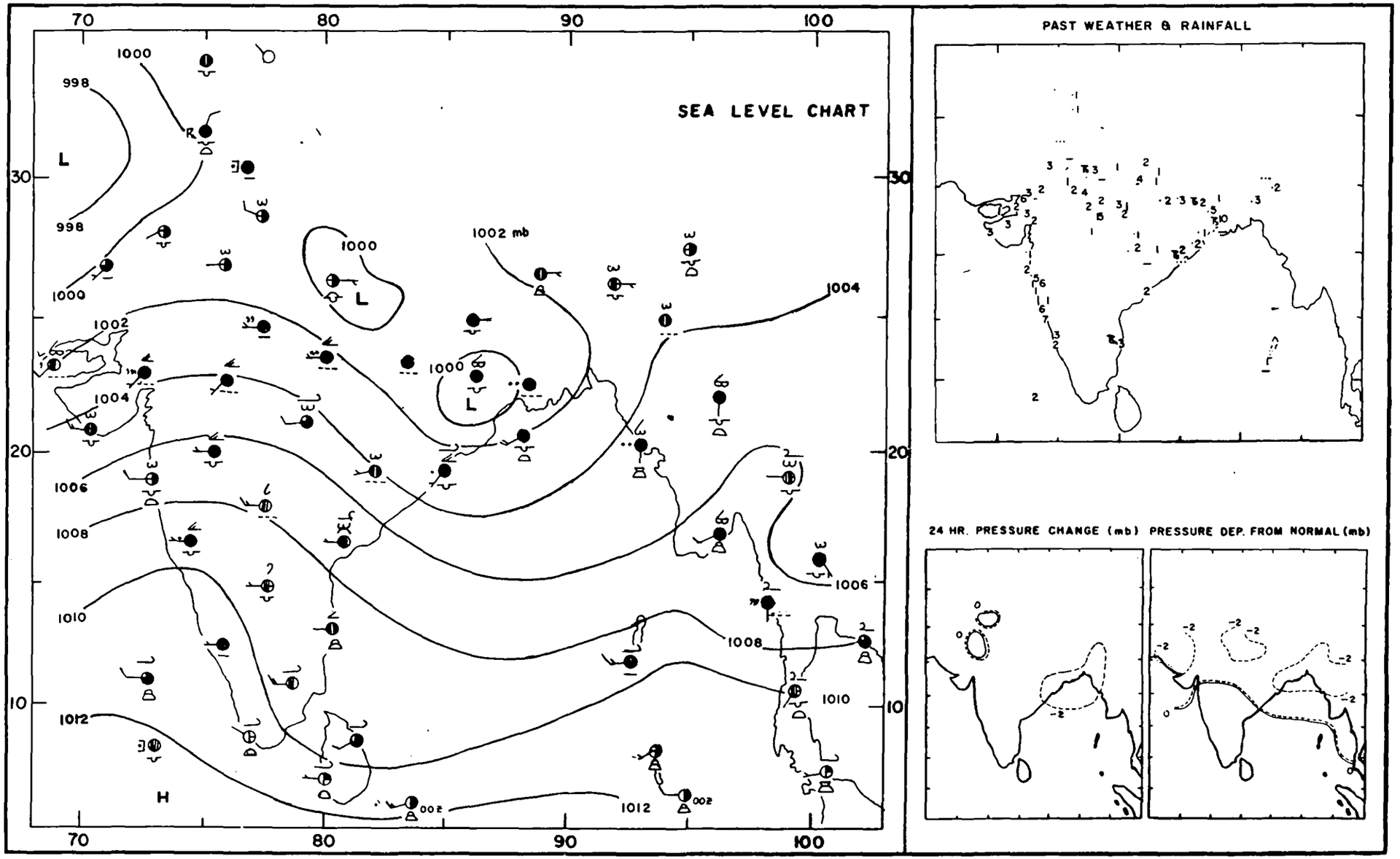


FIG. 5·3 SYNOPTIC CHARTS 0300 GMT 2 SEPT 70

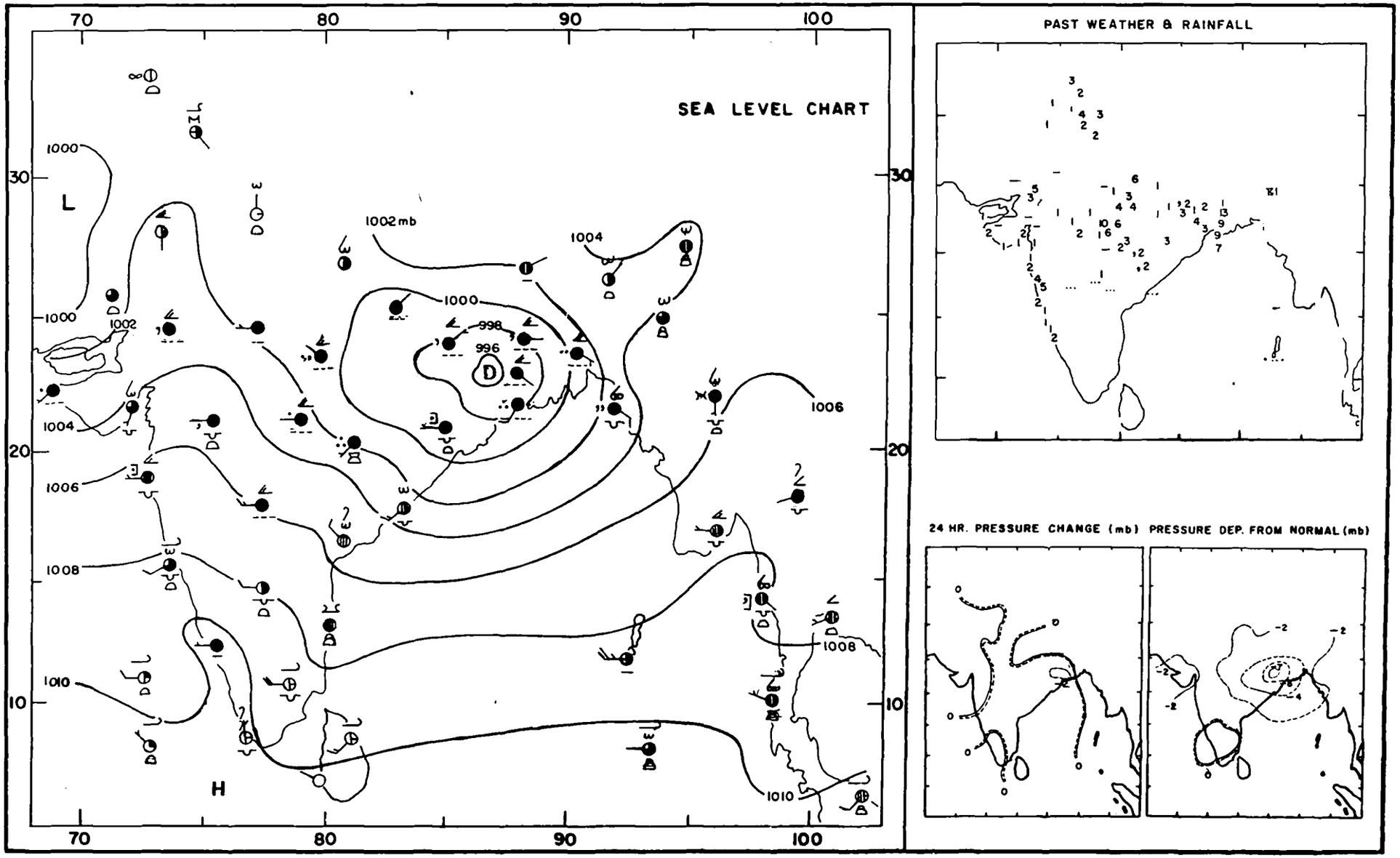
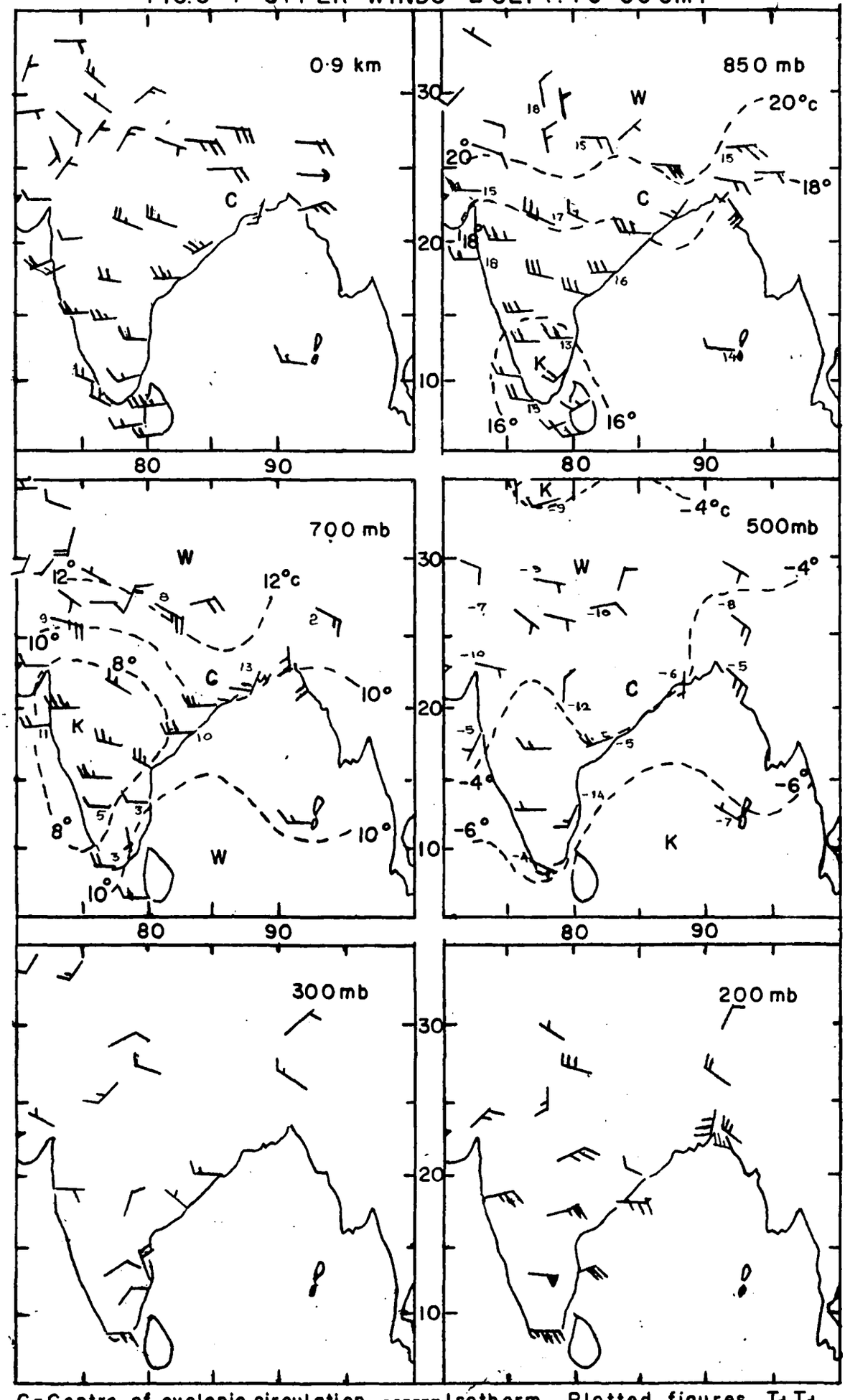


FIG. 5·4 UPPER WINDS 2 SEPT. 70 00 GMT



C - Centre of cyclonic circulation ------ Isotherm Plotted figures T_d T_d

W - Warm K - Cold

FIG. 5·5 SYNOPTIC CHARTS 0300 GMT 5 SEPT. 70

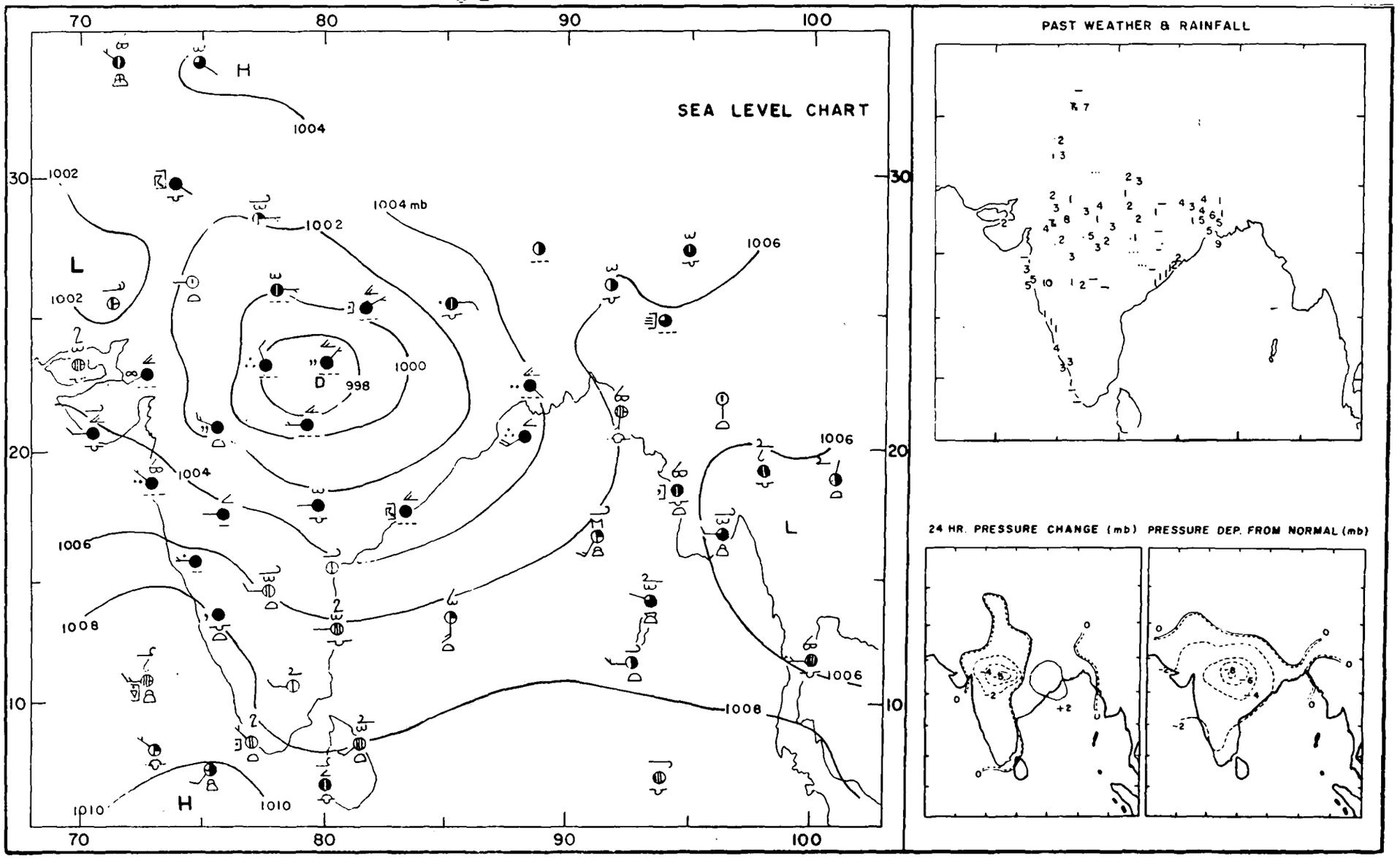
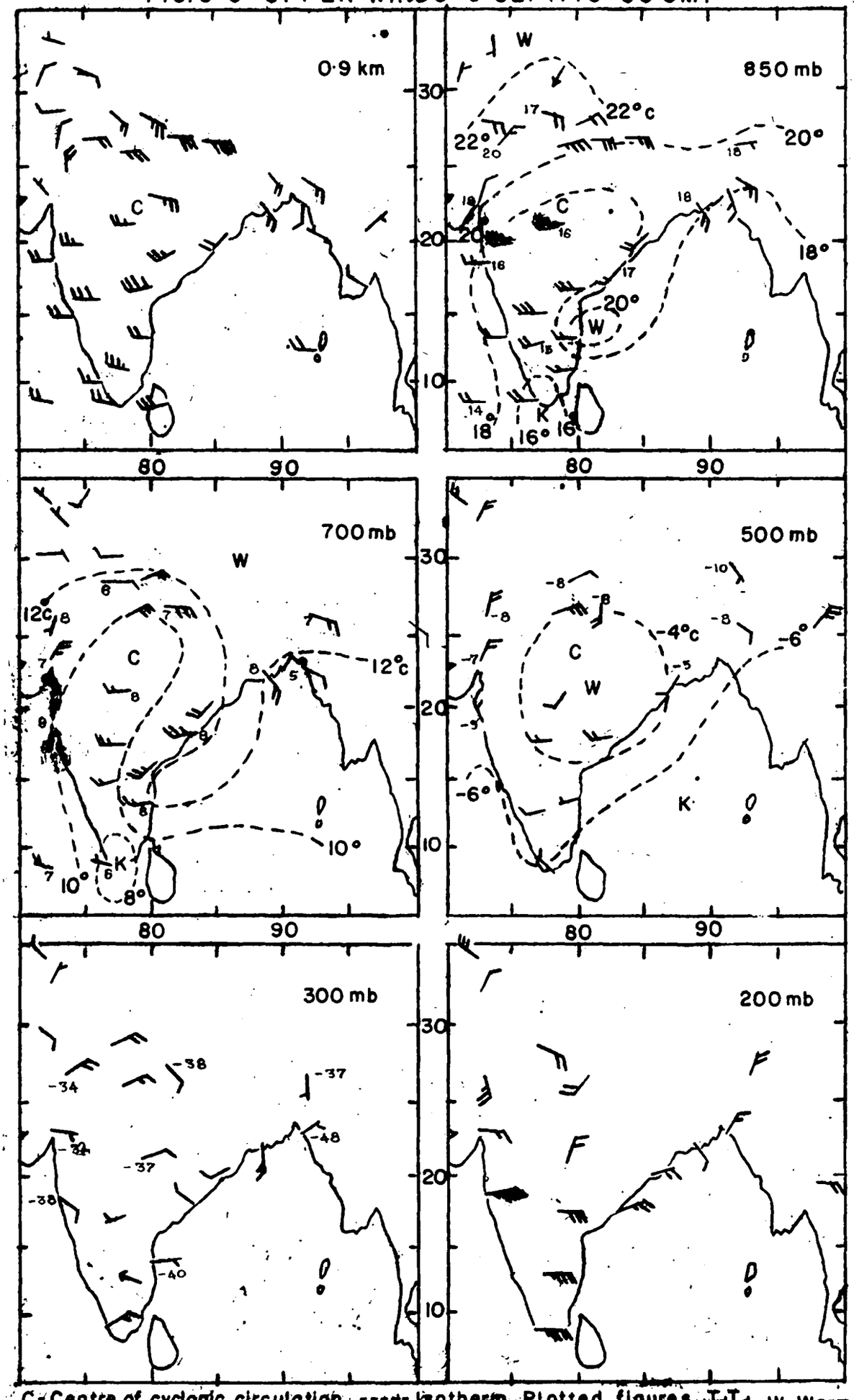


FIG. 5·6 UPPER WINDS 5 SEPT. 70 00 GMT



C-Centre of cyclonic circulation ----- Isotherm Plotted figures $T_d T_d$ W-Warm K-Cold

FIG. 5·7 SURFACE CHART 3 SEPT. 70 00GMT

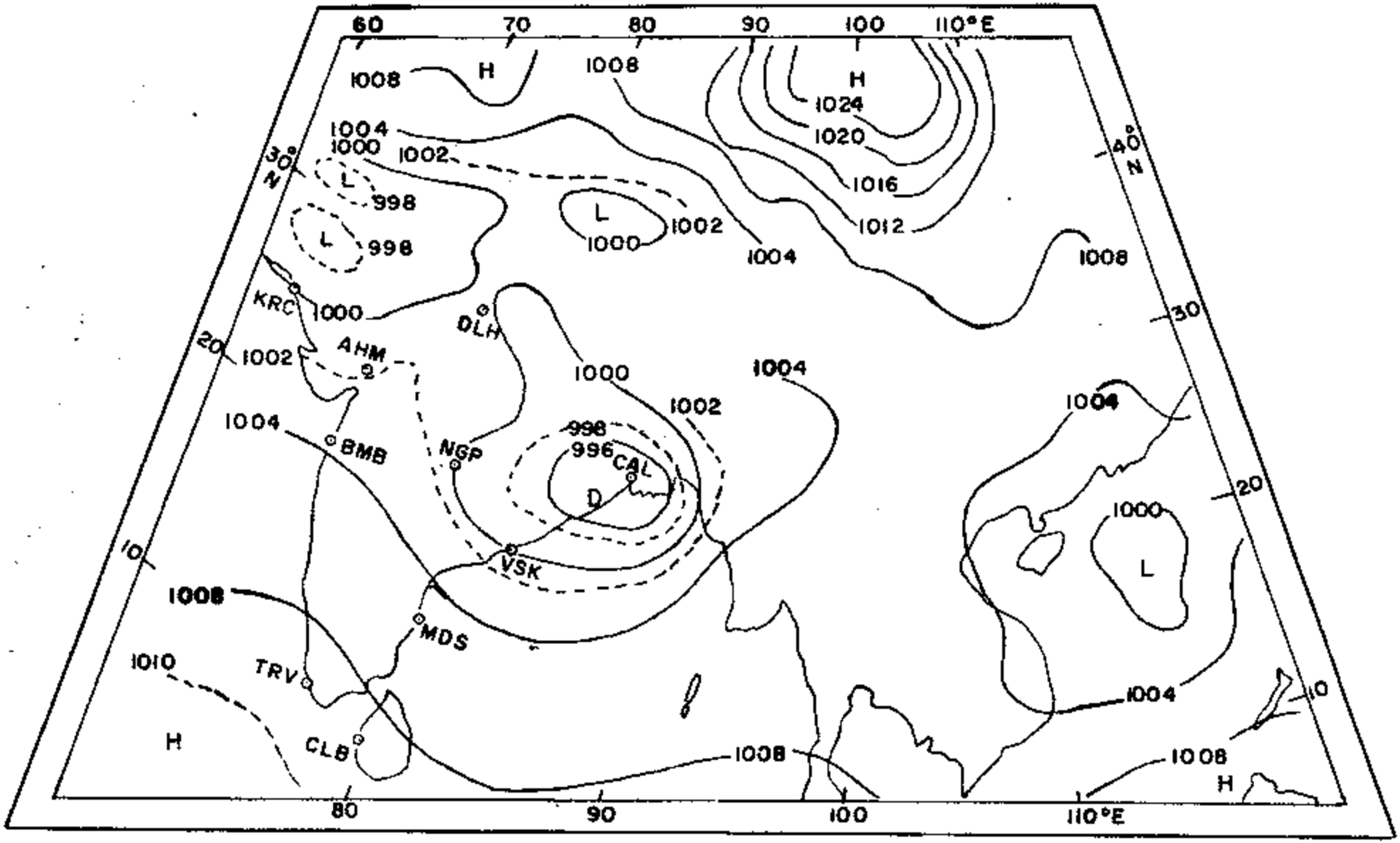


FIG. 5.8 UPPER AIR CHART 3 SEPT.70 00 GMT 500 mb

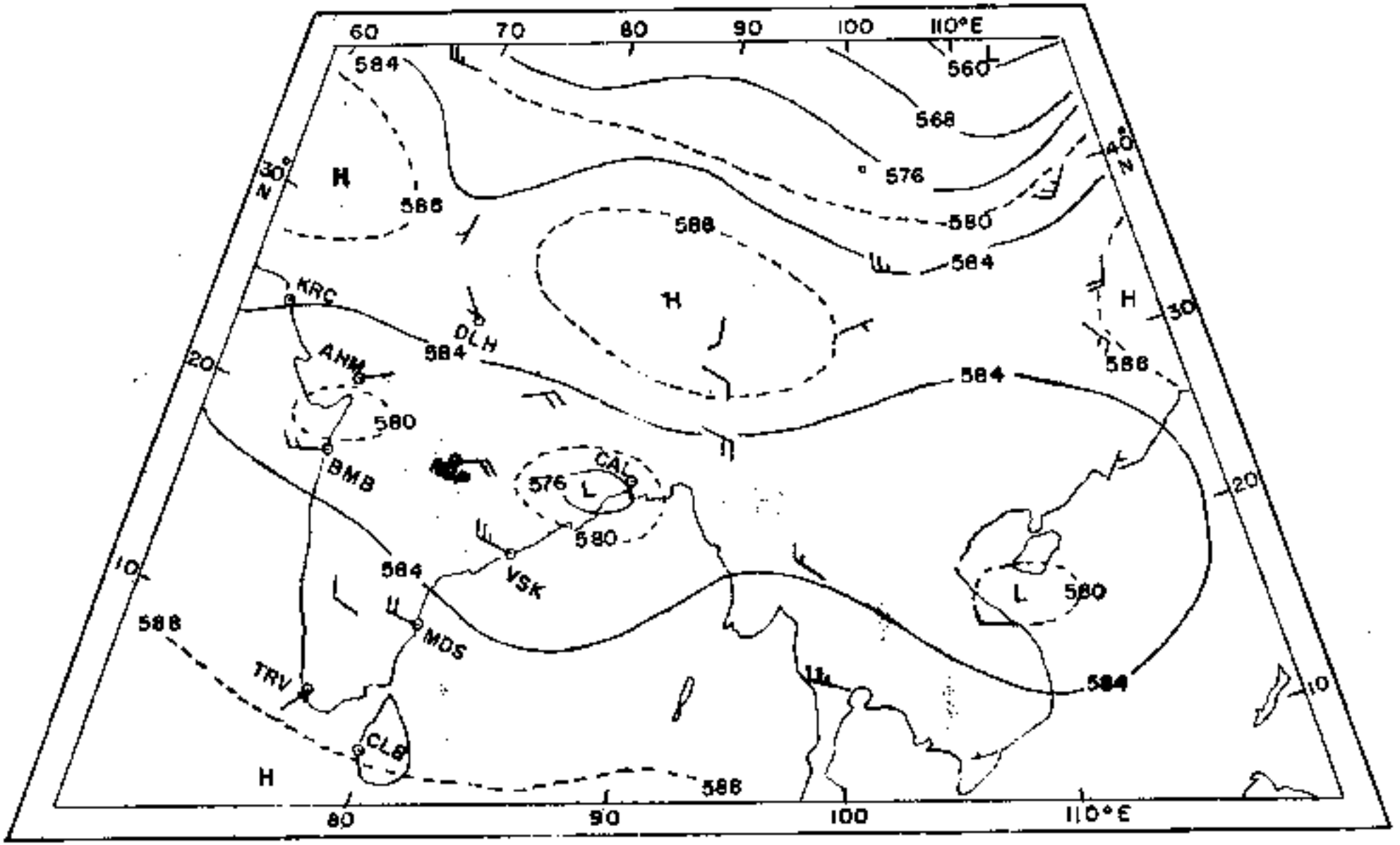
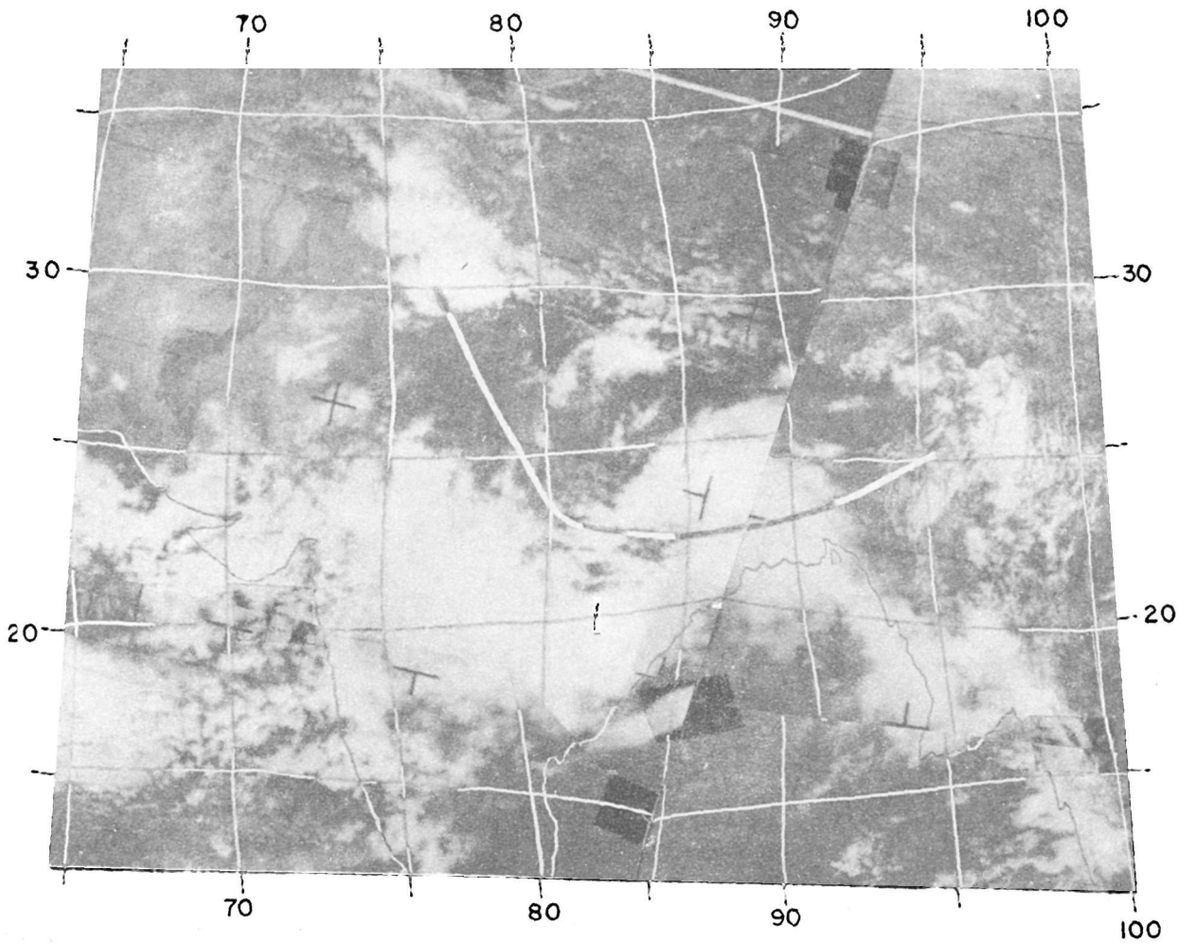


FIG. 5·9 (a)

ESSA – 8

ORBIT :- 7865, 7864

DATE :- 3 SEPT. 70



TROUGH LINE AT 0·9 km. a.s.l.

CENTRE OF DEPRESSION – NEAR LAT. 23°N, LONG. 86°E

FIG. 5·9 (b)

ITOS - I

ORBIT 2739, 2738

DATE 30 AUG. 70

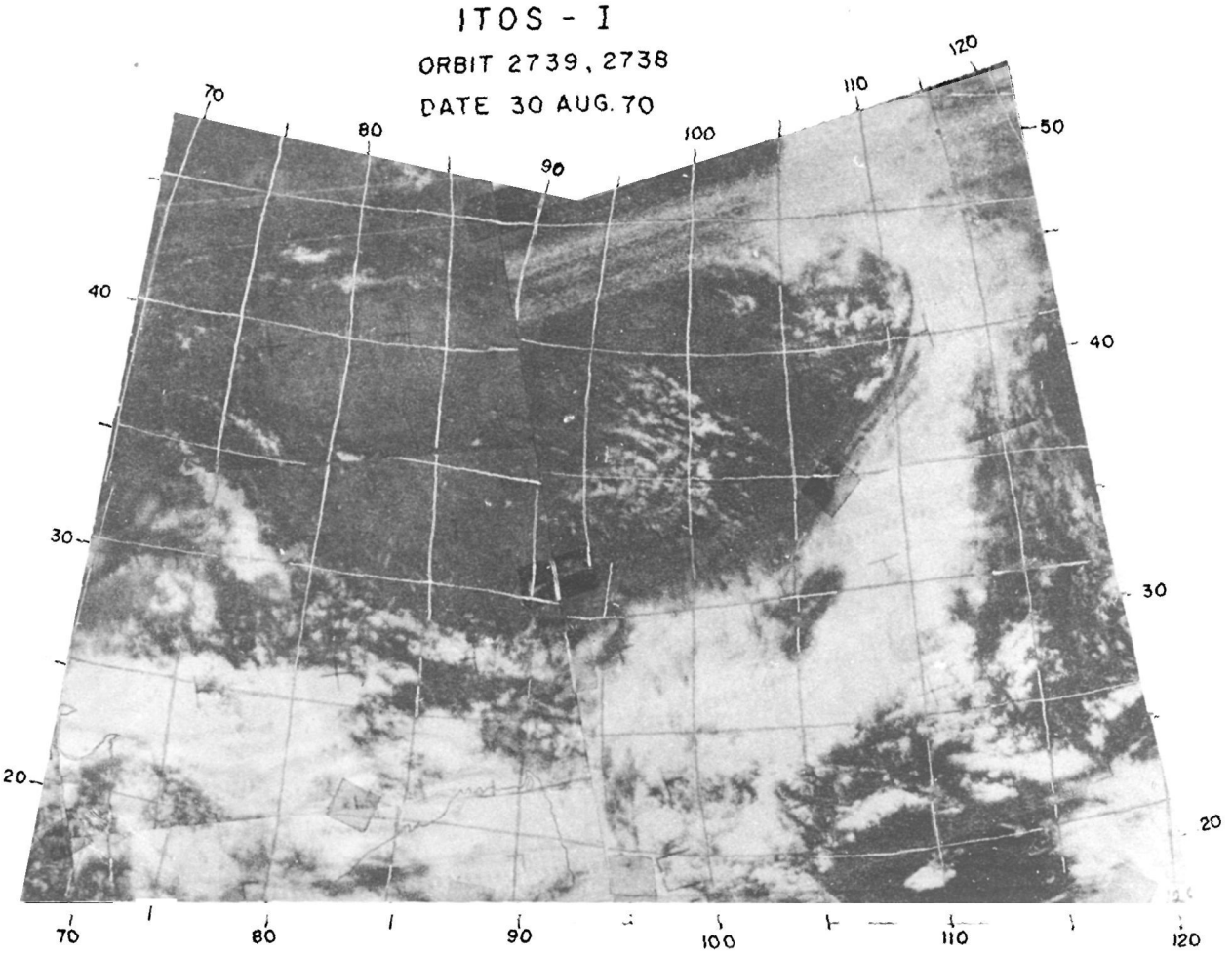


FIG. 5·10 TEPHIGRAMS OF GAUHATI & CALCUTTA - 00GMT - 3 SEPT. 70

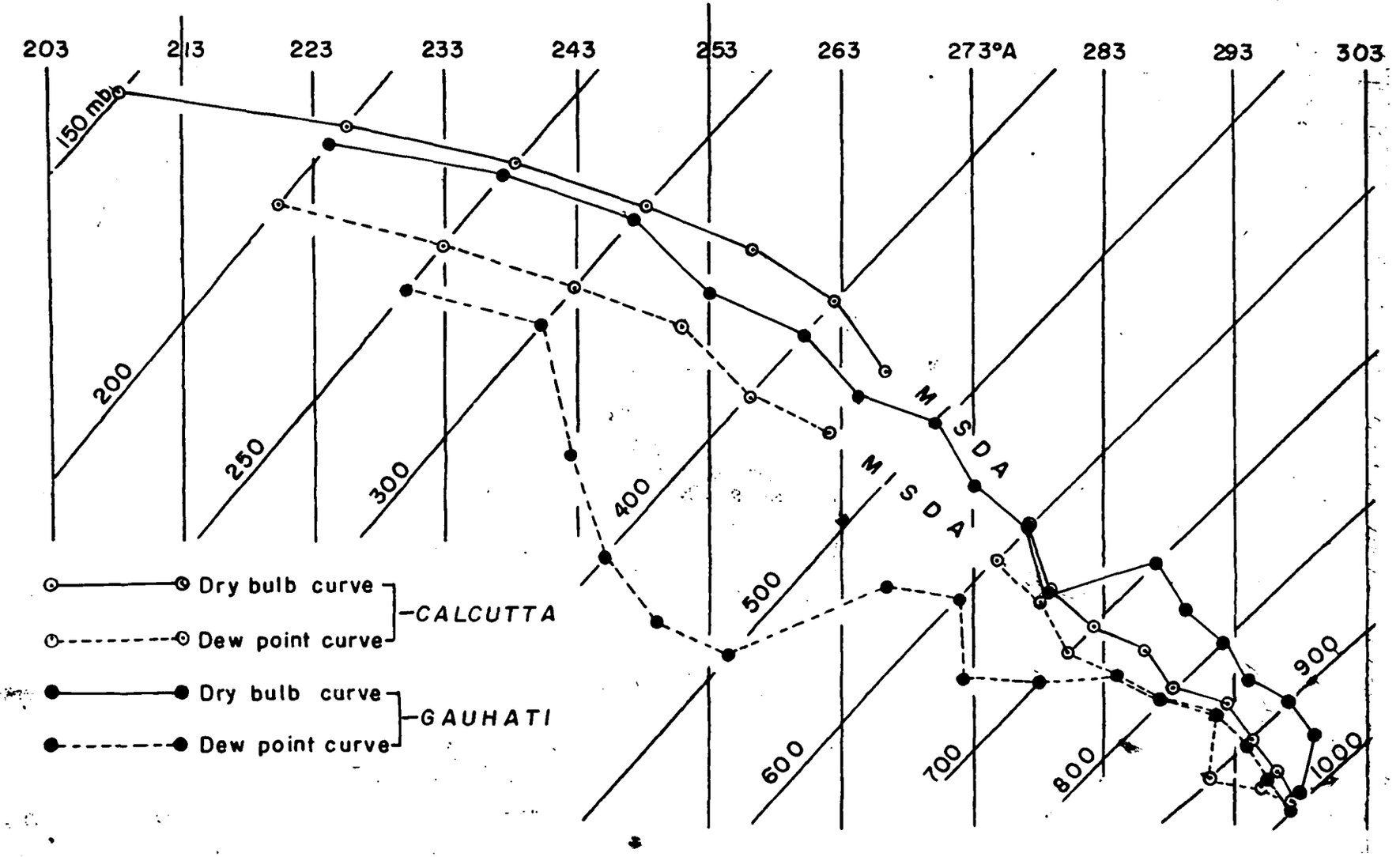


FIG. 6·1 SYNOPTIC CHARTS 0300 GMT 6 JUN 63

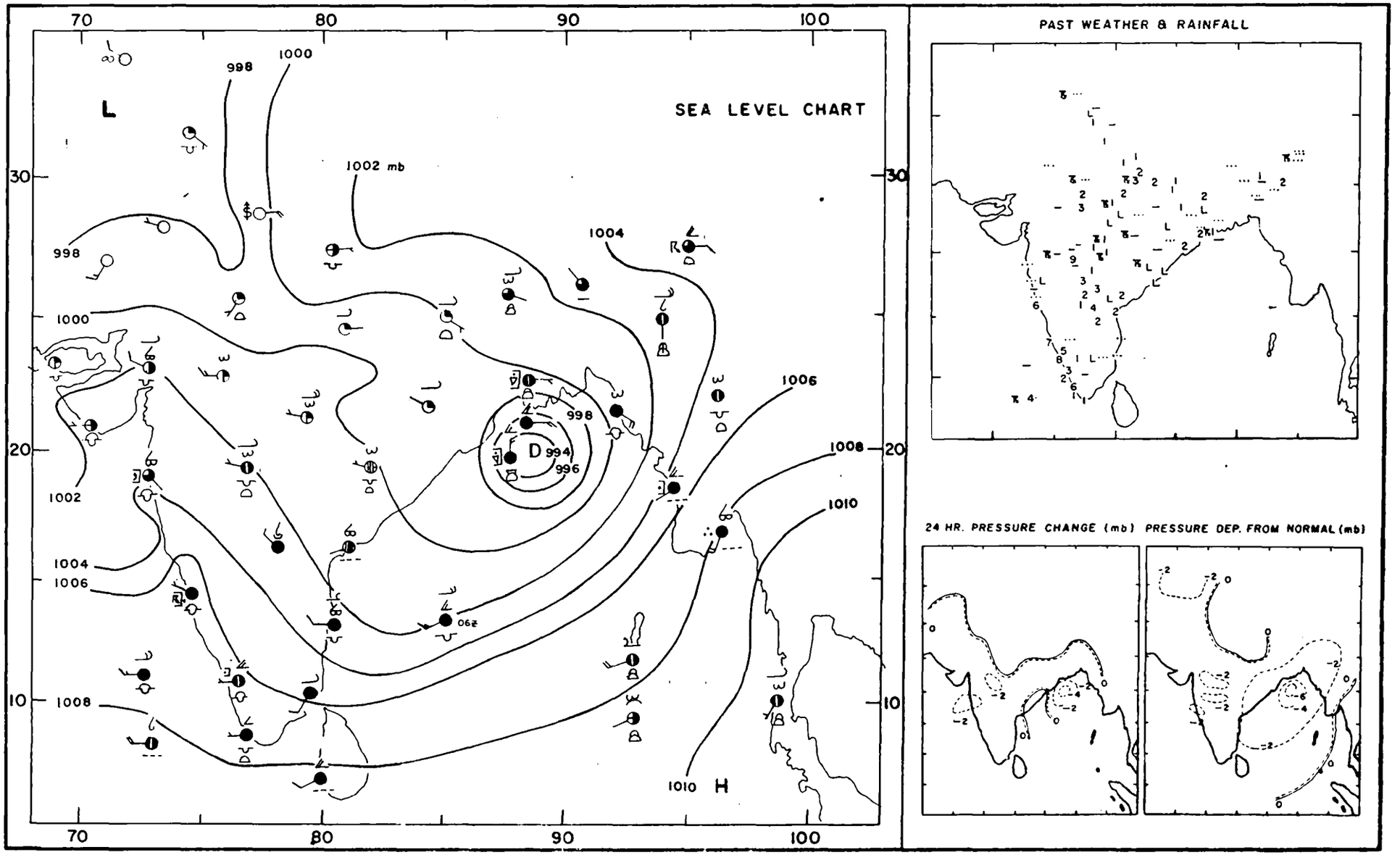
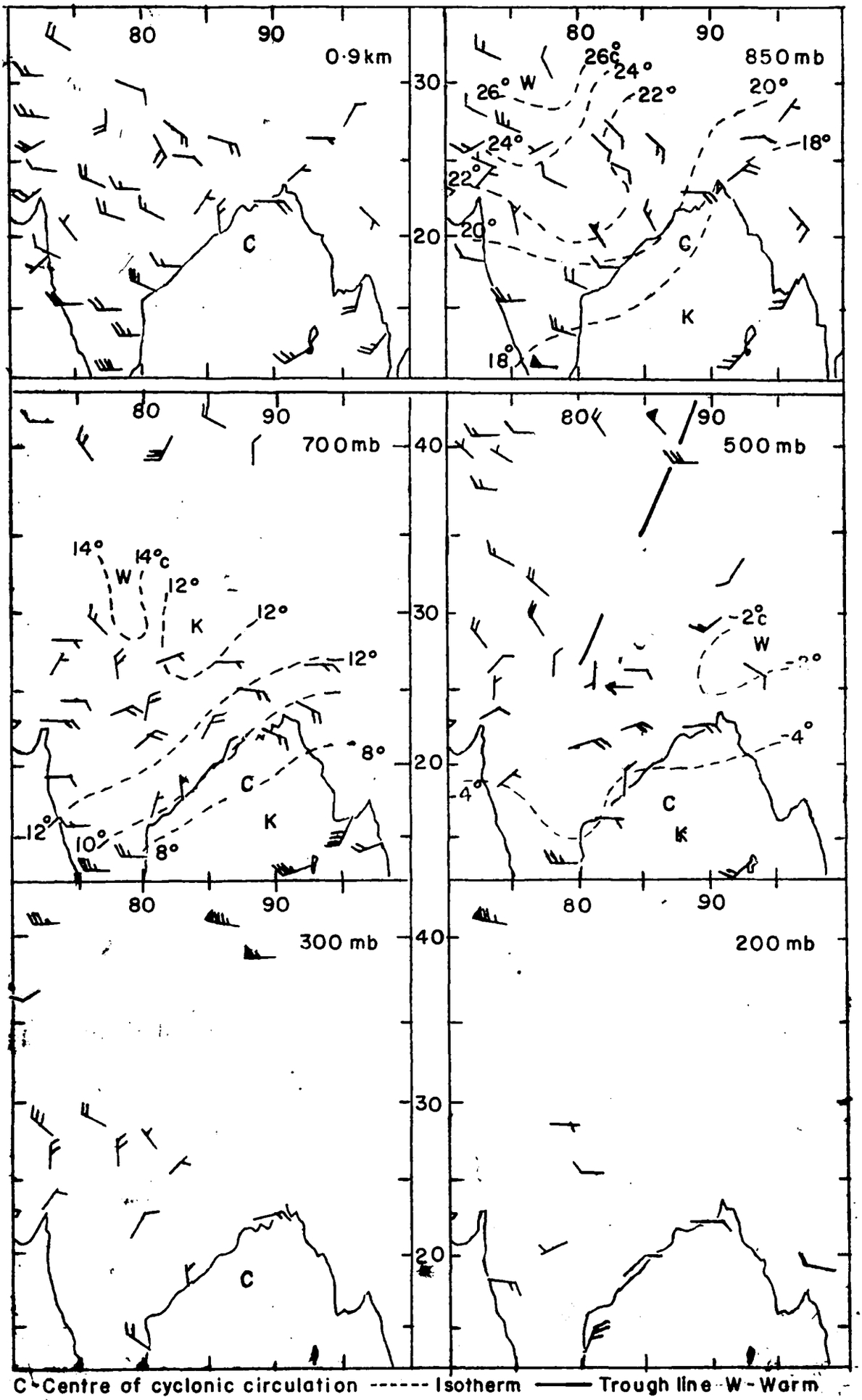


FIG. 6·2 UPPER WINDS 6 JUN. 63 00 GMT



C-Centre of cyclonic circulation ------ Isotherm —— Trough line W-Warm
K-Cold Plotted figures $T_d T_d$

FIG. 6·3 SYNOPTIC CHARTS 0300 GMT 7 JUN. 63

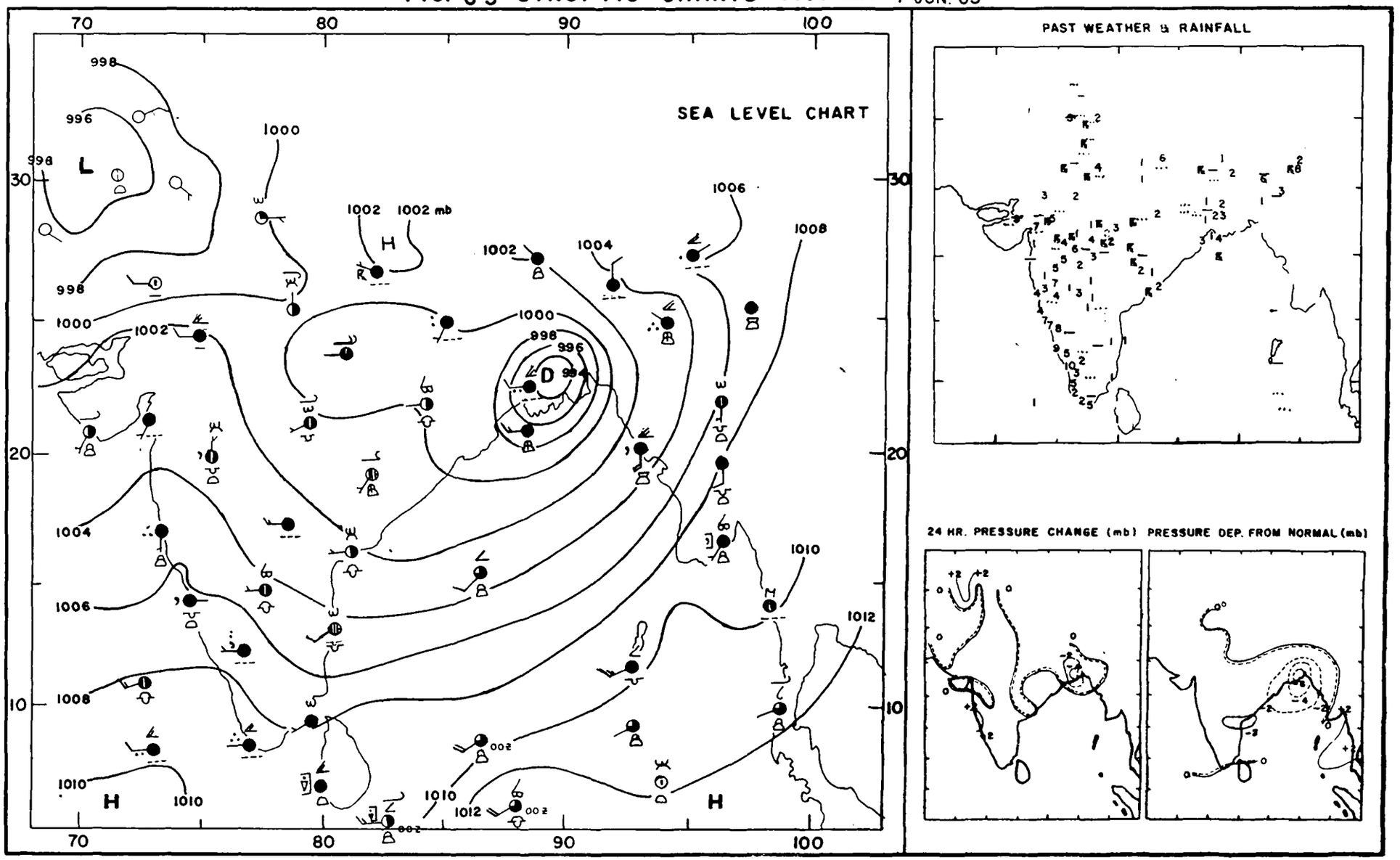
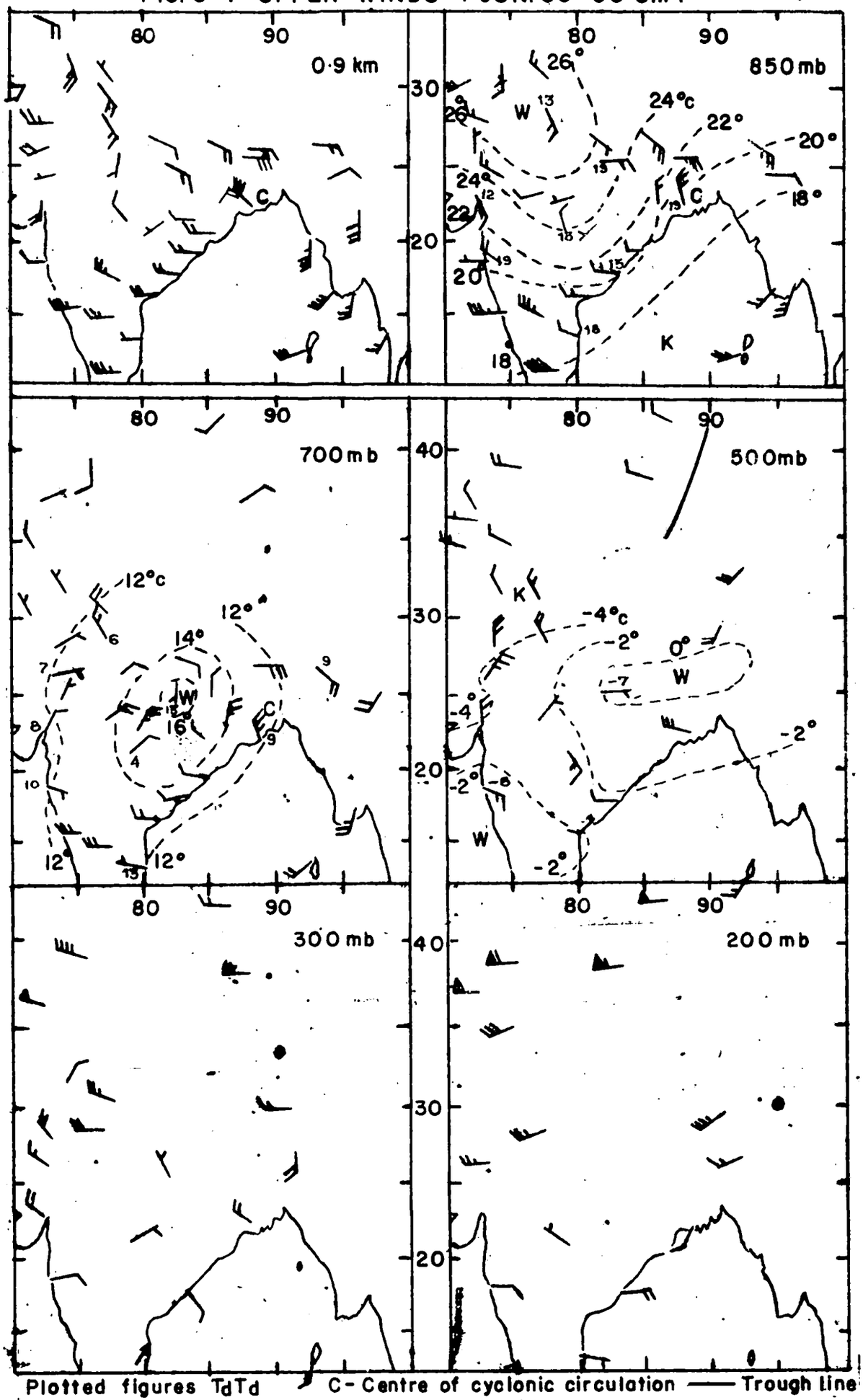


FIG. 6·4 UPPER WINDS 7 JUN. 63 00 GMT

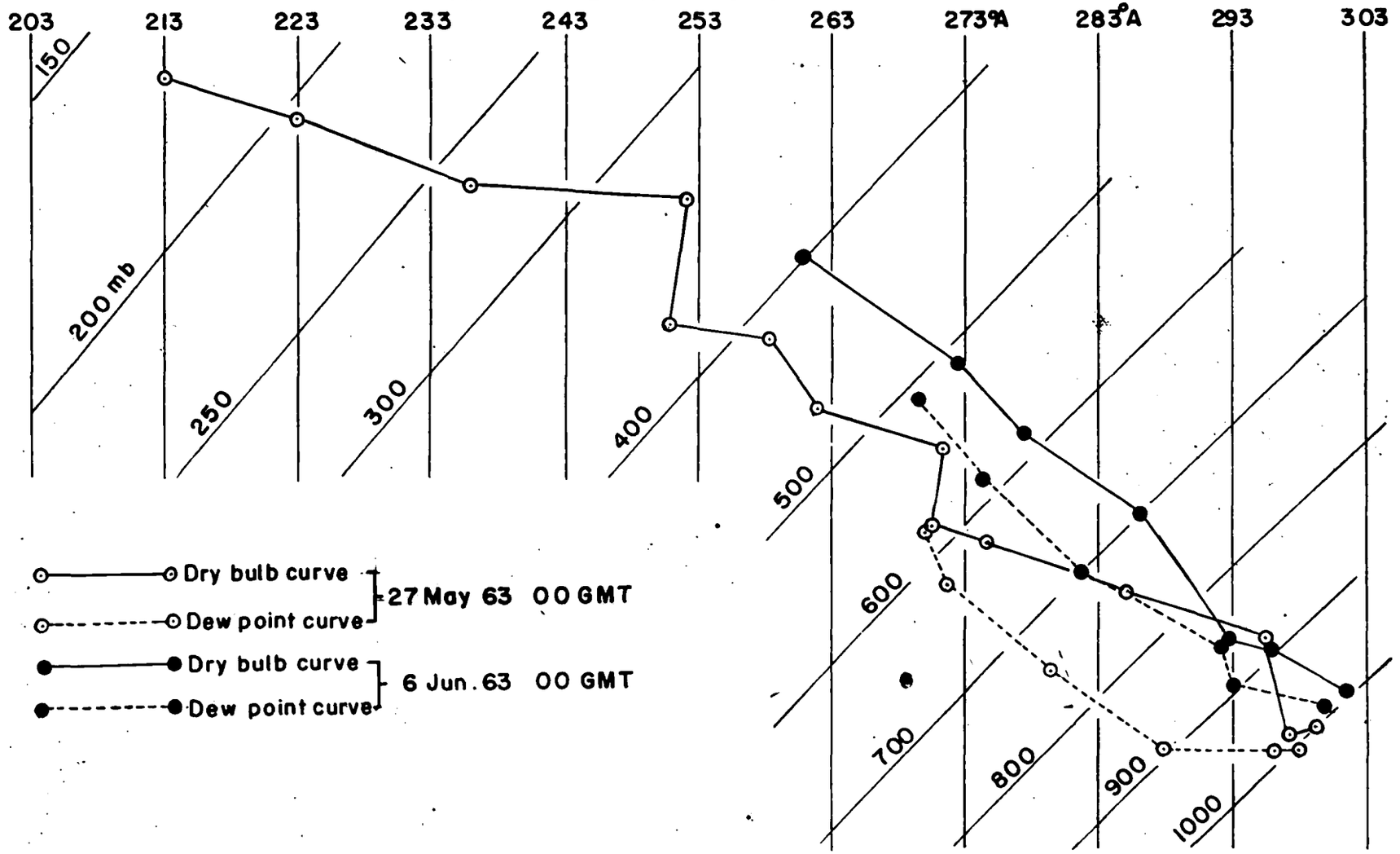


Plotted figures TdTd C - Centre of cyclonic circulation —— Trough line

----- Isotherm W - Warm K - Cold

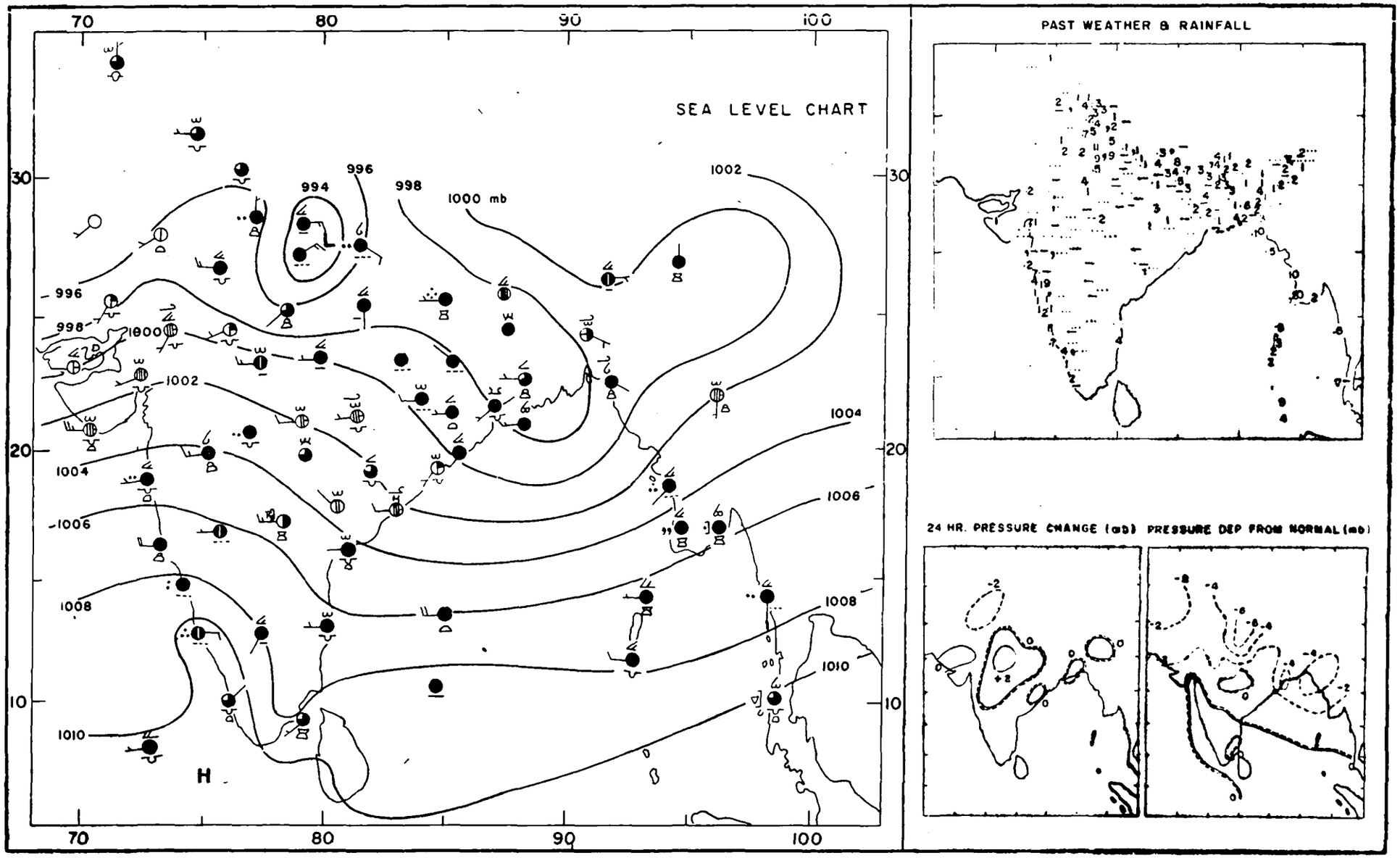
6·5

FIG. TEPHIGRAMS OF GAUHATI



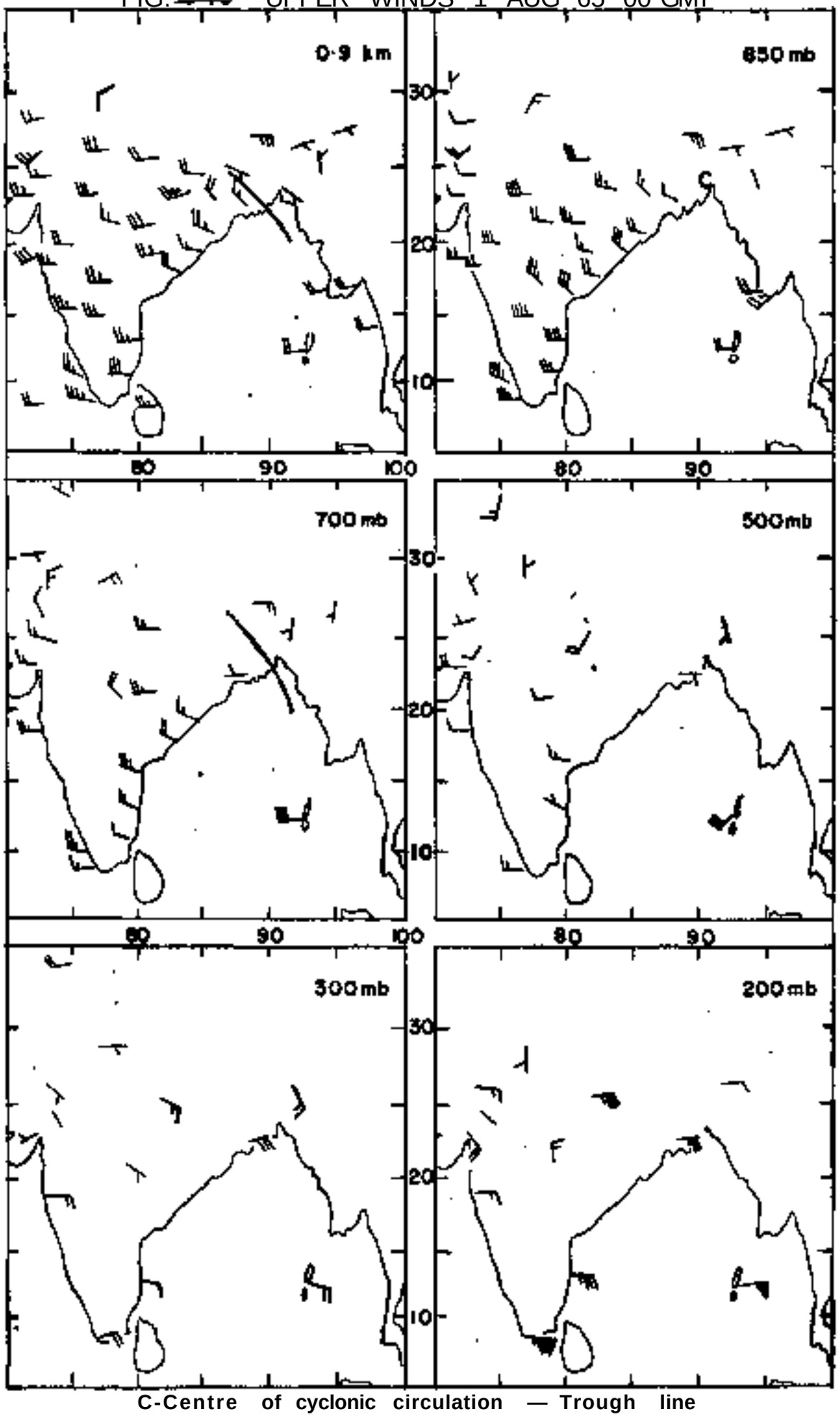
7.1

FIG. ~~5.12~~ SYNOPTIC CHARTS 0300 GMT 1 AUG. 65



7·2

FIG. 7·2 UPPER WINDS 1 AUG 65 00 GMT



C-Centre of cyclonic circulation — Trough line

FIG. 7.3 SYNOPTIC CHARTS 0300 GMT 2 AUG 65

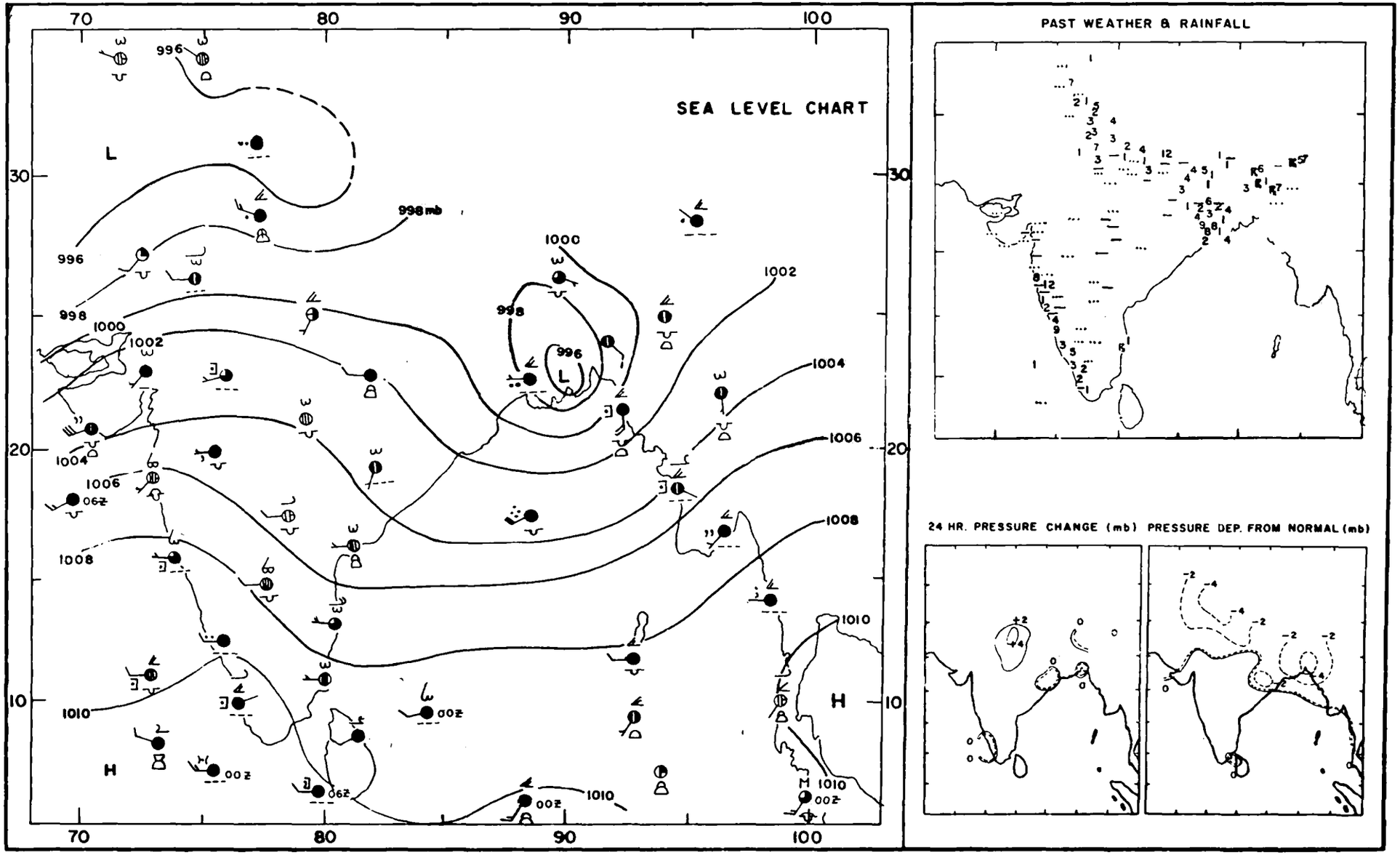
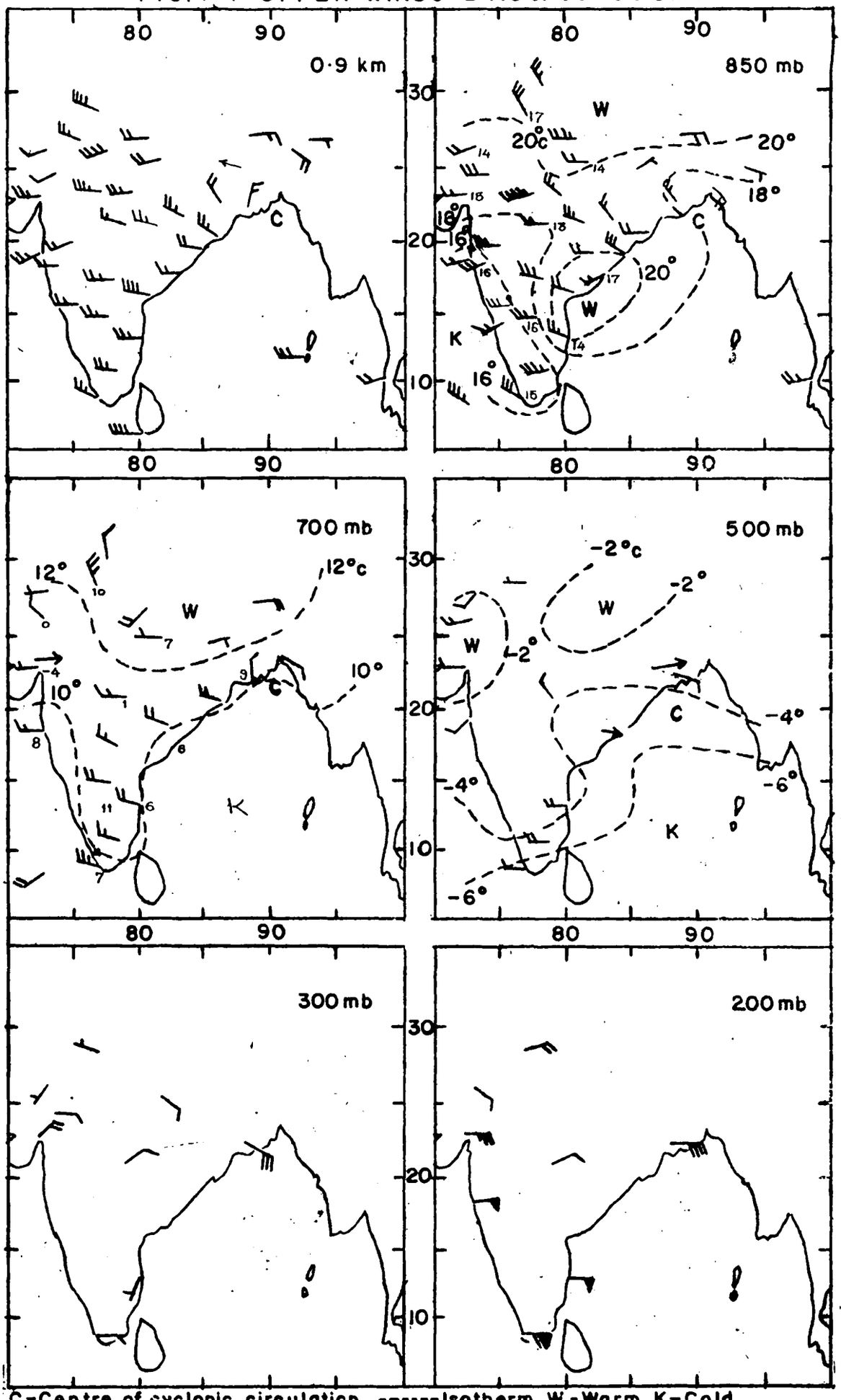


FIG. 7·4 UPPER WINDS 2 AUG. 65 00GMT

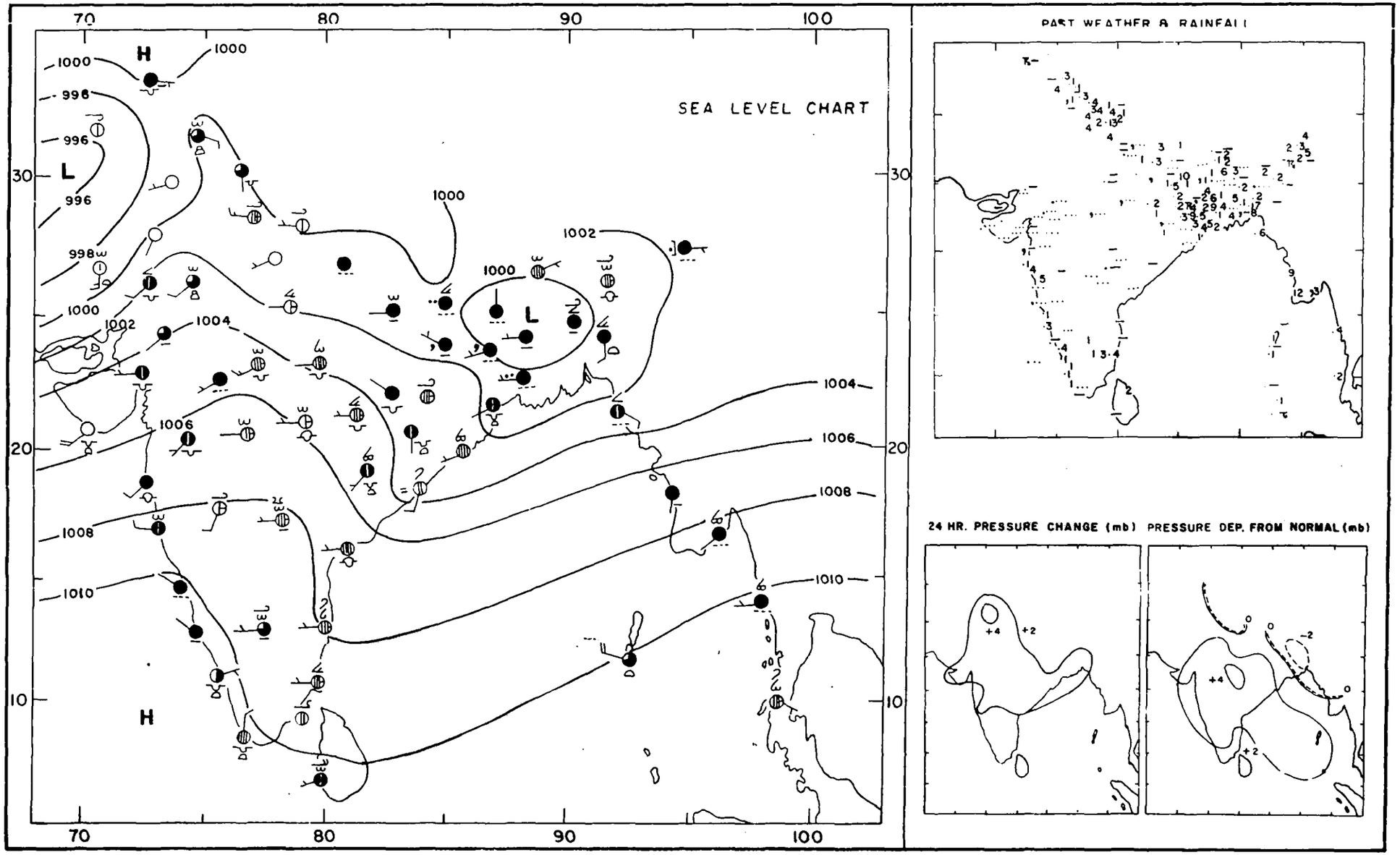


C-Centre of cyclonic circulation ------Isotherm W-Warm K-Cold

Plotted figures $T_d T_d$

7·5

FIG. ~~5·1c~~ SYNOPTIC CHARTS 0300 GMT 3 AUG. 65



7.6

FIG. ~~5-17~~ UPPER WINDS 3 AUG. 65 00 GMT

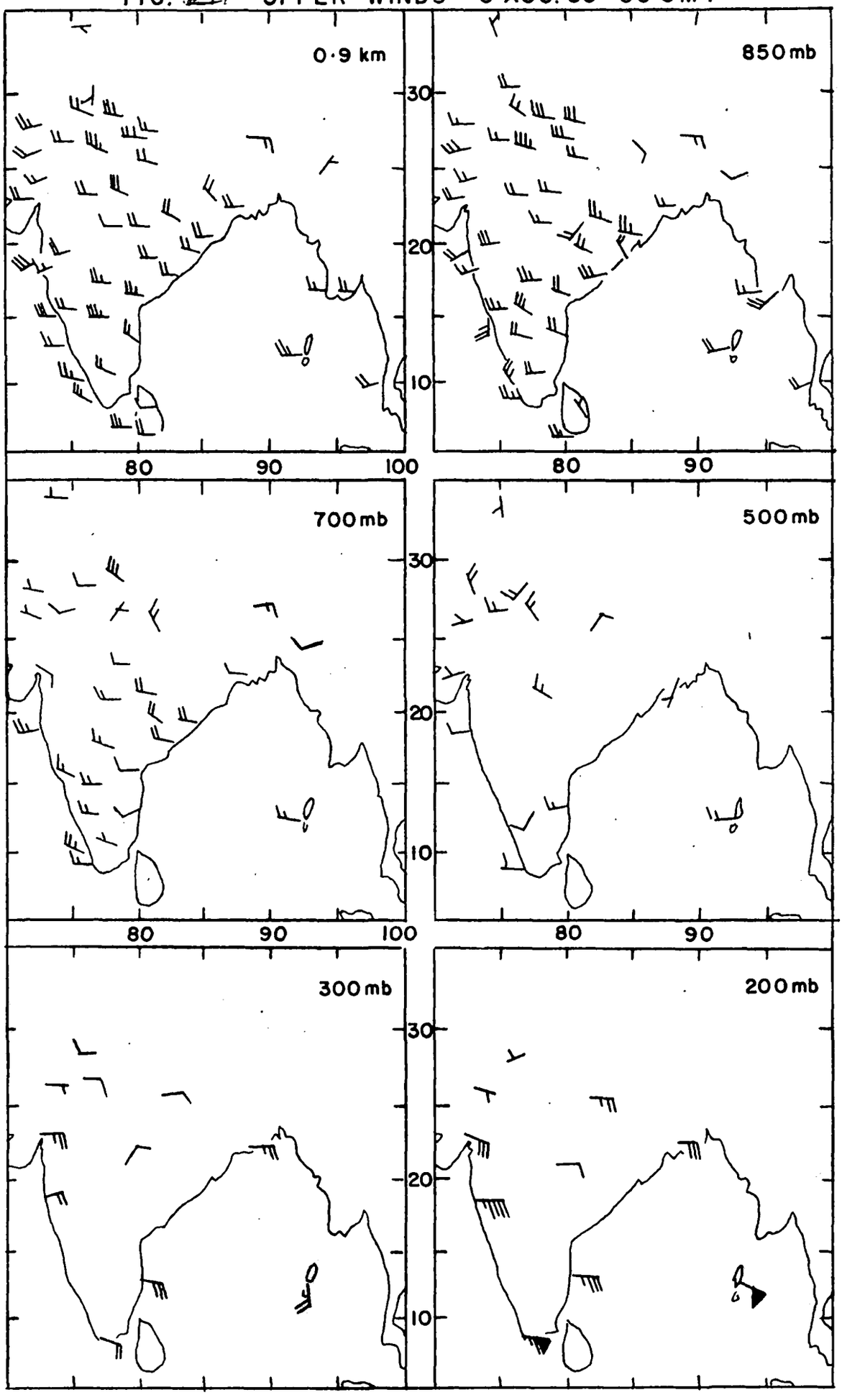


FIG. 7·7 TEPHIGRAMS OF CALCUTTA (2 & 3 AUG. 65)

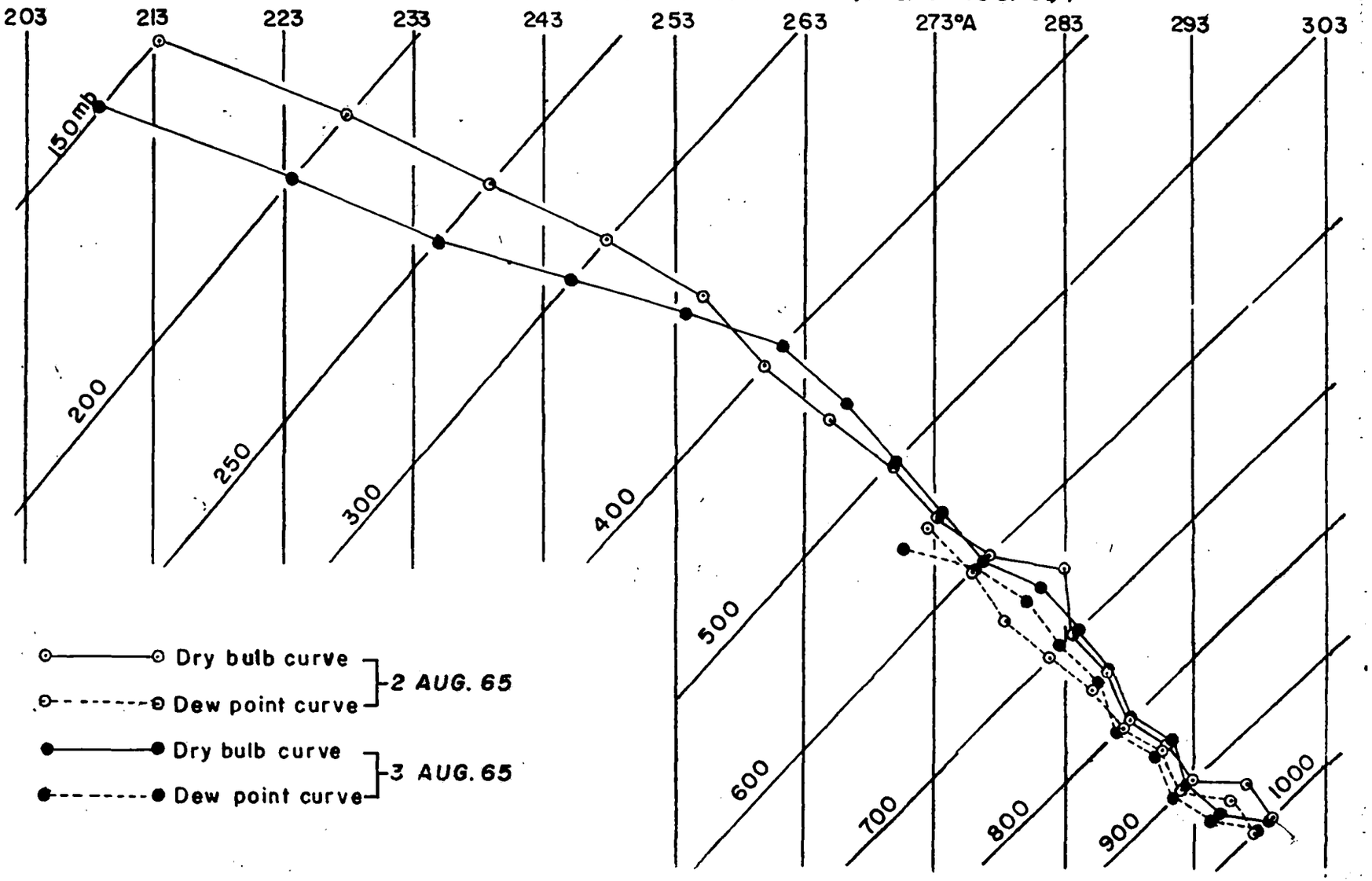


FIG. 8·1 SYNOPTIC CHARTS 0300 GMT 7 JUL. 67

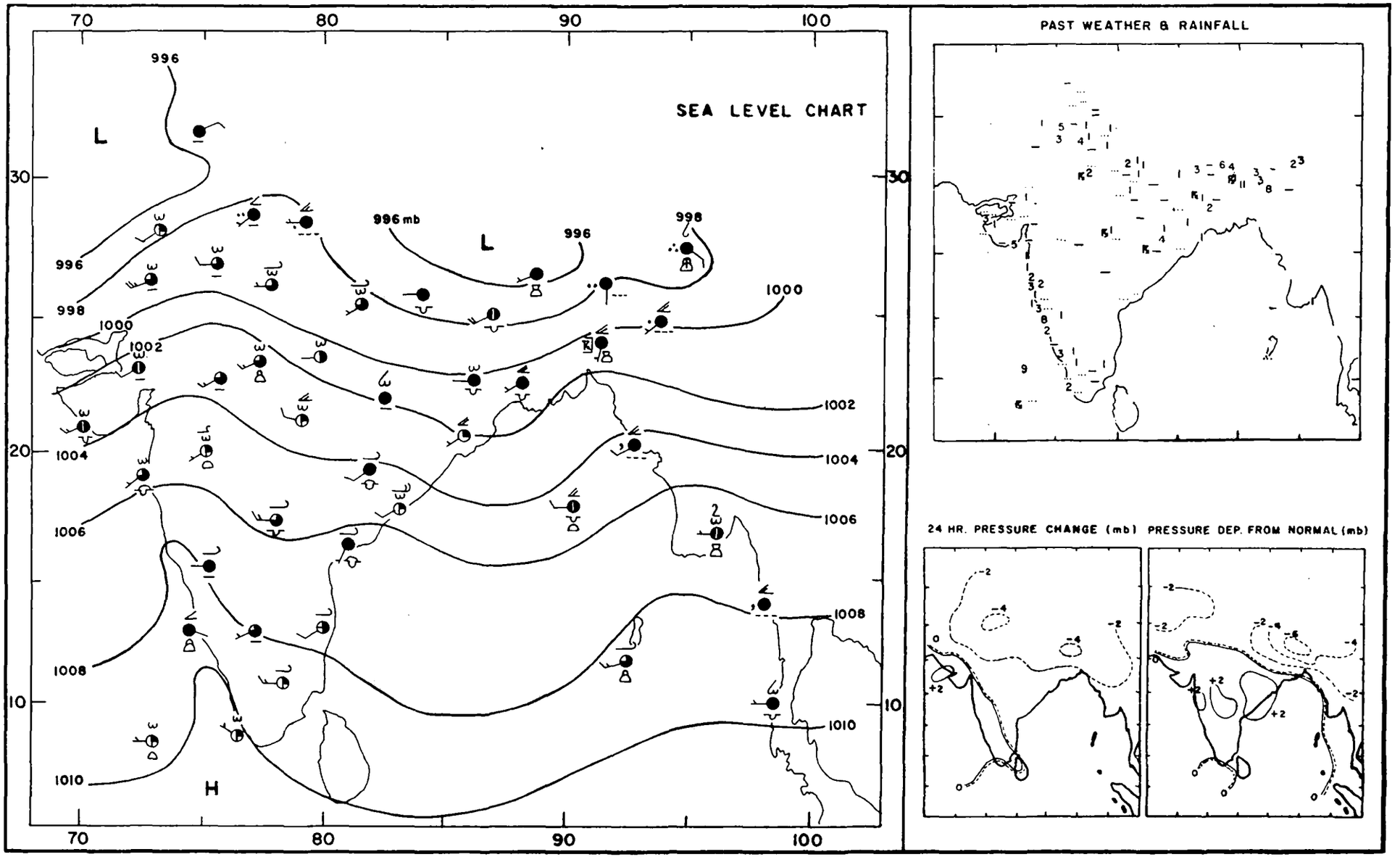


FIG. 8·2 UPPER WINDS 7 JUL.67 00 GMT

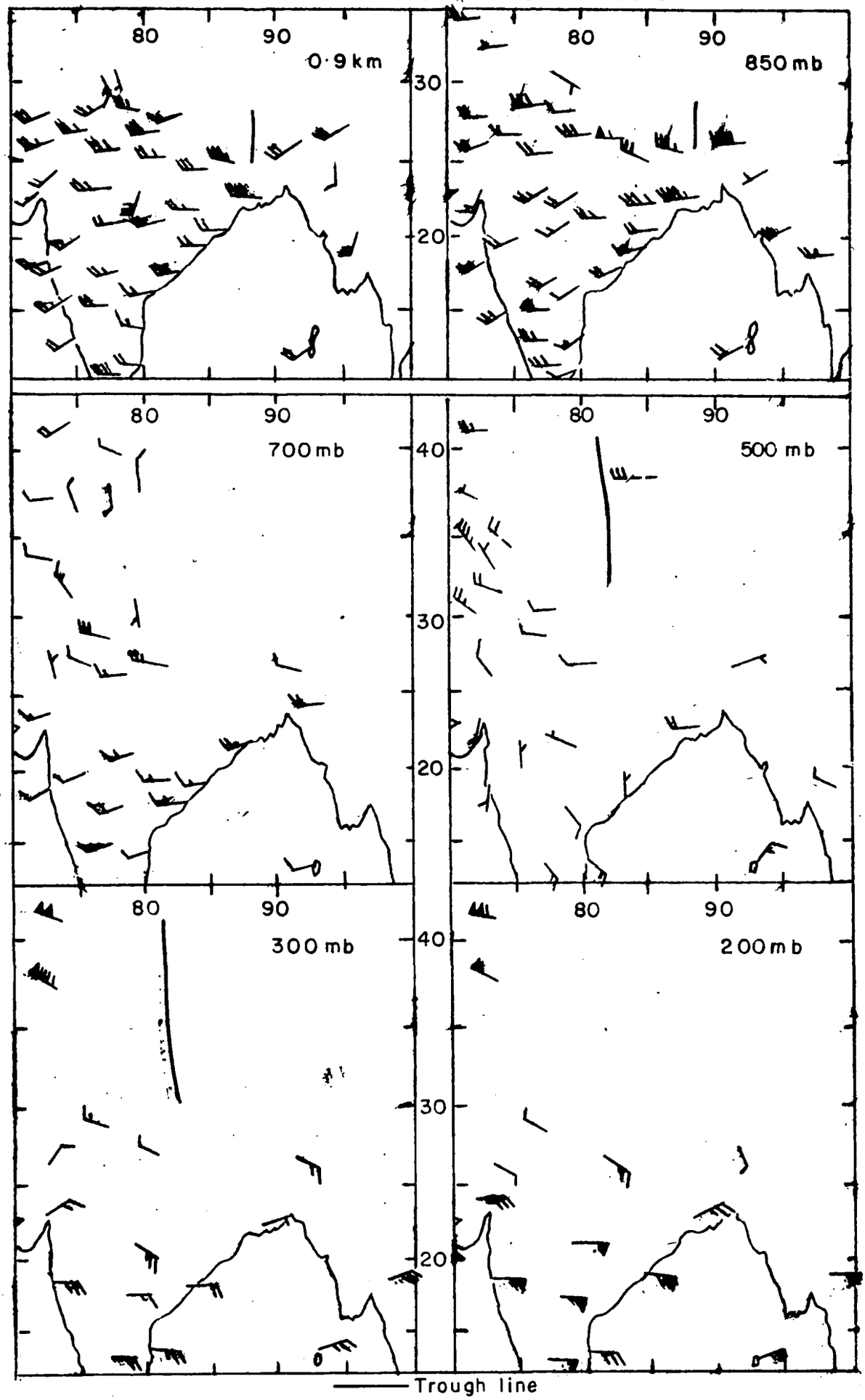


FIG. 8·3 UPPER WINDS 8 JUL. 67 00 GMT

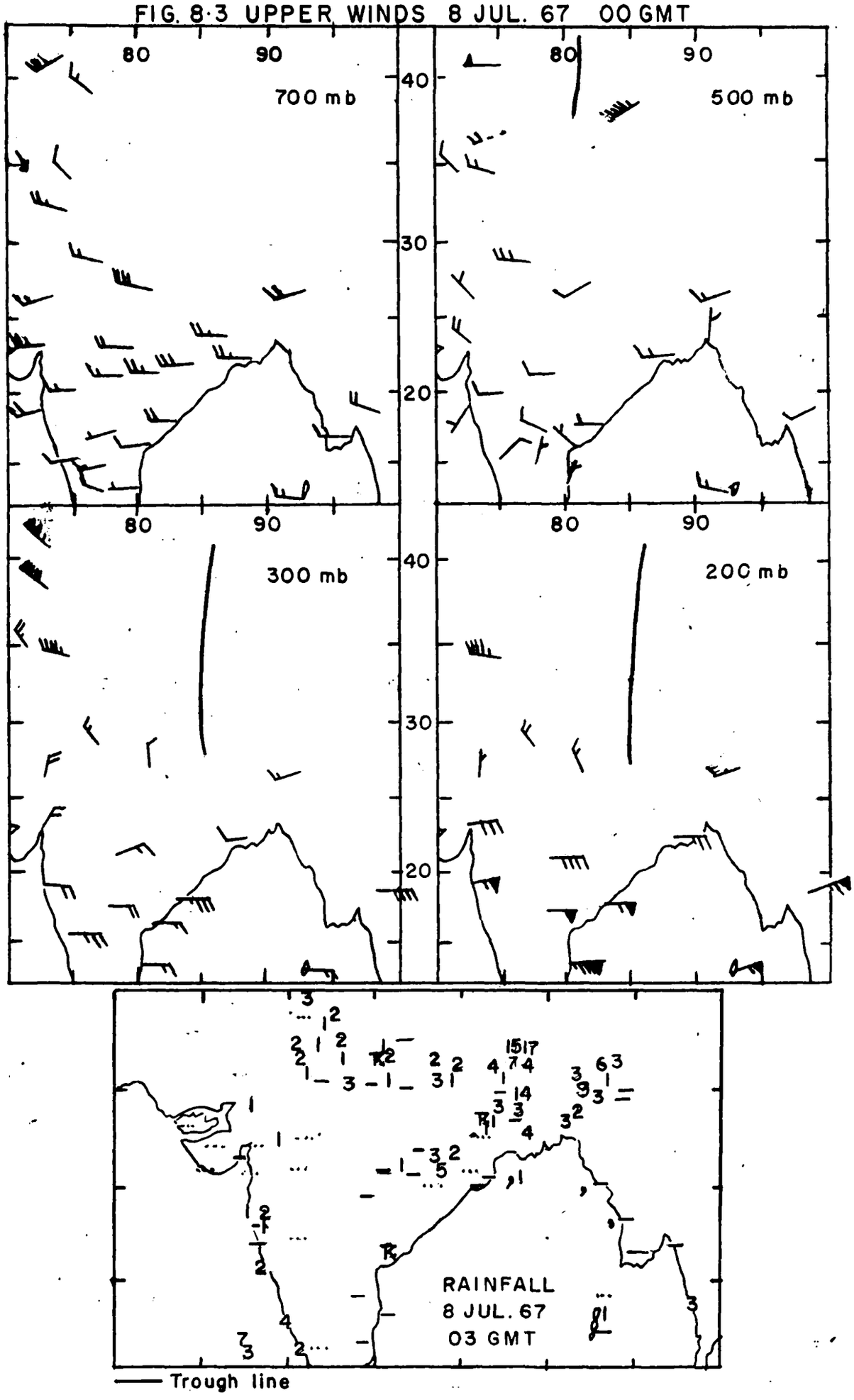


FIG. 8·4 UPPER WINDS 9 JUL. 67 00 GMT

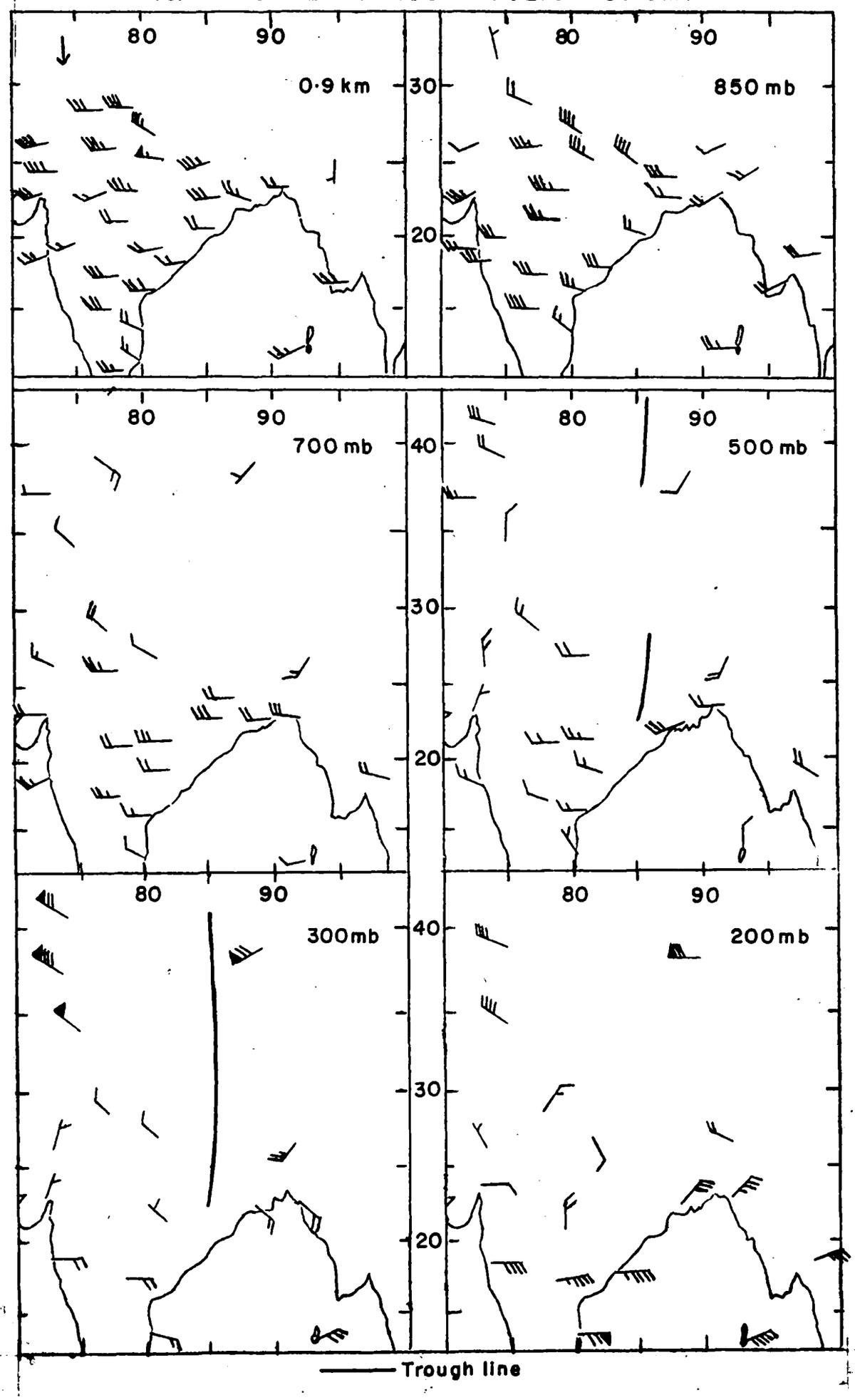


FIG. 8·5 SYNOPTIC CHARTS 0300 GMT 9 JUL. 67

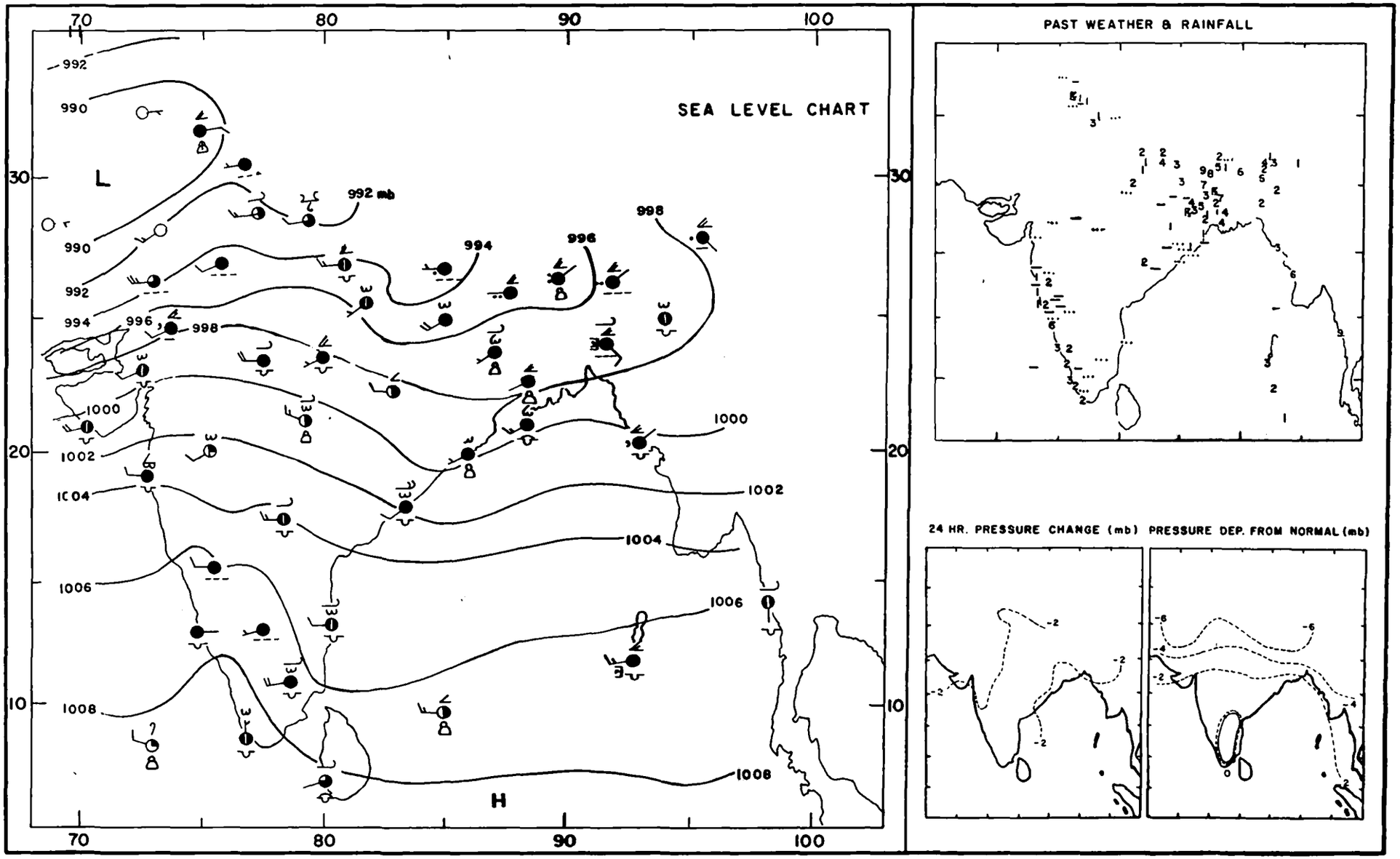
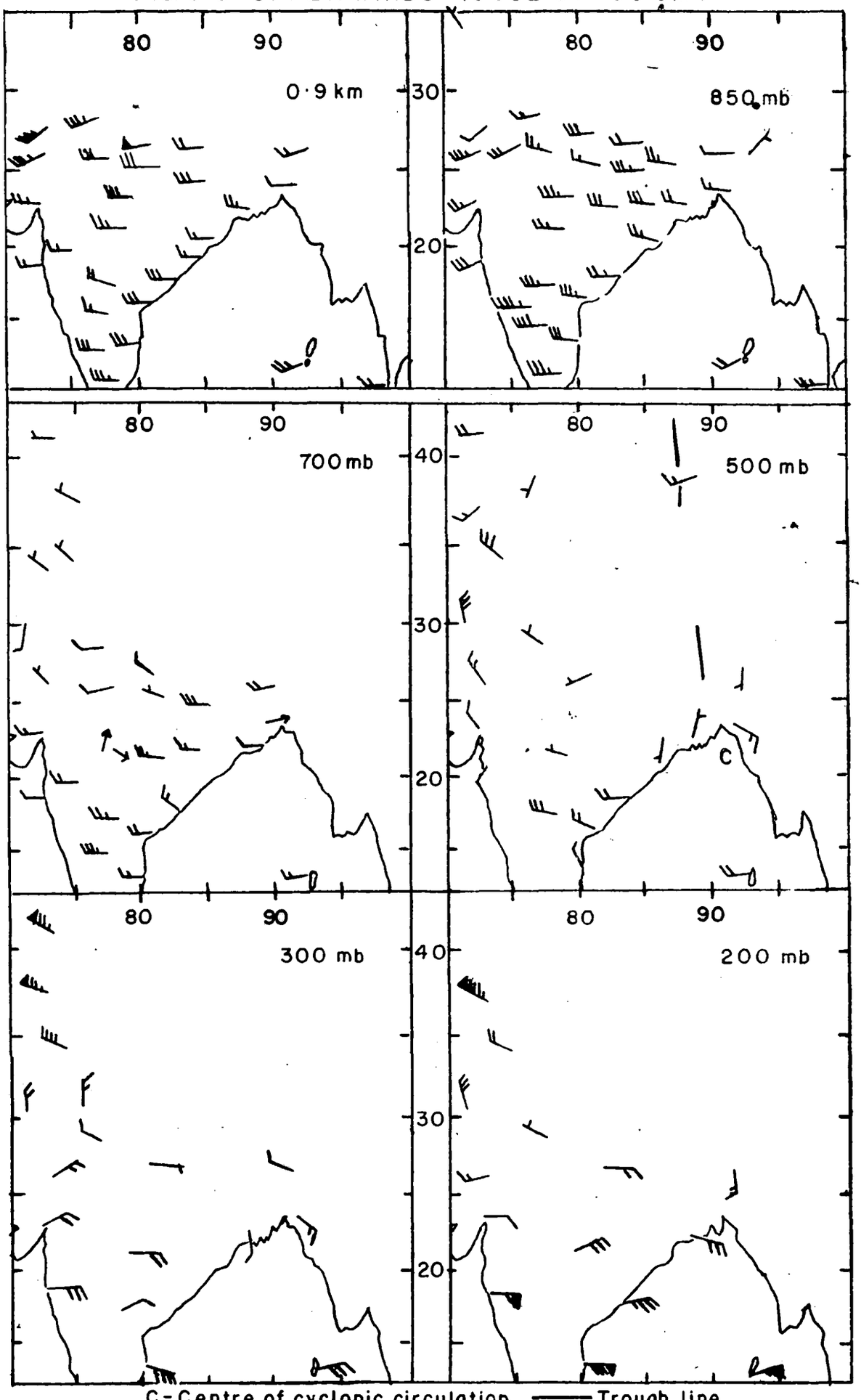
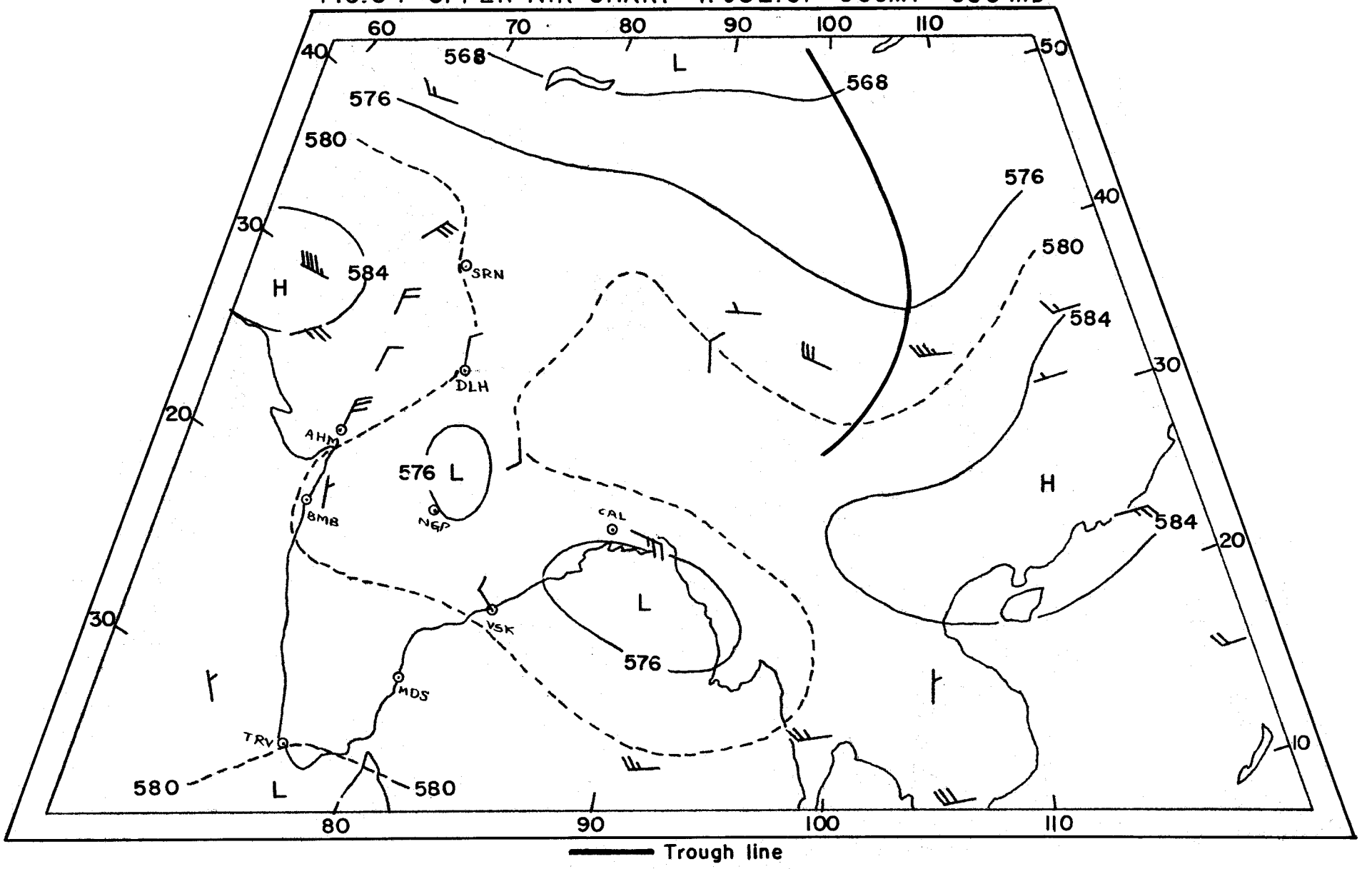


FIG. 8·6 UPPER WINDS 10 JUL 67 00 GMT



C - Centre of cyclonic circulation —— Trough line

FIG. 8·7 UPPER AIR CHART 11 JUL. 67 00GMT 500 mb



9.1

FIG. SYNOPTIC CHARTS 0300 GMT 12 AUG. 67

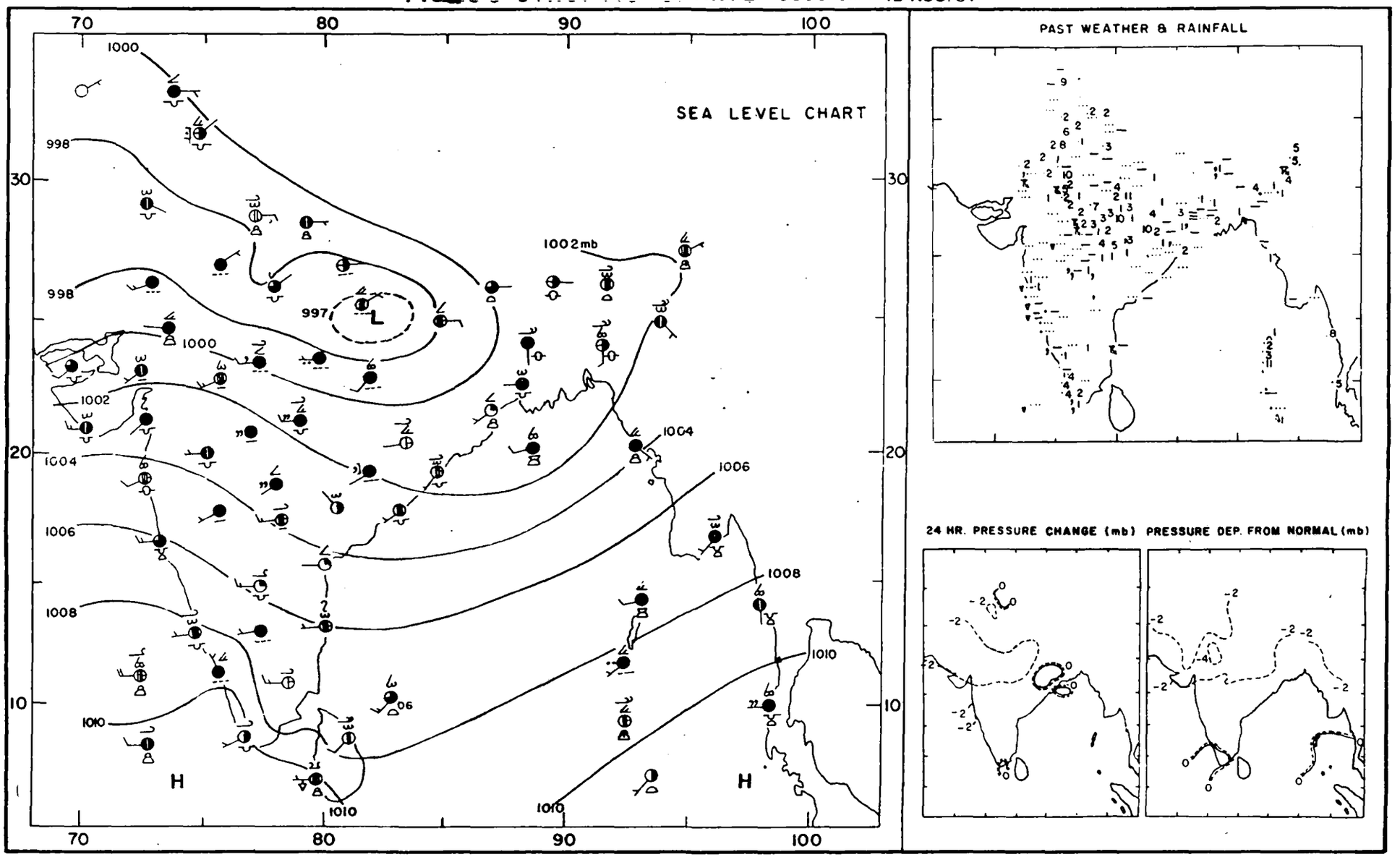
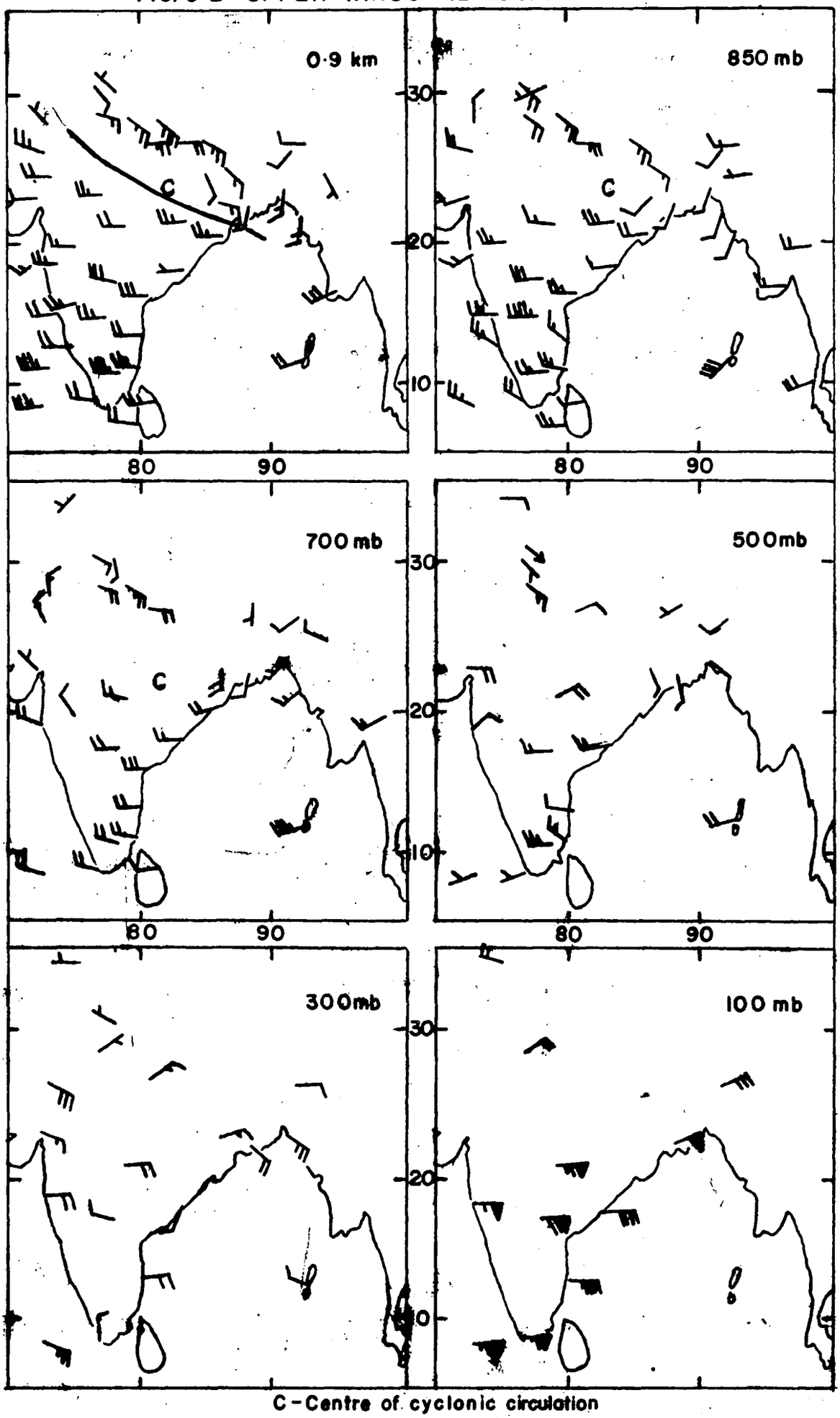


FIG. 9·2 UPPER WINDS 12 AUG. 67 00 GMT



C – Centre of cyclonic circulation

——— Trough line

FIG. 9.3 SYNOPTIC CHARTS 0300 GMT 13 AUG. 67

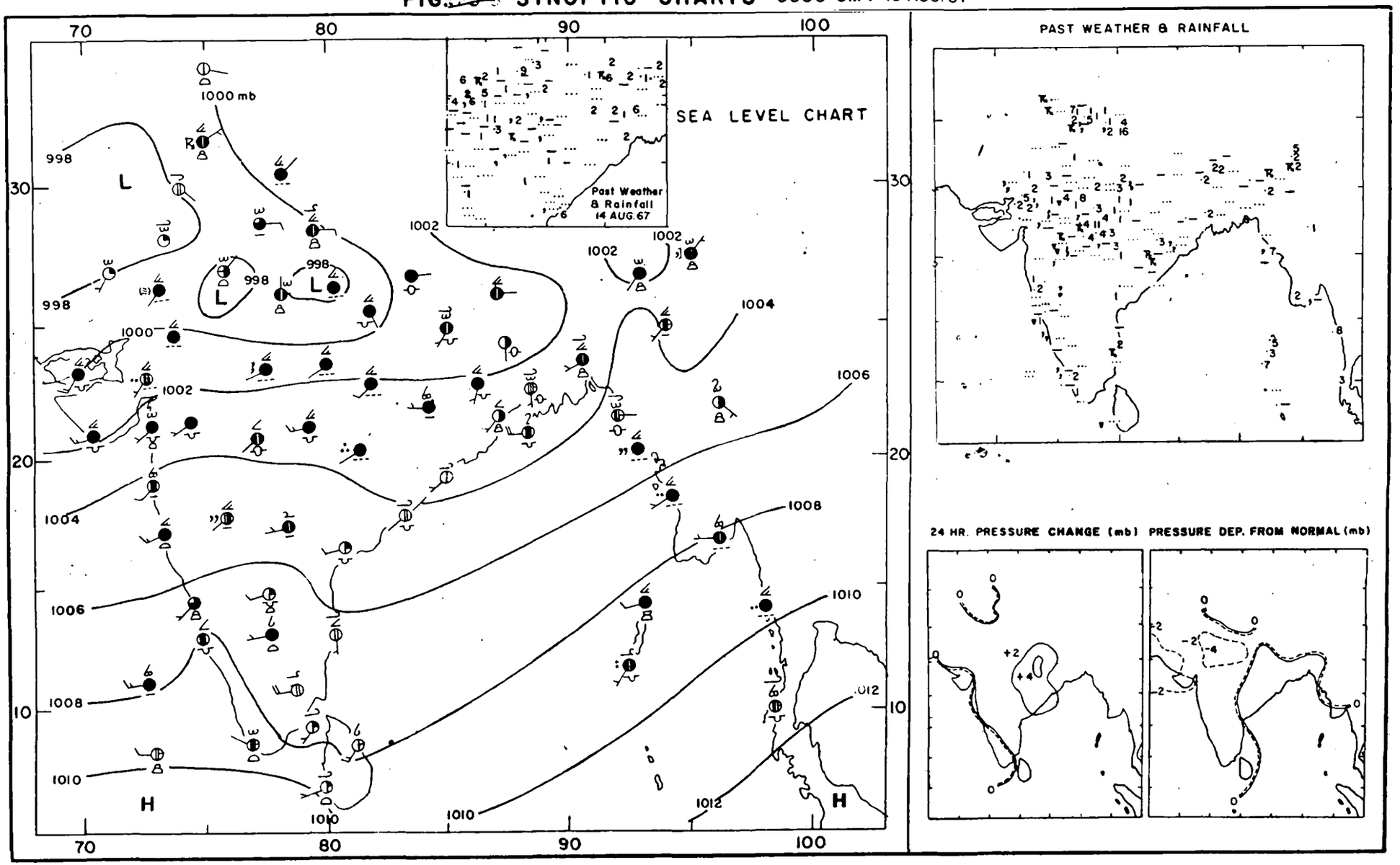
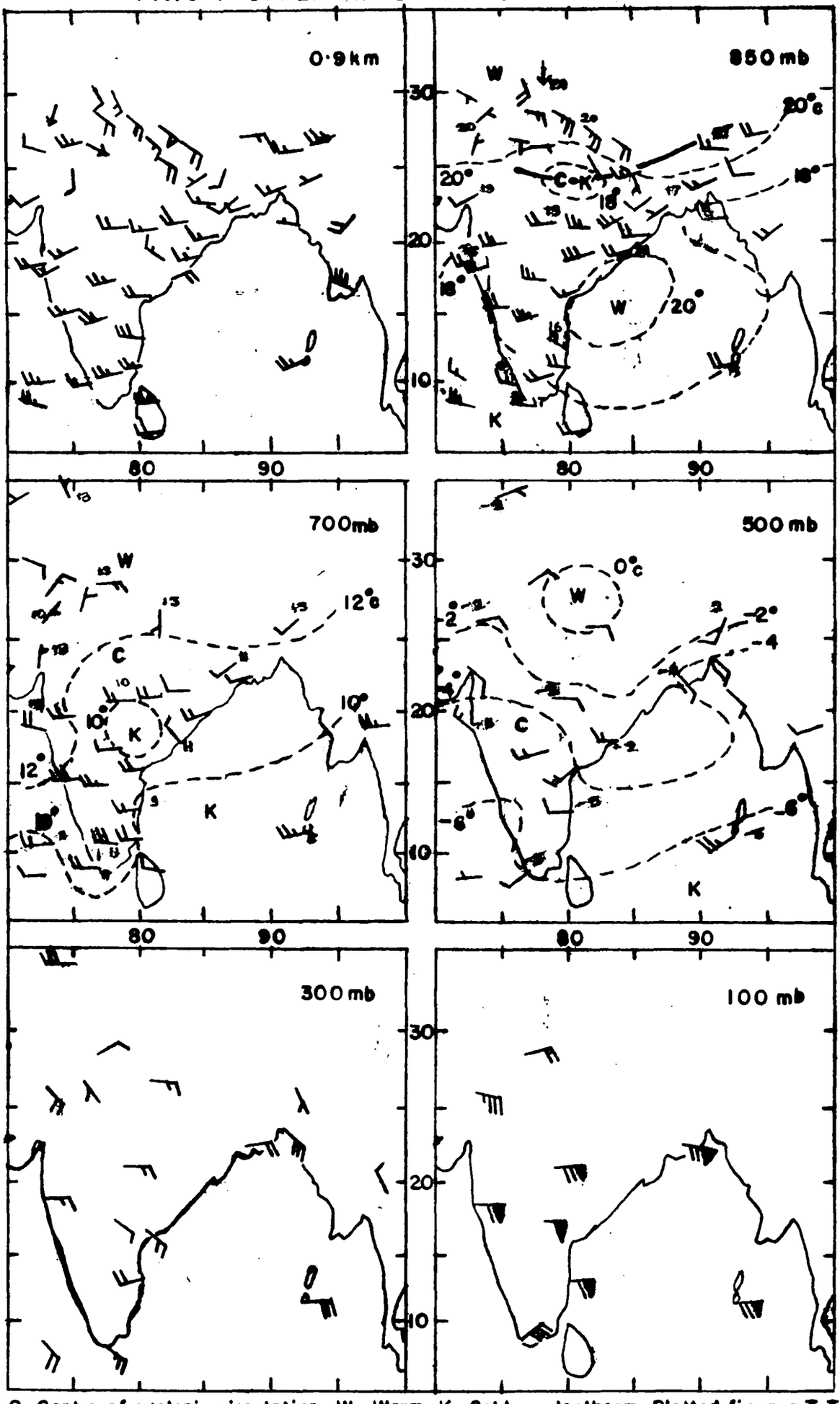


FIG. 9-4 UPPER WINDS 13 AUG. 67 00 GMT



C - Centre of cyclonic circulation W - Warm K - Cold ---- Isotherm Plotted figures $T_d T_d$

—— Trough line

FIG. 9·5 UPPER WINDS 15 AUG. 67 00GMT

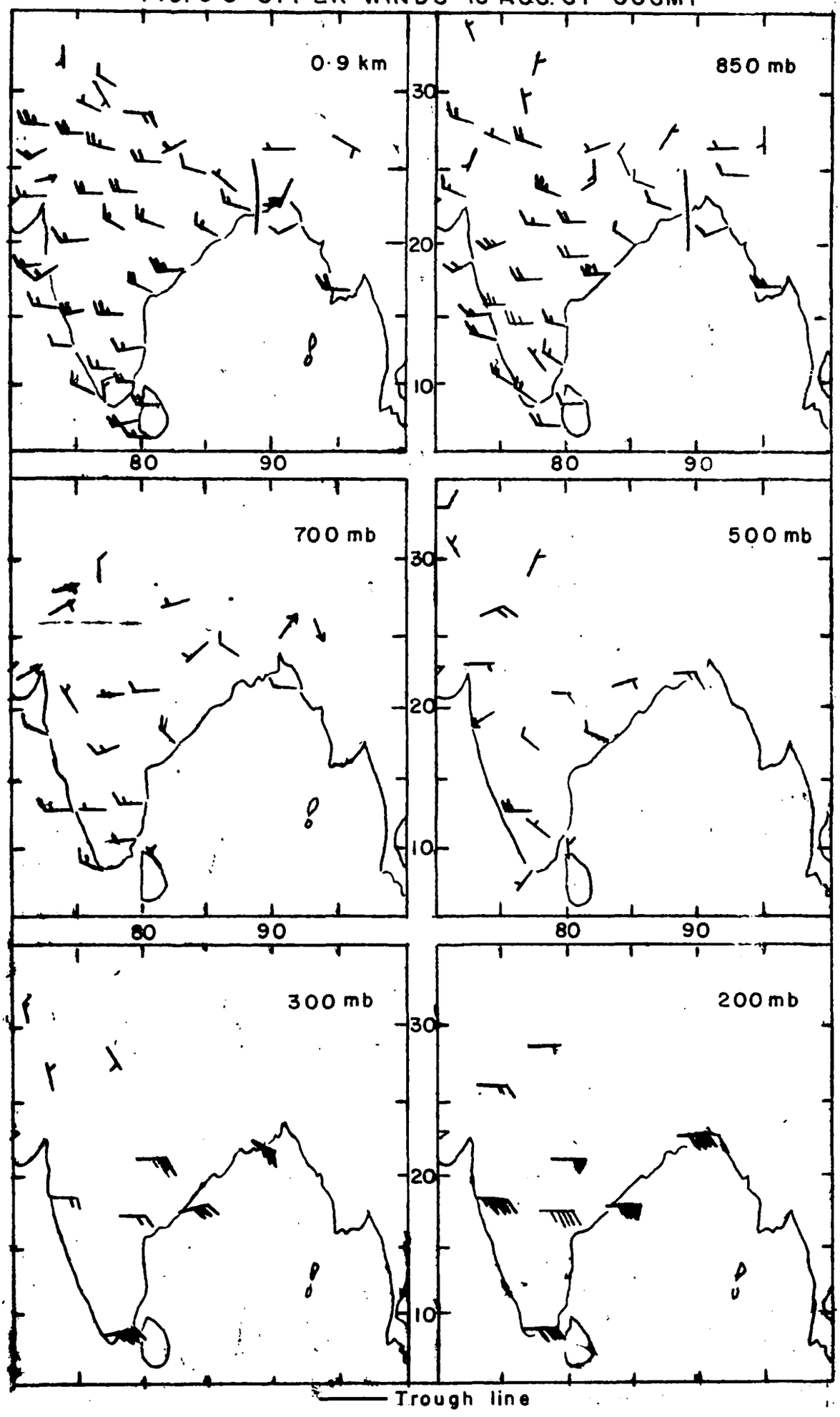


FIG. 9·6 SYNOPTIC CHARTS 0300 GMT 15 AUG. 67

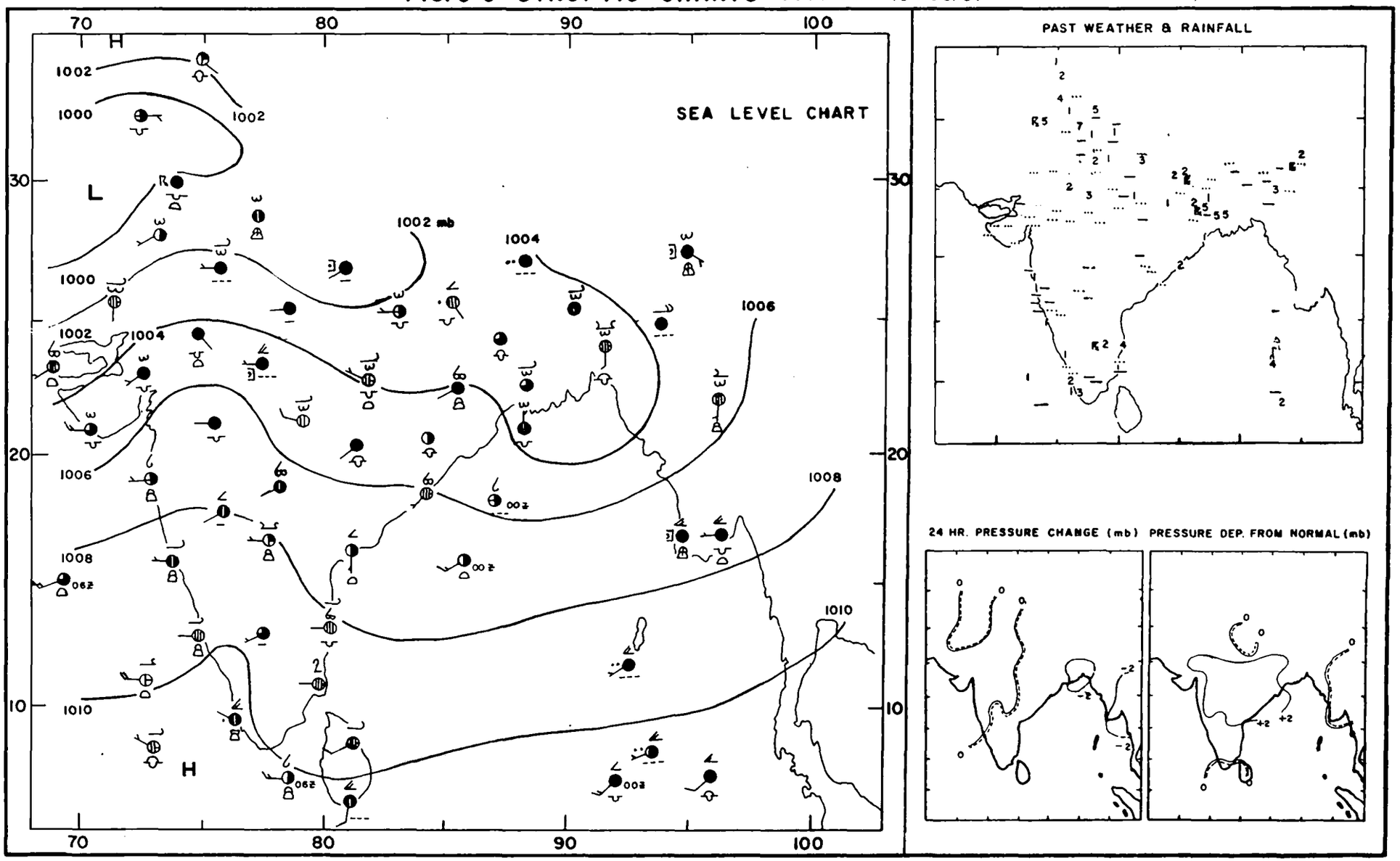


FIG. 9·7 SYNOPTIC CHARTS 0000 GMT 14 AUG. 67

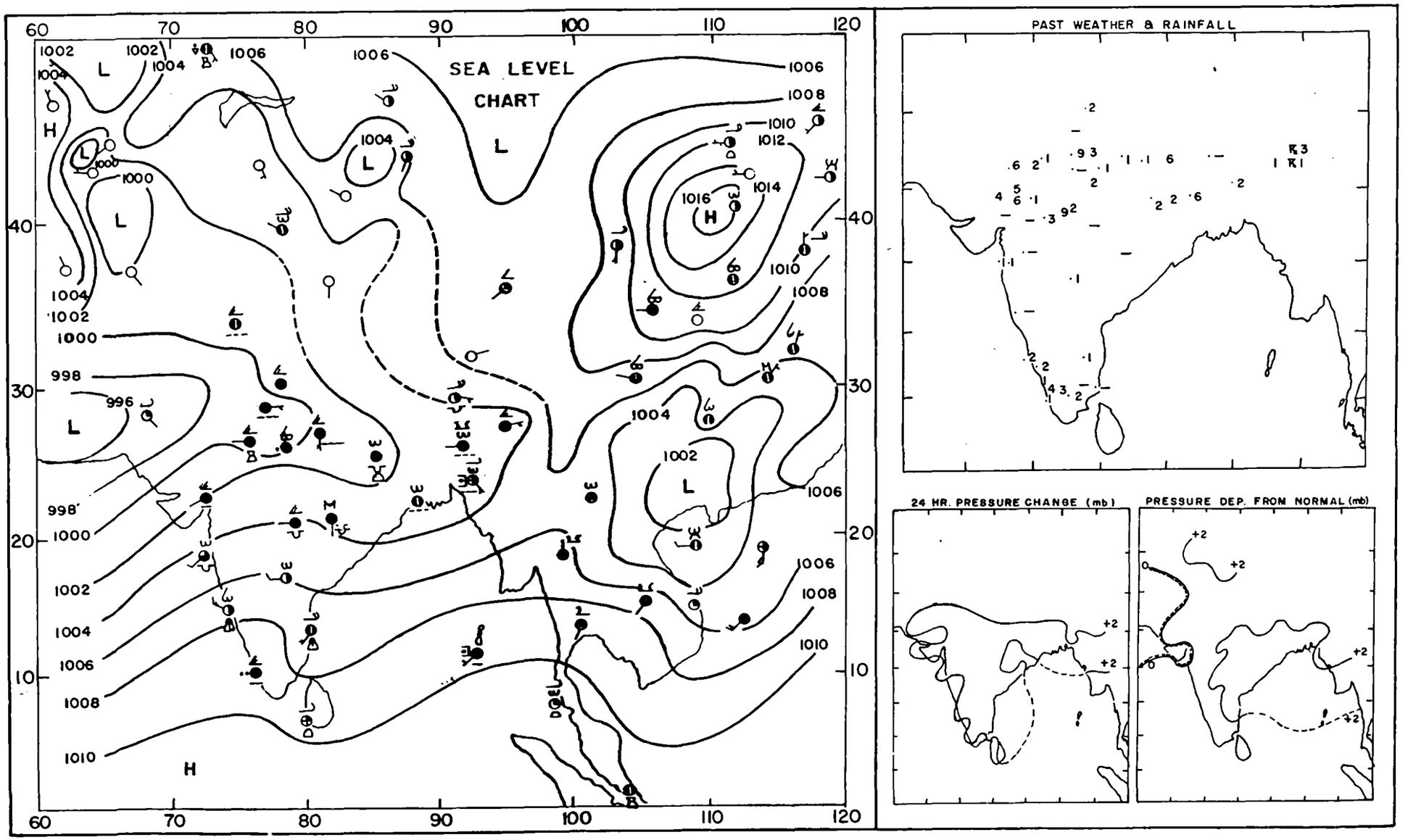
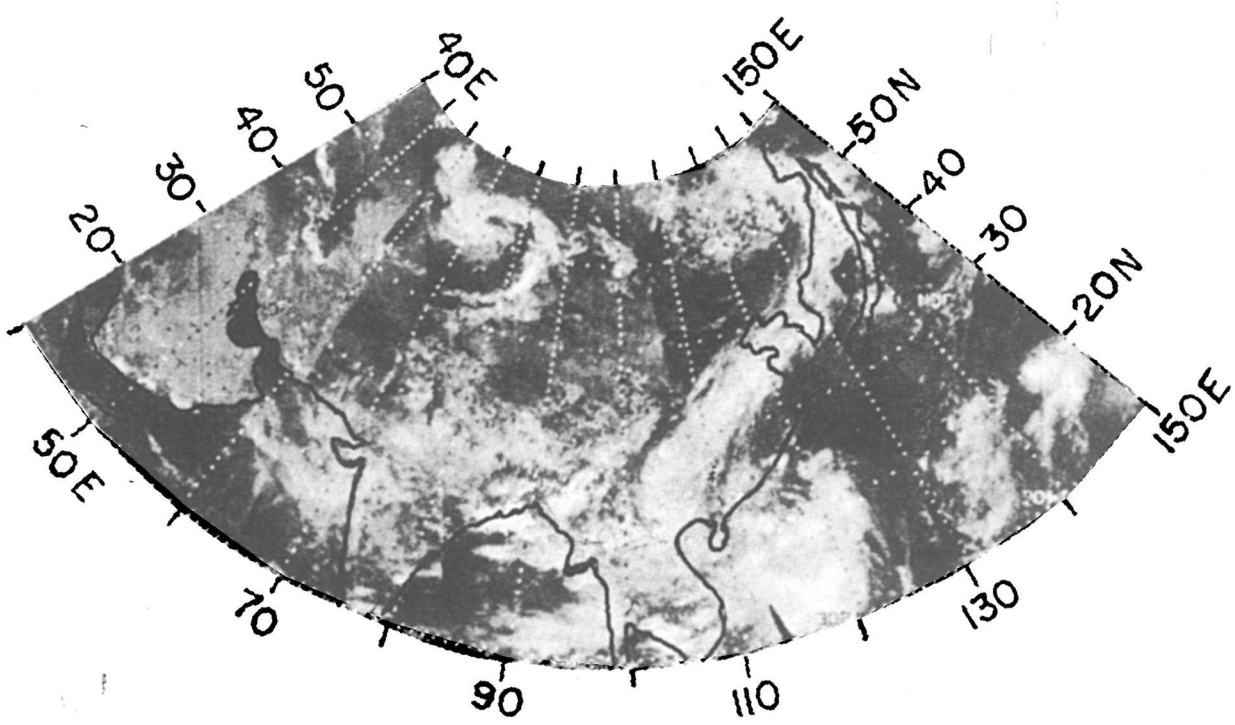


FIG. 9·8

ESSA-5

DATE : 14 August 67



Copied from Catalog of Meteorological Satellite Data
ESSA-3 & ESSA-5 Television Cloud Photography
(ESSA publication KMRD No. 5.315)

FIG. 9·9 MEAN TEPHIGRAMS OF GAUHATI

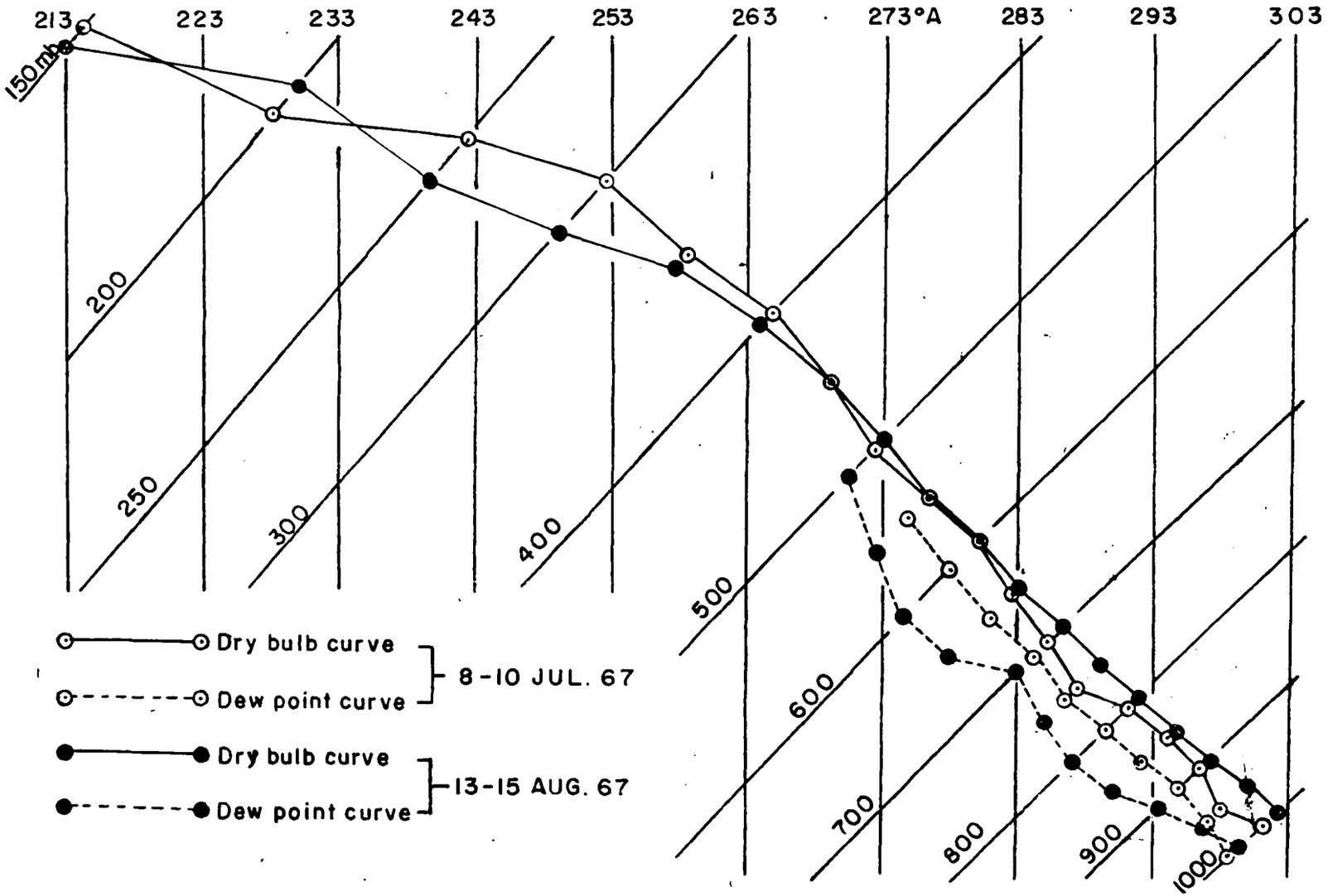


FIG. 10·1 SYNOPTIC CHARTS 0000 GMT 13 AUG. 69

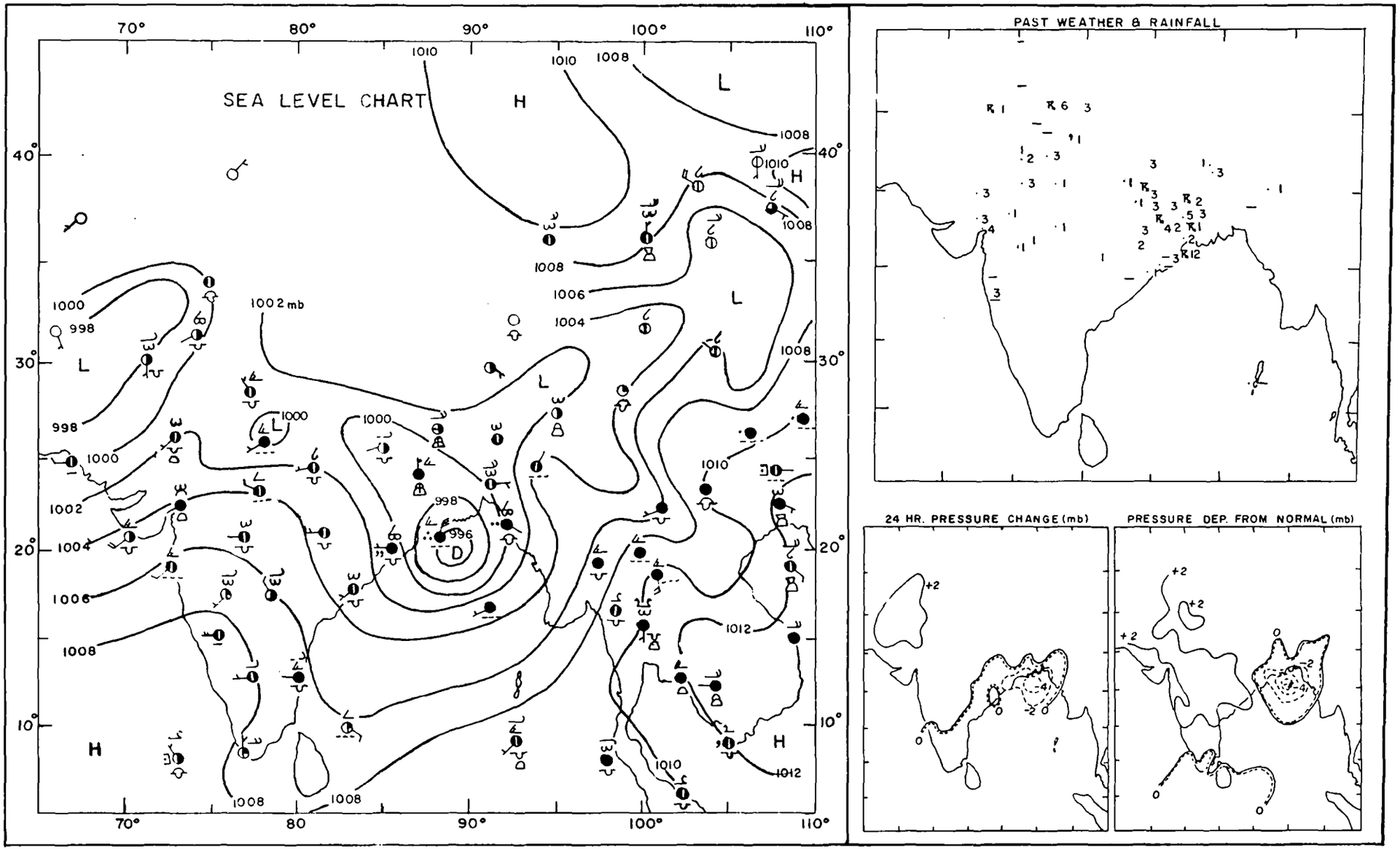
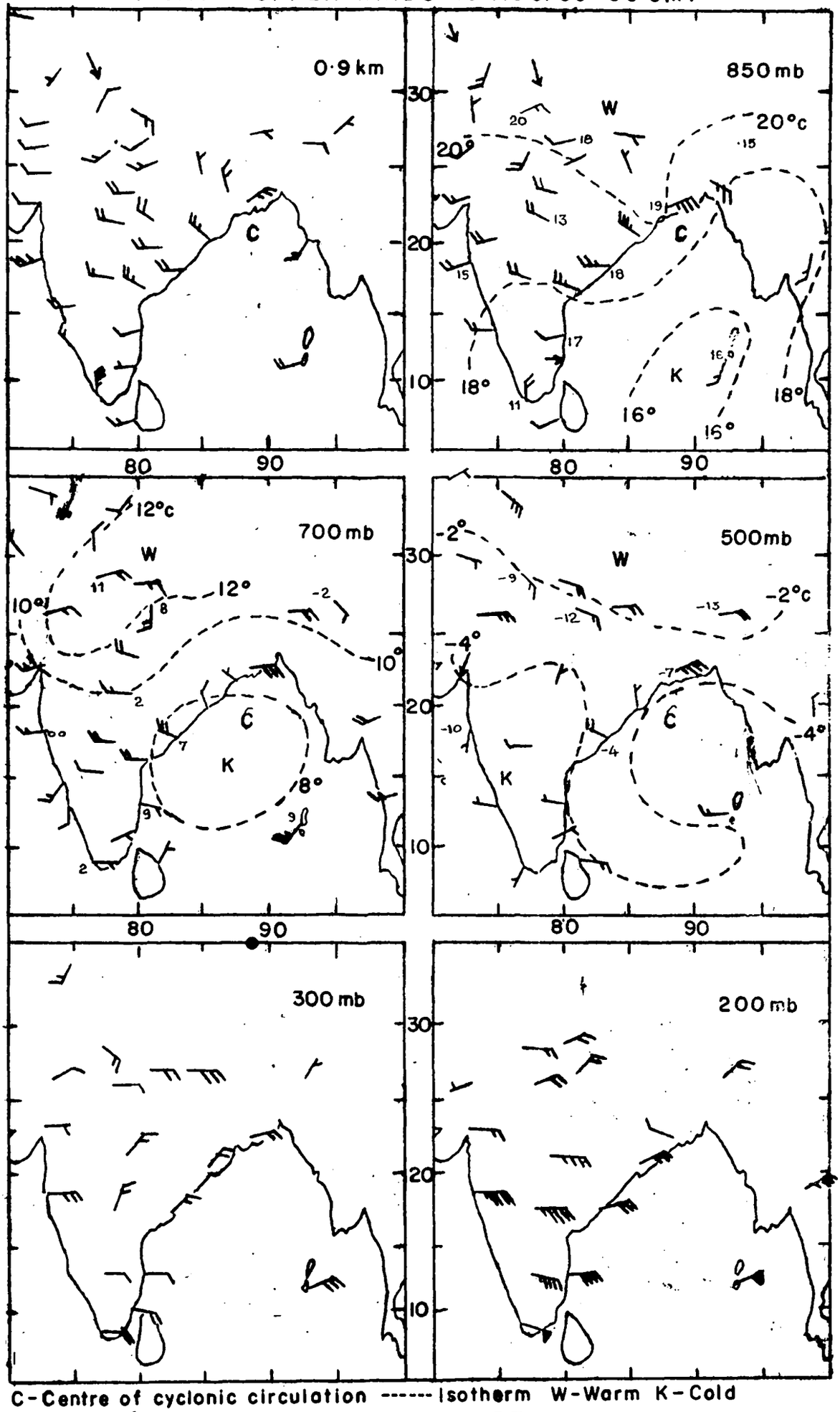


FIG. 10·2 UPPER WINDS 13 AUG. 69 00 GMT



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

Plotted figures $T_d T_d$

FIG. 10·3 SYNOPTIC CHARTS 0300 GMT 15 AUG. 69.

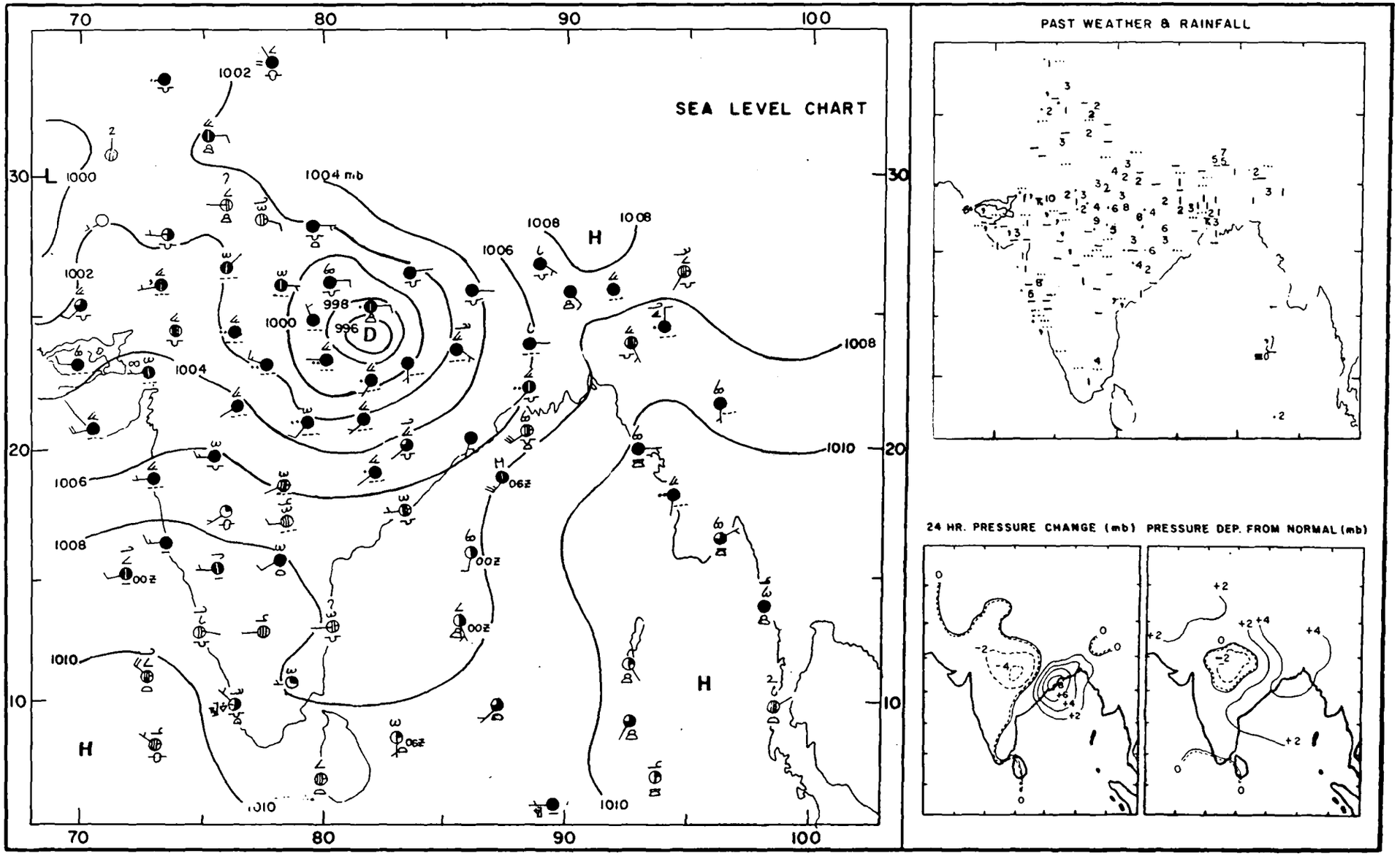
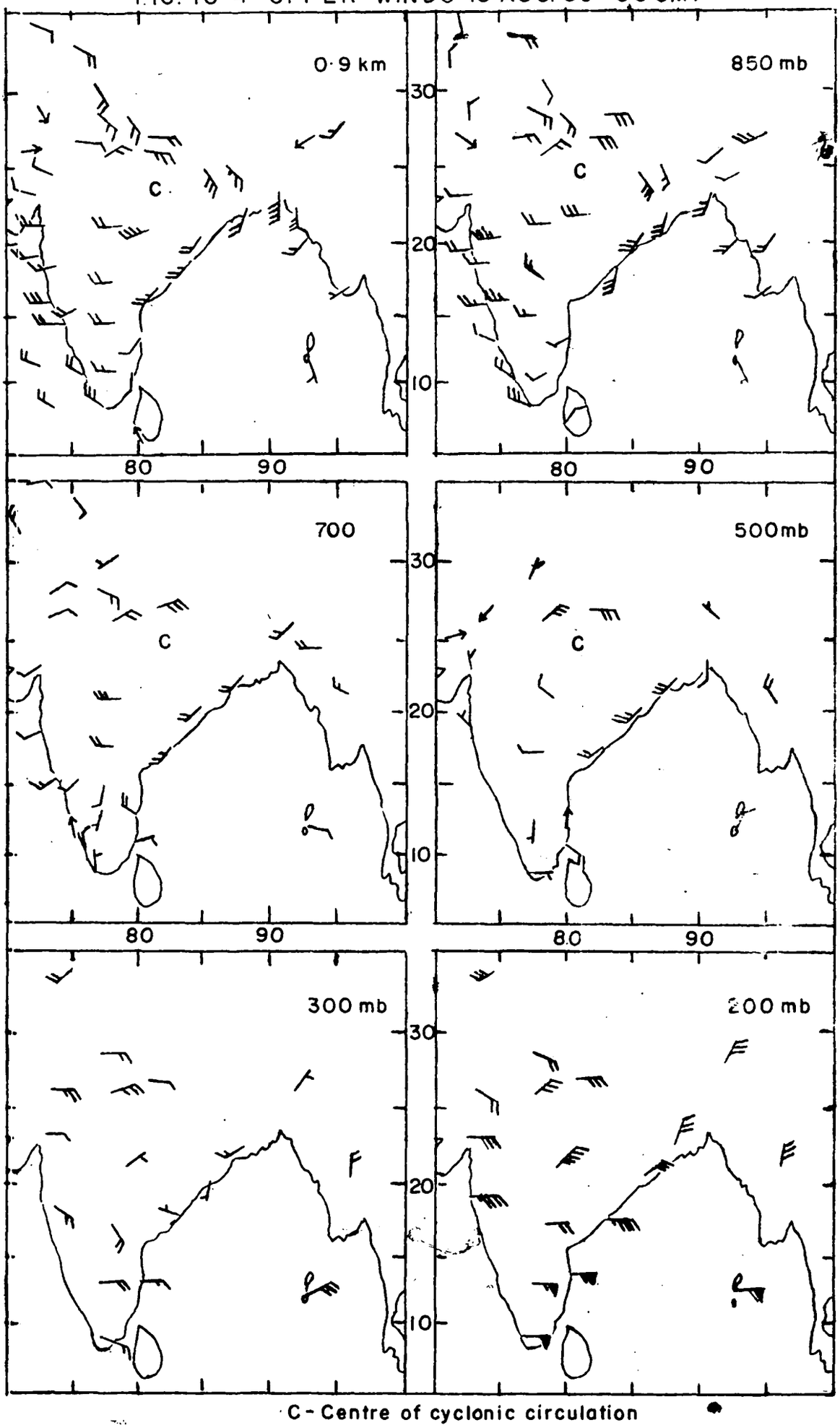


FIG. 10·4 UPPER WINDS 15 AUG. 69 00GMT



C - Centre of cyclonic circulation

10.5

FIG. ~~9~~ SYNOPTIC CHARTS 0300 GMT 16 AUG. 69

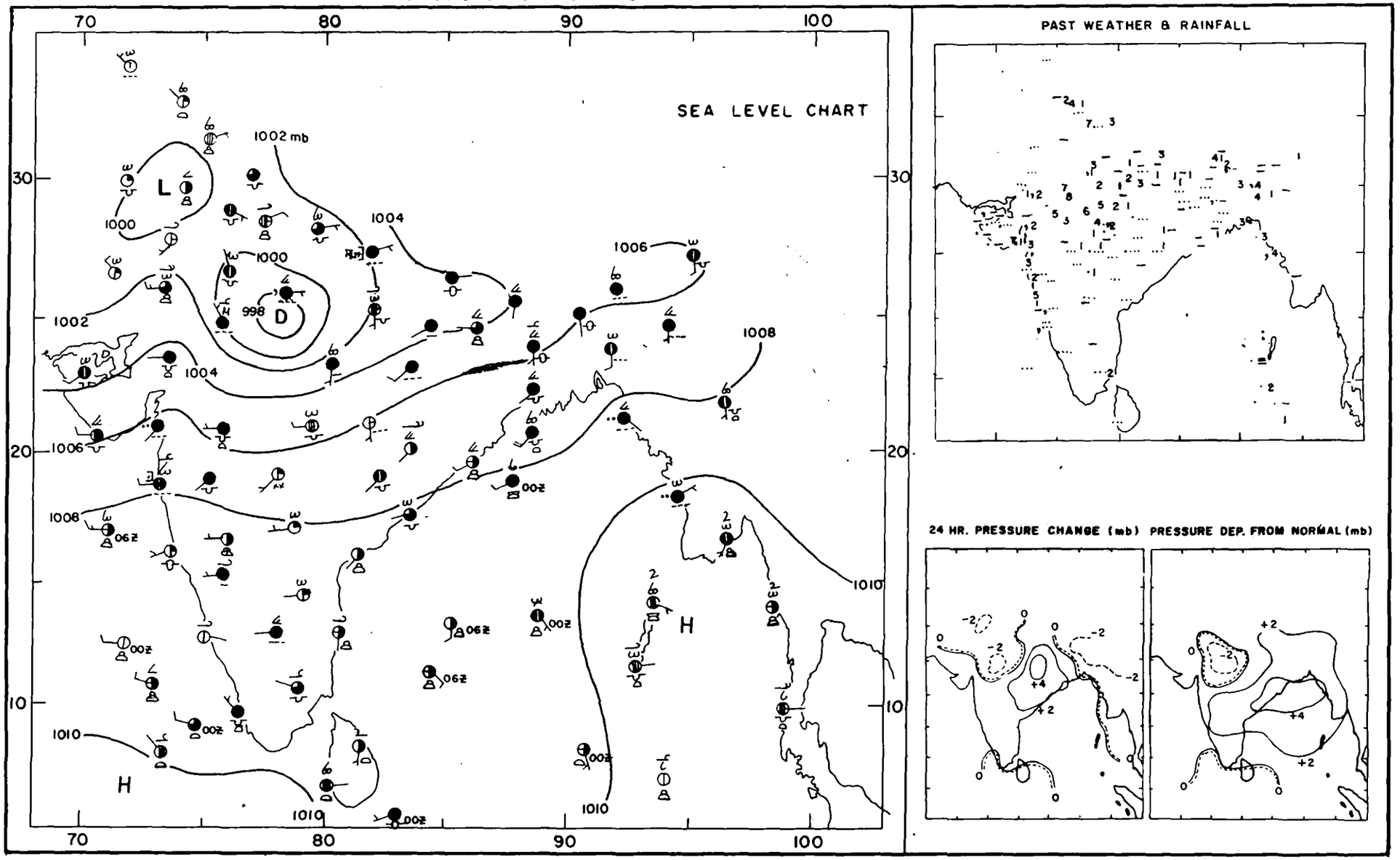
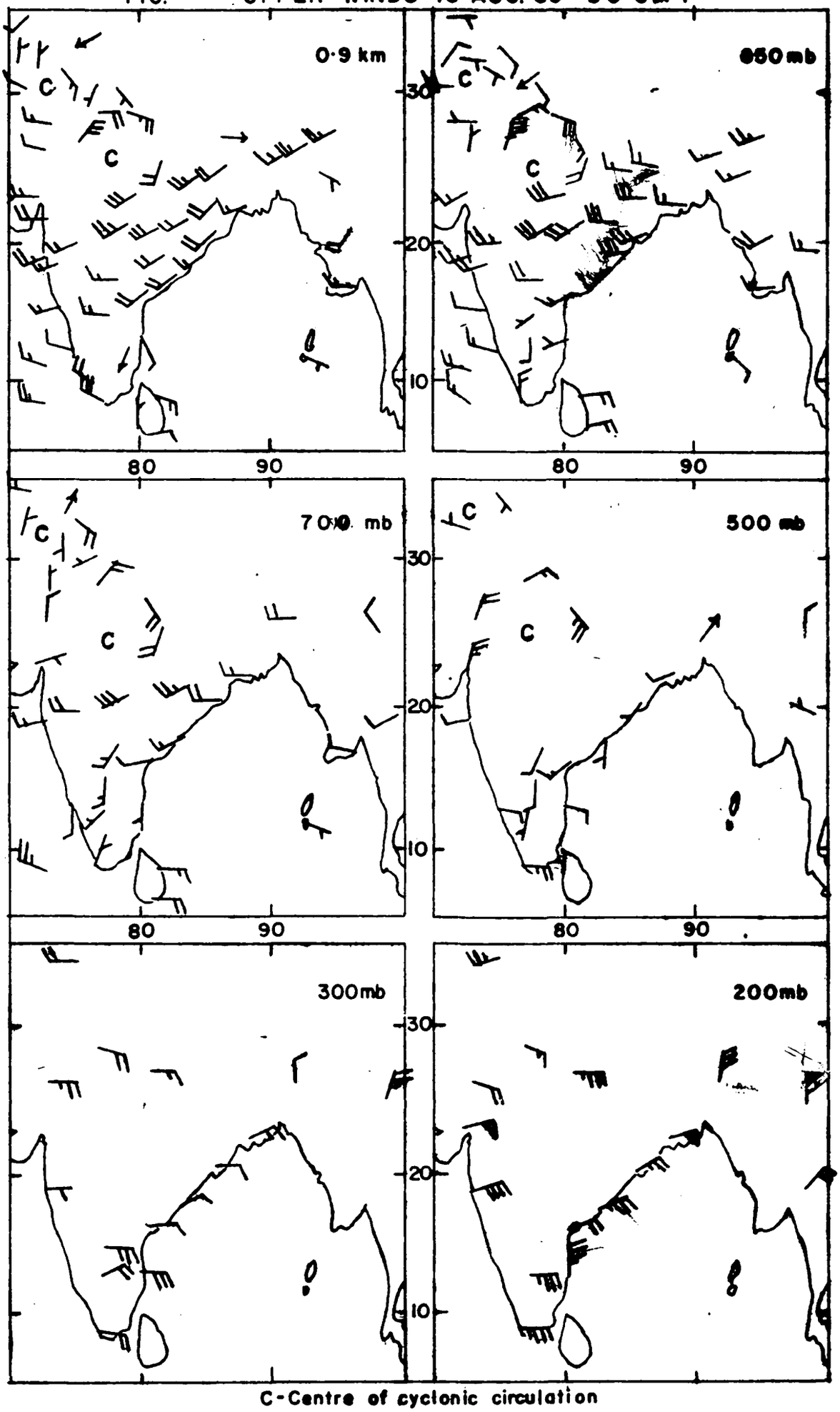
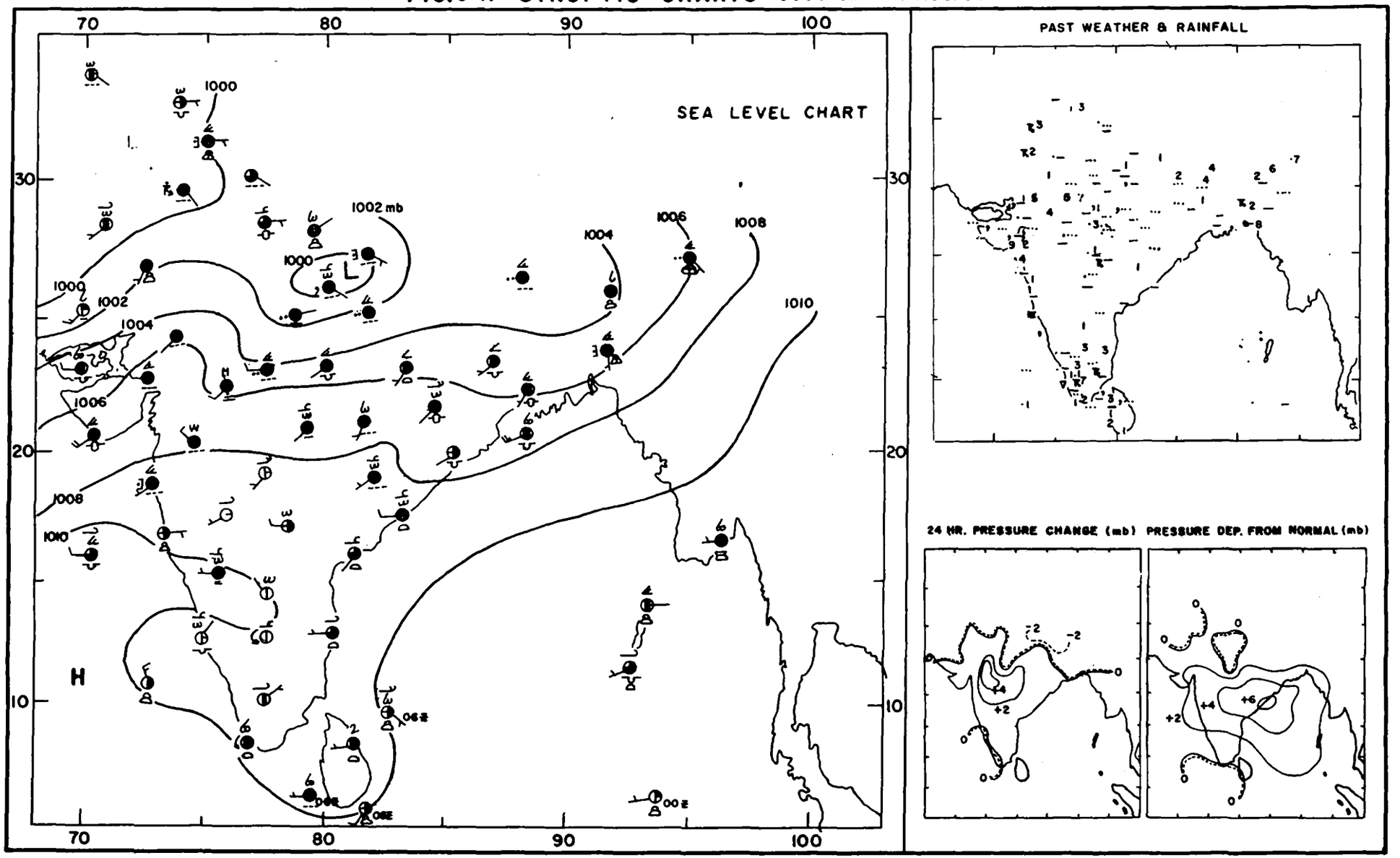


FIG. 10.6 UPPER WINDS 16 AUG. 69 00 GMT



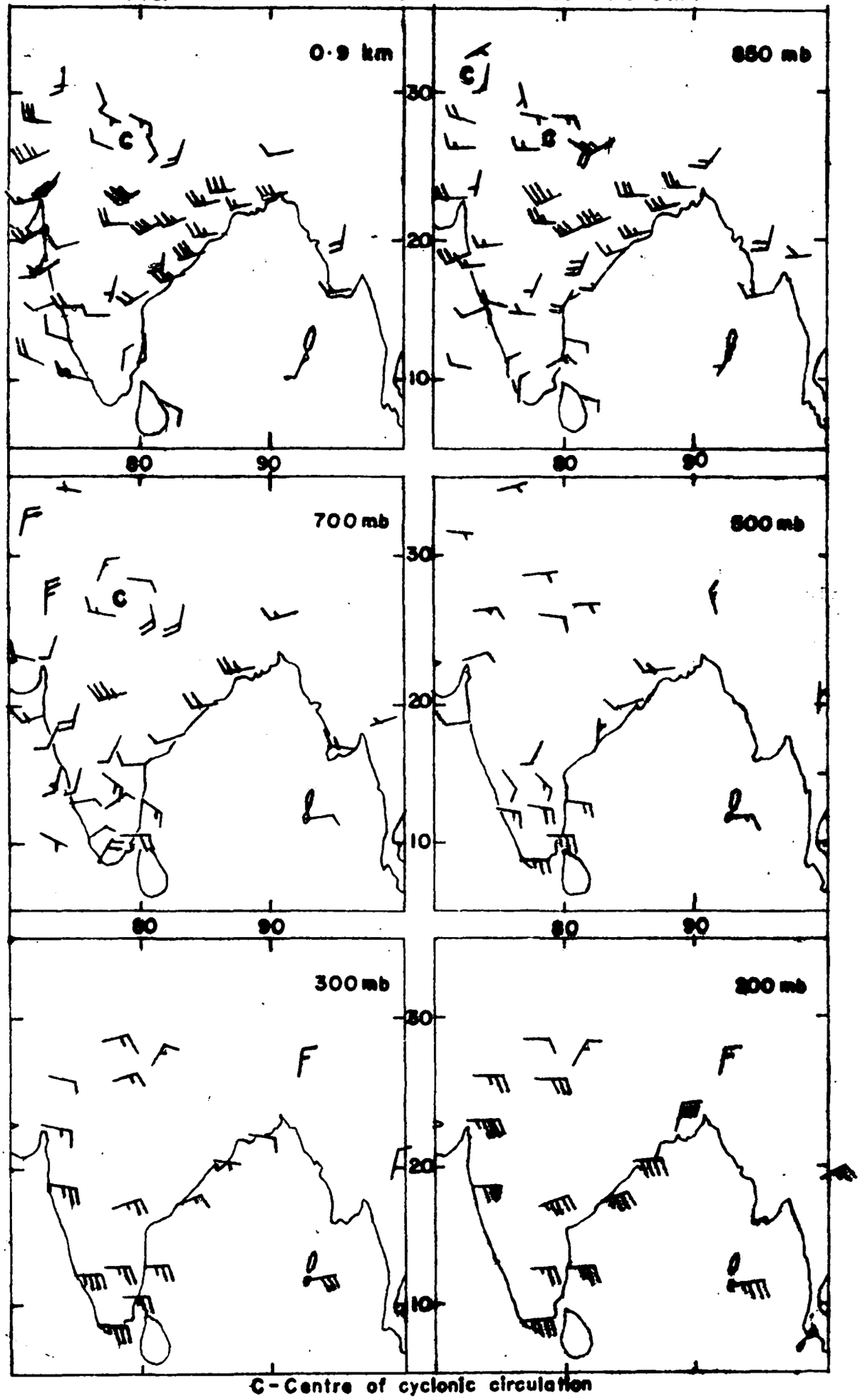
C-Centre of cyclonic circulation

FIG. ~~9 H~~ SYNOPTIC CHARTS 0300 GMT 17 AUG. 69



10.8

FIG. ~~5.12~~ UPPER WINDS 17 AUG. 69 00 GMT



C - Centre of cyclonic circulation

10.9

FIG. ~~9~~ SYNOPTIC CHARTS 0300 GMT 18 AUG. 69

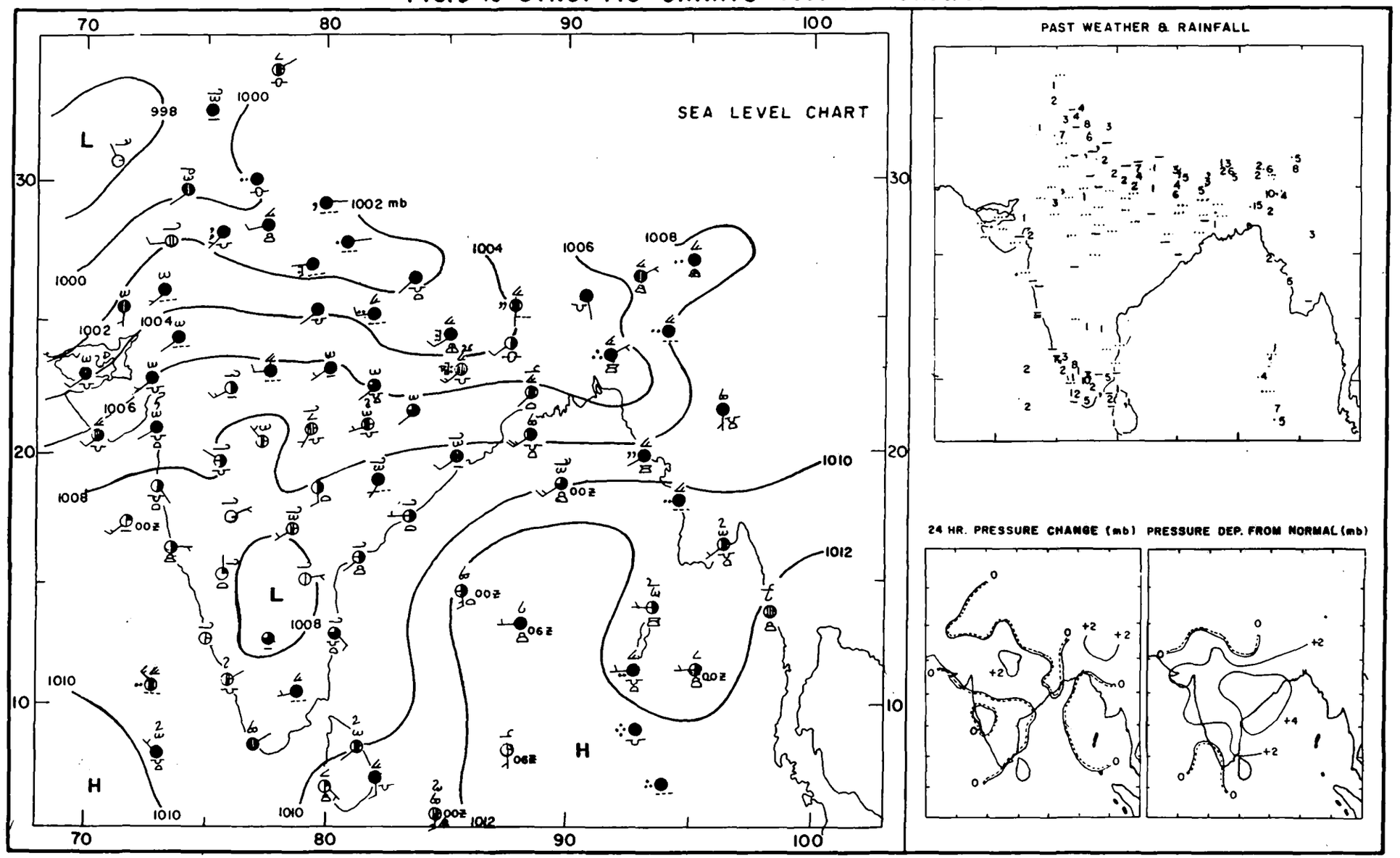


FIG. 10·10 UPPER AIR CHARTS 00 GMT

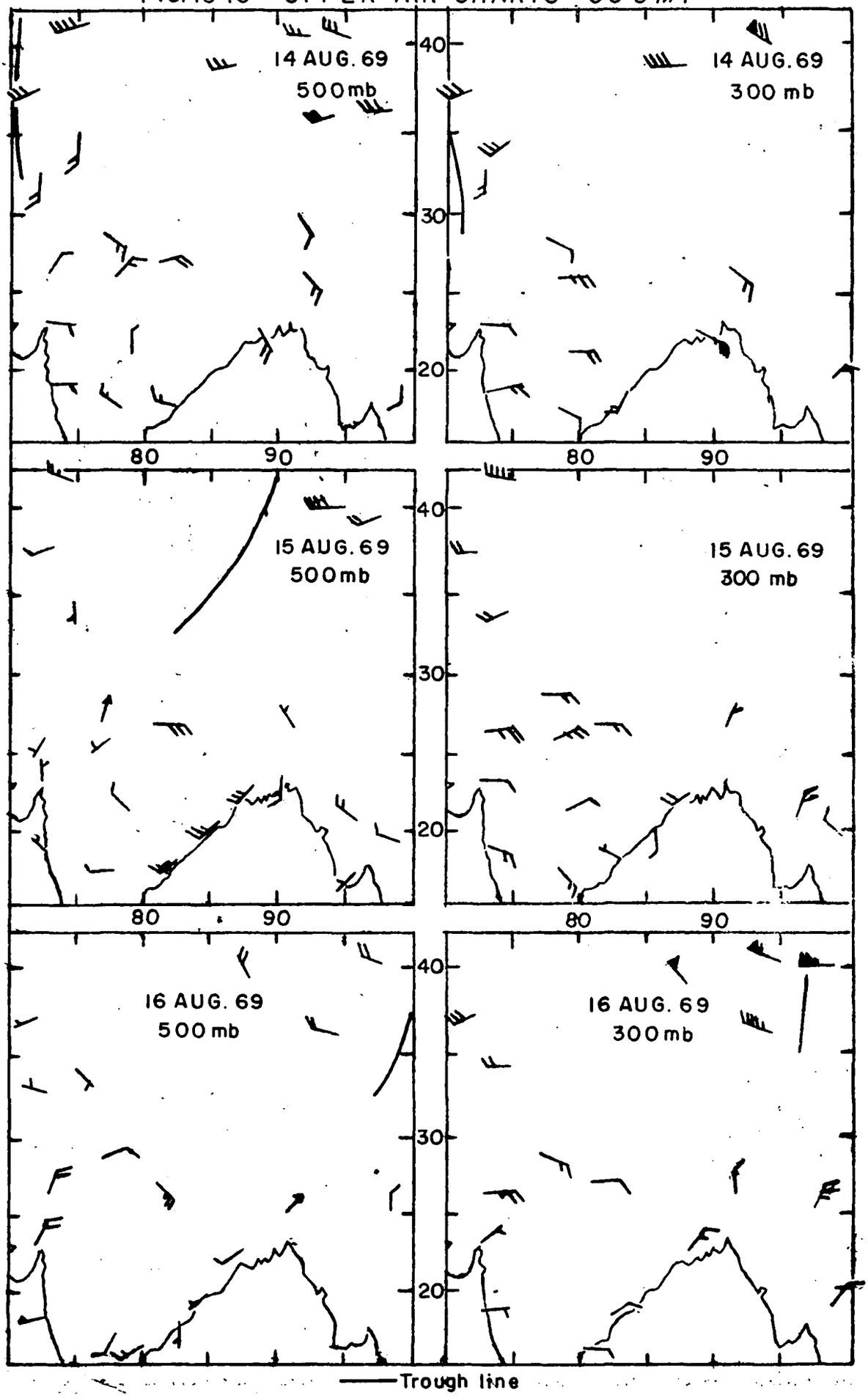


FIG. 10·11

NIMBUS-3

ORBIT 1689,1688

DATE 18 AUG.69

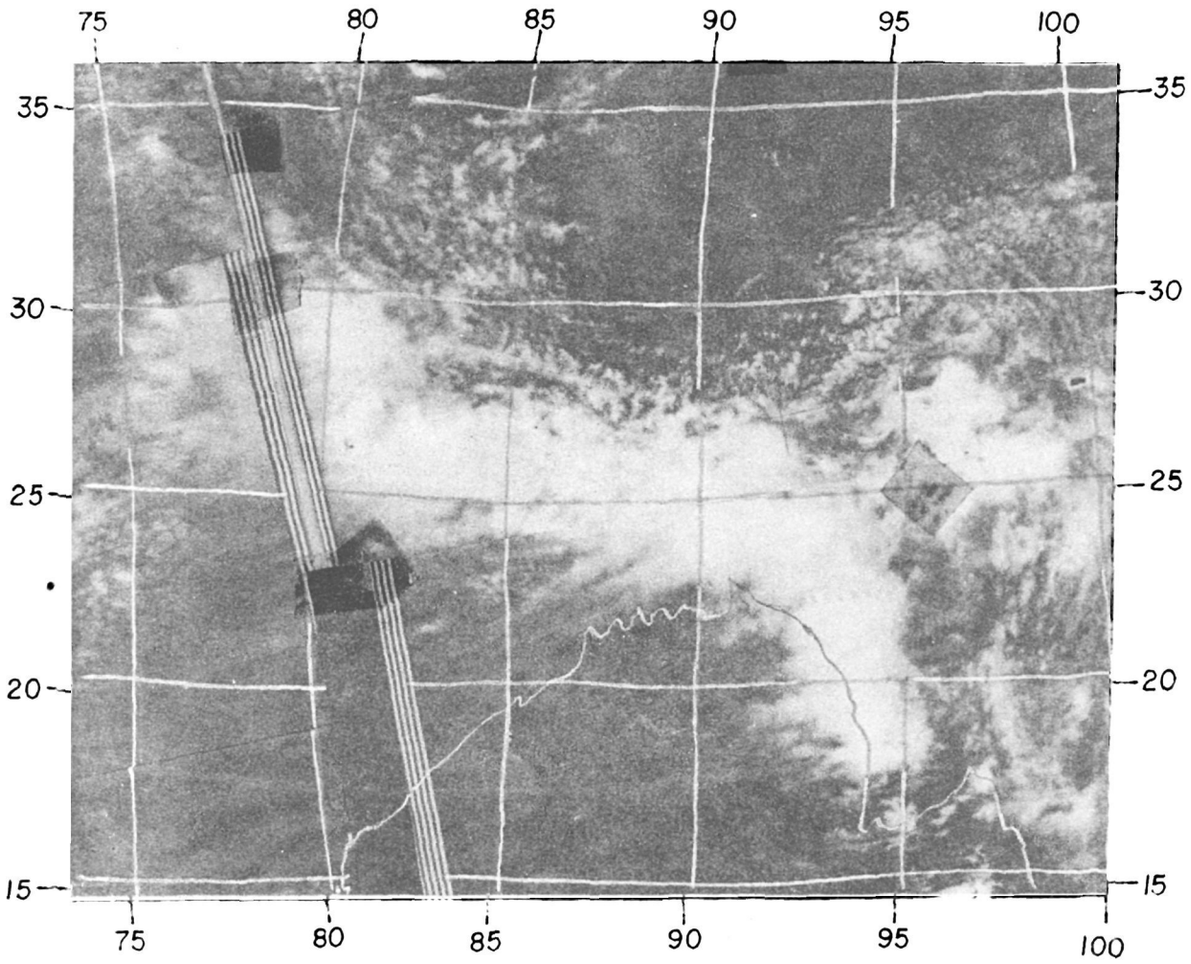


FIG. 6.1 SYNOPTIC CHARTS 0300 GMT 23 AUG. 66

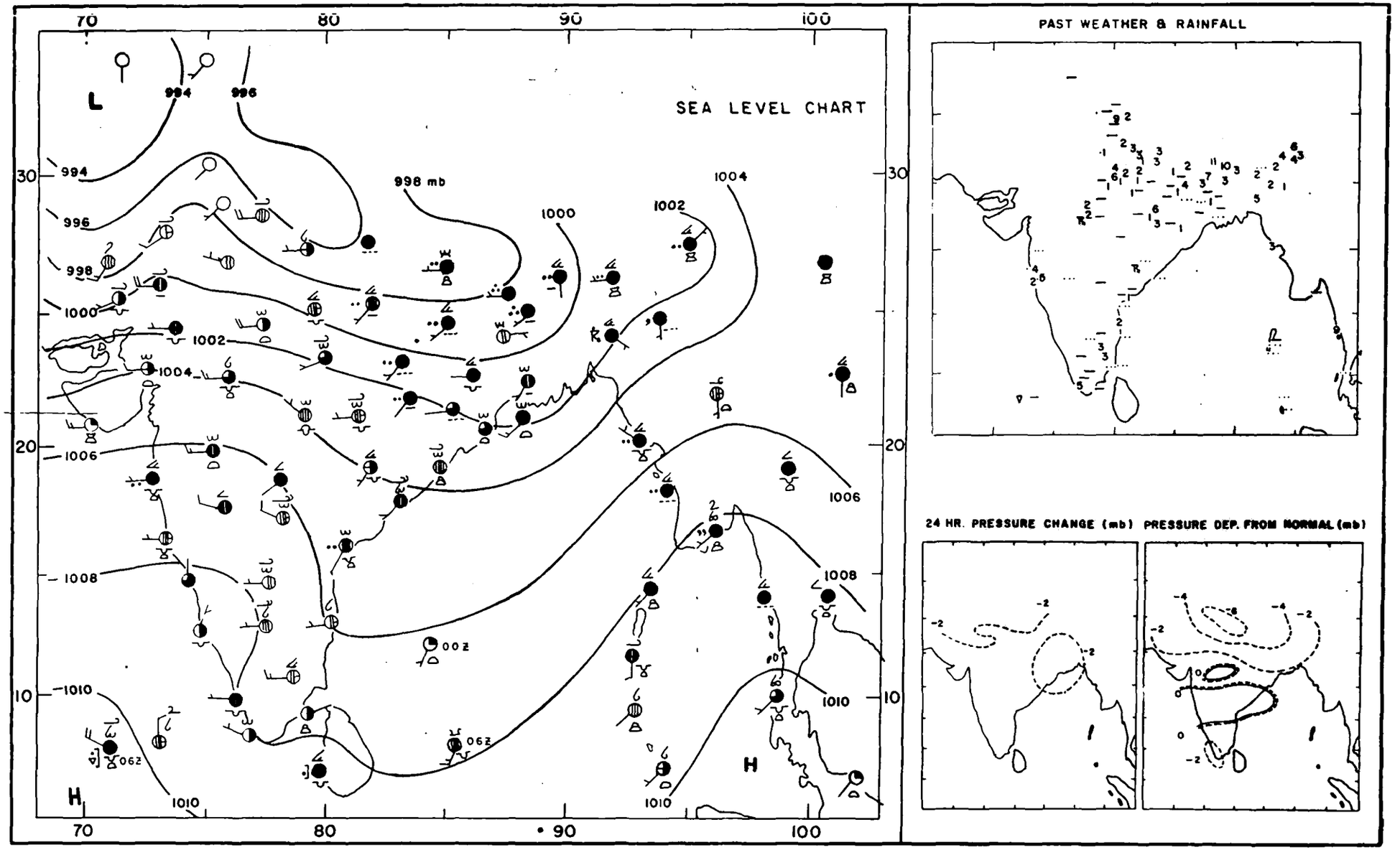


FIG. ~~6-5~~ 11.2 UPPER WINDS 23 AUG. 66 00 GMT

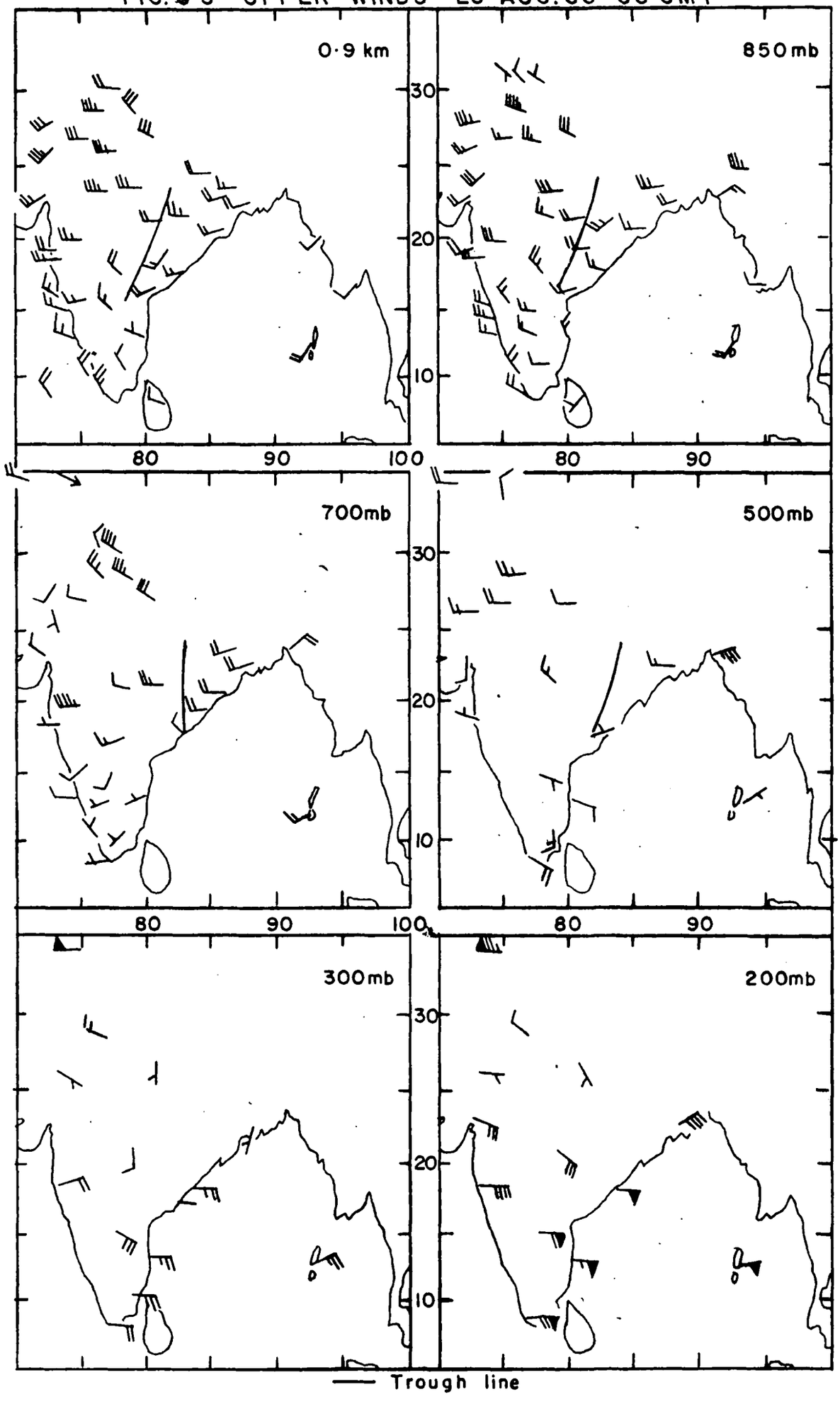
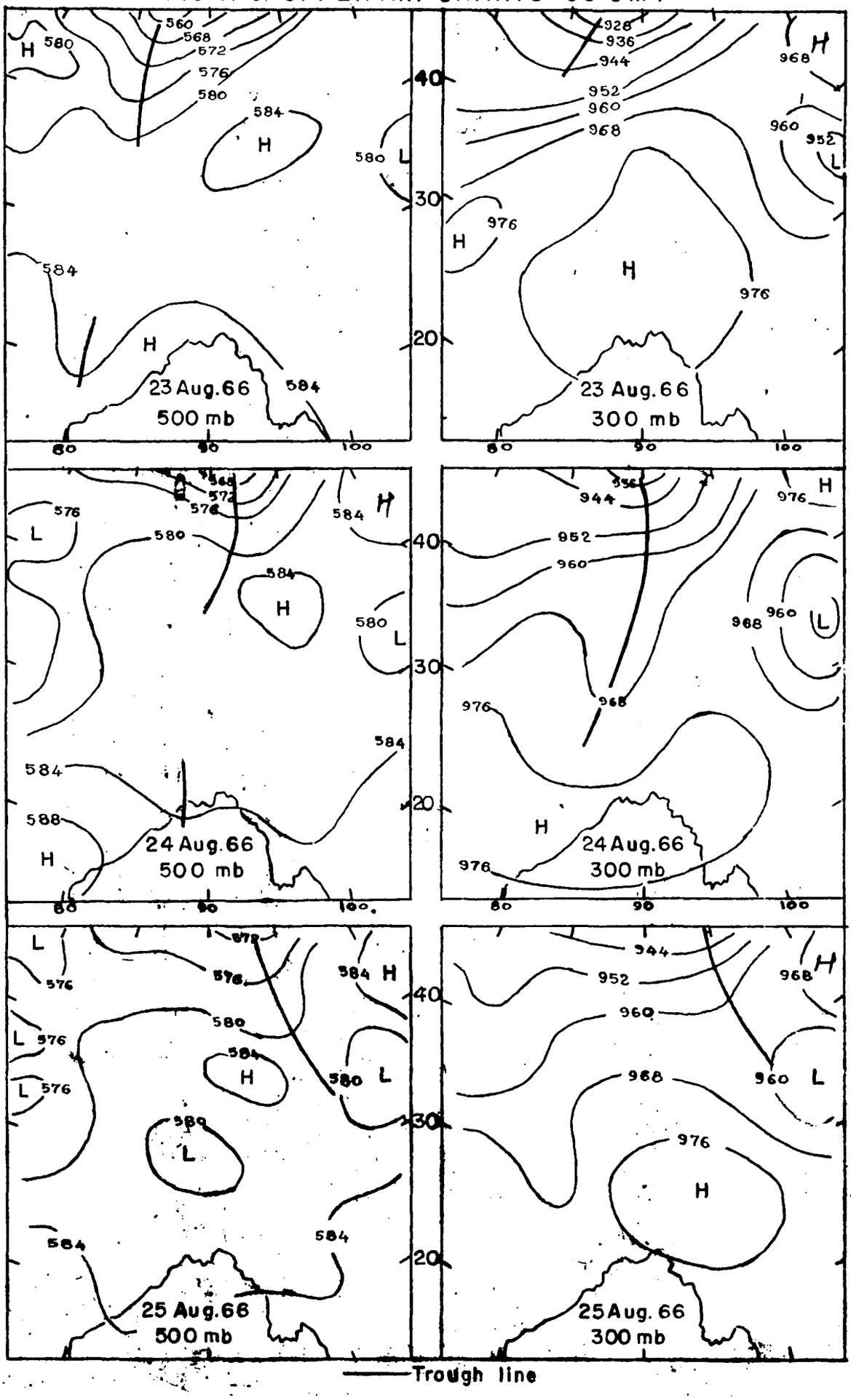


FIG. II·3 UPPER AIR CHARTS 00 GMT



11.4

FIG. ~~6-6~~ UPPER WINDS 24 AUG. 66 00 GMT

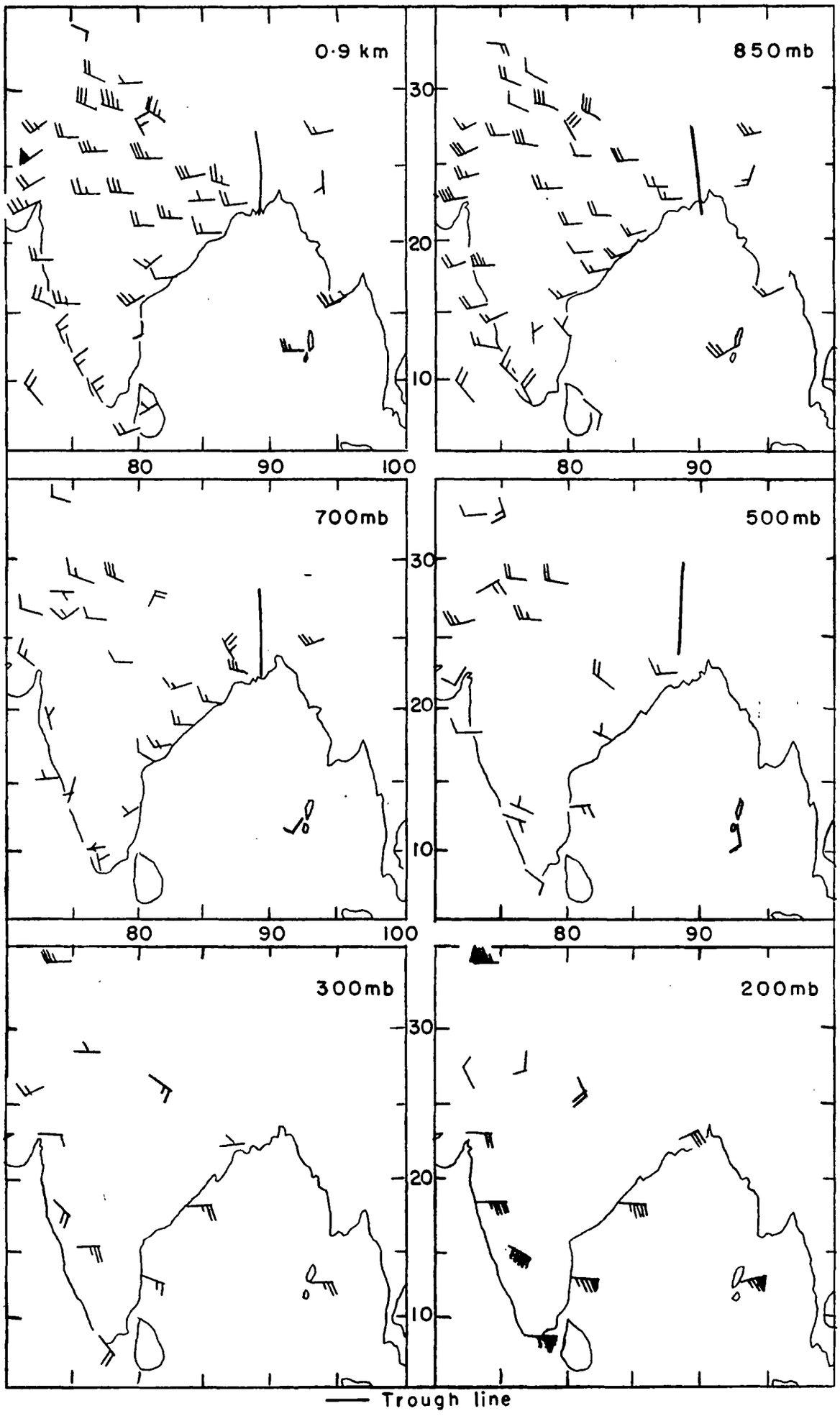
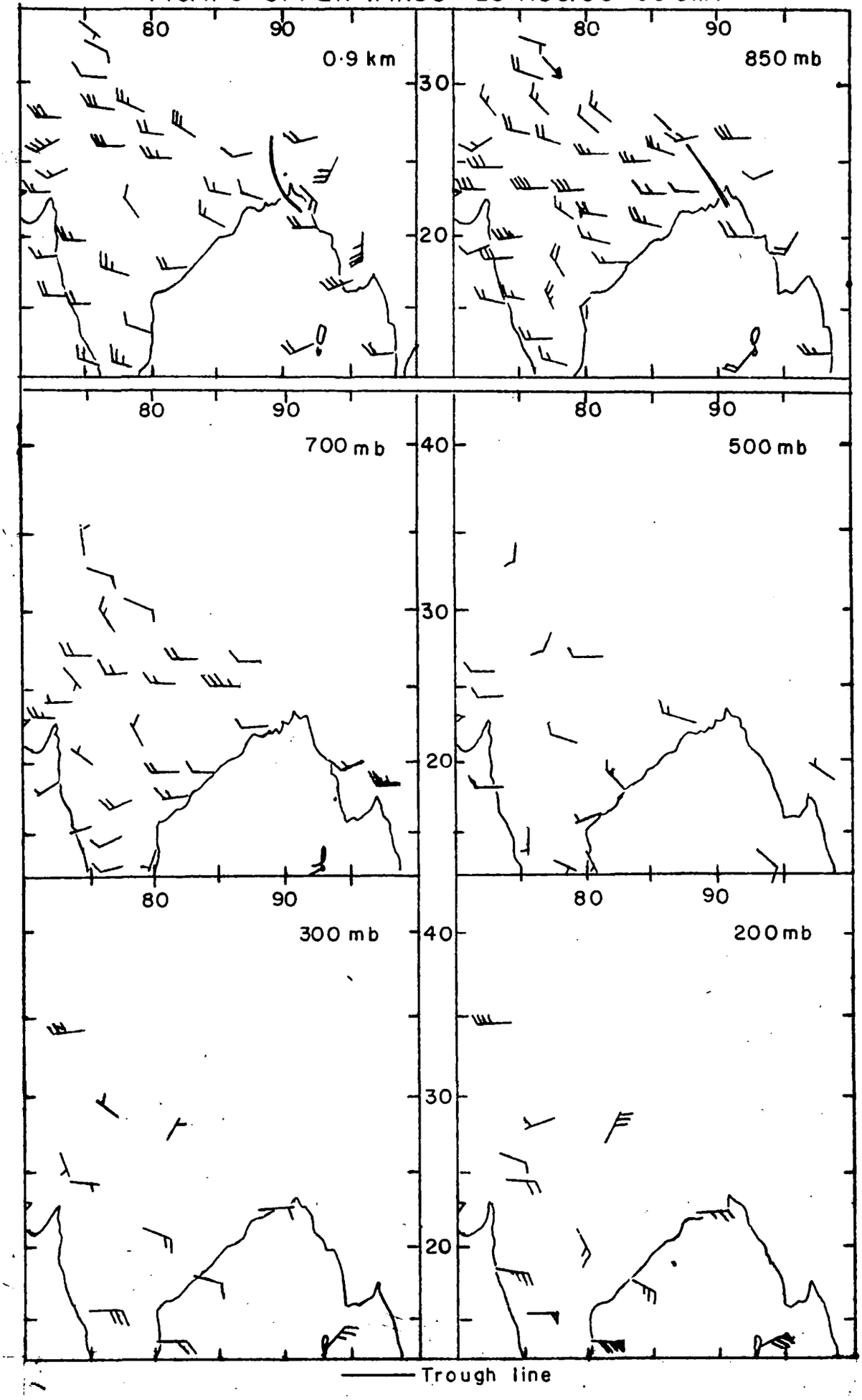
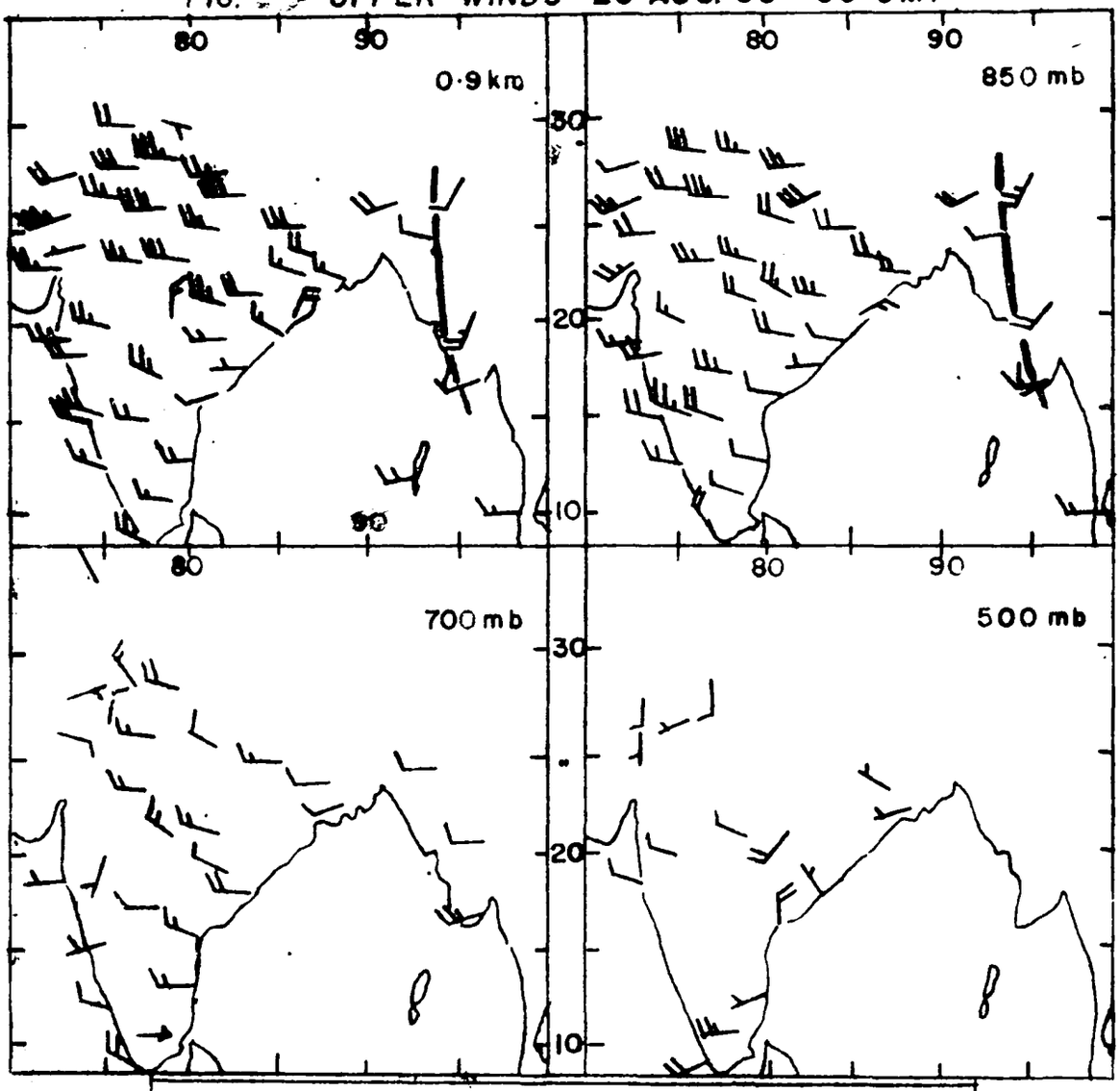


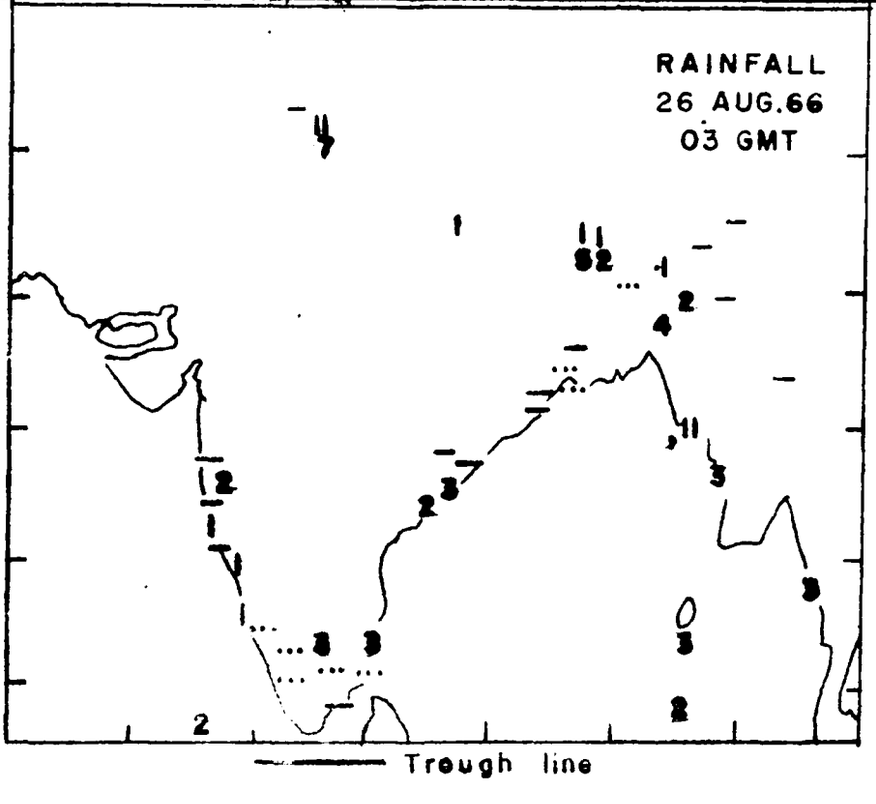
FIG. II·5 UPPER WINDS 25 AUG. 66 00 GMT



11·6

FIG. UPPER WINDS 26 AUG. 66 00 GMT





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