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INDIA METEOROLOGICAL DEPARTMENT

FORECASTING MANUAL

PART III

DISCUSSION OF TYPICAL SYNOPTIC WEATHER SITUATIONS

3·3: SOUTHWEST MONSOON – TYPICAL SITUATIONS OVER NORTHWEST INDIA.

BY

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Part III - Discussion of Typical Synoptic Weather Situations

3.3 Southwest Monsoon - Typical Situations over Northwest India

by

M.S.V. Rao, V. Srinivasan and S. Raman

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1. Introduction

The synoptic situations associated with strong and weak monsoon conditions over Northwest India are dealt with in this report. According to departmental convention Northwest India comprises the meteorological sub-divisions of Rajasthan (East and West), Haryana, Punjab, Himachal Pradesh and Jammu and Kashmir. The weather over the hills of West Uttar Pradesh is very similar to the weather over Himachal Pradesh in many respects; therefore, the present report will include this portion of West Uttar Pradesh also along with Northwest India.

2. General Features of the Weather over Northwest India during the Southwest Monsoon Season

2.1 Rainfall

2.1.1 The Southwest Monsoon normally sets in over northwest India outside West Rajasthan by the end of June and covers the entire northwest India before the middle of July. The progress of the monsoon over the region is not continuous; it usually occurs in two stages. West Rajasthan and Jammu and Kashmir are the two sub-divisions into which monsoon advances last. A point of interest to forecasters is that the monsoon sometimes advances into the hills of West Uttar Pradesh a little (say about a week) earlier than into the plains. When we consider the withdrawal of the monsoon, we find that this starts first in West Rajasthan by the beginning of September and the withdrawal is complete from the whole state by about the middle of the month. Thus the monsoon holds sway over the westernmost parts of Rajasthan only for about one and a half to two months, while over the rest of the state it lasts over two and a half months. From Punjab, Haryana and West Uttar Pradesh hills the monsoon withdraws a little later, viz., during the second half of September.

2.1.2 The monthly mean rainfall over northwest India for the months of June, July, August and September are shown in Fig. 2.1. Over East Rajasthan the rainfall during the months of July, August and September totals to 58 cm (which forms 83% of the annual rainfall of 70 cm). July and August are equally rainy, while in September rainfall decreases considerably, to about half the monthly value in July and August. In West Rajasthan the rainfall is much less than in East Rajasthan; during July and August it is about 10 cm per month - less than half that in East Rajasthan.

2.1.3 Both in July and August, the rainfall over Rajasthan decreases from about 25 to 30 cm in the extreme southeastern districts to about 5 to 10 cm along the western portions of the state bordering West Pakistan. The rainfall over the southeastern parts of Rajasthan is enhanced by the Aravallies.

2.1.4 In the other sub-divisions of northwest India viz., Haryana, Punjab, Himachal Pradesh and Jammu and Kashmir (and also hills of West Uttar Pradesh) the rainfall is more towards the hills than in the plains both in July and in August. The area of maximum rainfall (of 30 to 40 cm) extends in a northwest to southeast orientation from Jammu and Riasi districts of Jammu and Kashmir to Nainital district of West Uttar Pradesh in both the months. Over Himachal Pradesh and the hills of West Uttar Pradesh monthly rainfall locally exceeds 70 cm. In September there is a general decrease of rainfall over the area; but the hills of West Uttar Pradesh still get about 20 to 30 cm. In all these months, July to September, the rainfall rapidly decreases westwards towards the plains. Over Jammu and Kashmir, the rainfall decreases rapidly northwards, the northern half of the sub-division getting hardly 5 cm per month. The Pir Panchal Range appears to be an effective barrier, preventing the monsoon rainfall reaching the northern half of Jammu and Kashmir, Indeed, over Kashmir the main rainfall season is winter and not the southwest monsoon period.

2.1.5 A notable feature of the monsoon rainfall over Rajasthan is its very high variability, similar to Gujarat. The highest values of the coefficient of variation ($\frac{\text{Standard deviation}}{\text{Mean}} \times 100$) of rainfall is in Rajasthan. It ranges from 30% in the extreme southeast to over 70% in Jaisalmer district in the west. Rainfall equal to almost the season's total has occurred in a single day at some stations in West Rajasthan. A study of 50 years rainfall at selected stations in Rajasthan shows that heavy rainfalls of the order of 12 cm per day have occurred on 20 to 30 occasions in the extreme southeastern parts; such heavy amounts rarely occur over the rest of Rajasthan. Rainfall exceeding 25 cm is very rare even in the southeastern districts. Heavy to very heavy rains are not uncommon in Punjab, Haryana, Himachal Pradesh and hills of West Uttar Pradesh and southern parts of Jammu and Kashmir. Rainfall of the order of 25 to 35 cm has occurred in 24 hours over these areas except Haryana where such amounts are extremely rare. In the northern half of Jammu and Kashmir heavy falls of this magnitude do not occur. Even on occasions of very heavy rains over Western Himalayas, the northern portions of Jammu and Kashmir get considerably less rainfall.

2.1.6 The percentage frequency of occurrence of vigorous, strong, normal and weak monsoon* days in July and August for the various sub-divisions of northwest India, is given in the following Table.

TABLE - I.

Percentage frequency of occurrence of Vigorous, Strong, Normal and Weak Monsoon days over Northwest India (based on data for 1966-1969)

Sub-Division	July					August					July and August				
				Weak					Weak					Weak	
	Vig	Stg	Nor	with some rain	dry	Vig	Stg	Nor	with some rain	dry	Vig	Stg	Nor	with some rain	dry
Haryana and Punjab	7	11	28	25	29	8	14	31	23	25	7	13	29	24	27
Himachal Pradesh	0	19	37	28	16	2	18	40	35	6	1	18	39	31	11
Jammu and Kashmir	0	0	39	15	47	0	0	39	19	43	0	0	39	17	45
West Rajasthan	0	1	34	13	52	2	1	25	17	56	1	1	29	15	54
East Rajasthan	2	9	37	34	19	2	12	36	22	28	2	11	37	28	23
West Uttar Pradesh hills	1	14	43	28	14	4	19	39	27	11	2	16	41	27	13

* Specifications for the strength of the monsoon over land areas (from DDGF's Technical Circular No.23) are given in Appendix.

2.1.7 The following points emerge from a study of the figures presented in the above table.

i) The frequency of strong and vigorous monsoon days is highest (about 20%) in Haryana, Punjab, Himachal Pradesh and the West Uttar Pradesh hills. It is almost nil in Jammu and Kashmir and West Rajasthan. Although heavy falls occur in these two sub-divisions, the rainfall does not satisfy simultaneously the two criteria for classification into active and vigorous monsoon conditions. It is noticed that more often it is the criterion for two adjacent observatory stations in a sub-division reporting more than 3 or 5 cm (as the case may be), that is not satisfied.

ii) The highest frequency of dry days occur in Jammu and Kashmir and West Rajasthan (45% to 55%) and the lowest frequency in Himachal Pradesh and West Uttar Pradesh hills (about 10%). Over these latter areas perfectly dry weather is rare. Perhaps orography is responsible for this.

iii) There is a slight increase in the frequency of active monsoon days from July to August in the hills of West Uttar Pradesh. There is a slight decrease in the frequency of dry days from July to August in northwest India as a whole except in Rajasthan where there is an increase, presumably due to a greater number of 'break' days in August.

2.2 Pressure

The most intense part of the monsoon low lies over West Rajasthan and adjoining areas of West Pakistan where the sea level pressure goes down to 995 mb even in the mean. The axis of the seasonal monsoon trough is over extreme north Rajasthan and adjoining parts of Haryana (at the surface and in very low tropospheric levels) in the monthly mean charts . The position of the axis varies from day to day.

2.3 Upper Winds and Temperatures

2.3.1 The mean upper winds over selected stations in northwest India and adjoining Russian Turkistan are shown in Fig. 2.2. They are generally light over northwest India in the *lower troposphere. However, there are spells when the lower tropospheric winds (both easterlies and westerlies) strengthen considerably over the area generally under the following synoptic conditions:-

i) 'breaks' in monsoon, when westerlies strengthen

ii) intensification of the seasonal low when southerlies to westerlies may strengthen over Rajasthan. In such situations, especially in July, dust-raising winds and dust-storms may prevail over Rajasthan, just like in pre-monsoon months

iii) monsoon trough south of normal position, particularly with lows embedded in it, when strong easterlies may prevail

iv) disturbances in middle latitude westerlies moving across extreme north of India or presence of lows to the south or west of Punjab and Haryana when strong southeasterlies may prevail over these sub-divisions.

2.3.2 In the mean, the easterlies/southeasterlies to the north of the trough line over northwest India, are very shallow and hardly extend upto 850 mb level. Sometimes the trough line is seen only on the surface chart and not even at 0.9 km. On occasions of good monsoon activity, however, the trough may extend to much higher levels over northwest India.

2.3.3 Above 850 mb level an anticyclonic flow of winds prevails over northwest India. The axis of the monsoon trough rapidly slopes southwards with height.

2.3.4 In the upper troposphere the axis of the sub-tropical ridge passes roughly through 30°N over India during the monsoon. Immediately to the south of the ridge the easterlies are light. However during spells of strong monsoon over north or central India and in the absence of any deep westerly system to

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* In this report, the layer between ground and 700 mb is referred to as the lower troposphere, the layer from 700 to 300 mb as the middle troposphere and the layer 300 mb and above (upto the tropopause) as the upper troposphere.

the north of India, easterlies spread further northwards and also strengthen (particularly south of 30°N) over northwest India.

2.3.5 We have already noted that the low level easterlies are usually weak and shallow over northwest India to the north of 30°N. Over this area, the flow pattern from mid-tropospheric level upwards is one of zonal westerlies. Hence this area is liable to be affected by disturbances in these zonal westerlies resulting in spurts of rainfall. Some of the troughs in westerlies influence the weather even to the south of 30°N when the sub-tropical ridge pattern is relatively weak.

2.3.6 The mean tephi-grams of Jodhpur and Delhi for weak, normal and active/vigorous monsoon days over the respective areas, are given in Fig. 2.3. As the frequency of active/vigorous monsoon days is insignificant over West Rajasthan, the mean tephi-grams for weak and normal monsoon days alone are given in respect of Jodhpur. The tephi-grams show that the main difference between weak monsoon and strong monsoon days lies more in the moisture content than in the dry bulb temperatures. The air between ground level and 850 mb becomes a little colder with the increase in monsoon activity and above this level there is practically no change. The changes in moisture are more marked above 850 mb level. The tephi-grams for Delhi show that there is not much difference between normal and active monsoon days. An examination of individual days' tephi-grams, reveals that weak monsoon days are characterised by (a) stable layers at one or more levels (b) general lack of moisture content and (c) a steep decrease in moisture above 850 or 800 mb level. The rapid decrease of moisture with height rather than the presence of the stable layer appears to be the more common feature. Active monsoon days are characterised by almost neutral lapse rates with high humidity content extending to very high levels. Two typical tephi-grams of Delhi (illustrative of weak and active monsoon days) are given in Fig. 2.4.

2.3.7 In this connection it is interesting to note that the monthly mean precipitable water in July and August over New Delhi and Jodhpur is quite high (of the order of 5 to 6 gms), and is nearly the same as at Bombay (6 gms), though the monthly mean rainfall amounts at Jodhpur/New Delhi and Bombay do not bear any comparison.

2.3.8 Instability forms of clouding and precipitation are common over northwest India. On a half to two-thirds of the occasions, precipitation is accompanied by thunder in Jammu and Kashmir, Haryana, hills of West Uttar Pradesh and most of Rajasthan and on a third of the occasions over the rest of northwest India.

3. Survey of Synoptic Systems affecting Northwest India during the Southwest Monsoon Season

3.1 Active monsoon conditions over northwest India are associated with the following synoptic situations:-

i) Approach and movement of monsoon depressions and low pressure areas into the region from the east

ii) Intensification of the seasonal monsoon trough, or its shift towards foot of the Himalayas

iii) Disturbances in the mid-latitude westerlies moving from west to east across the extreme north of the country.

3.2 An examination of the reports on floods in northwest India during the period 1956-64 (as published in the IJMG) also confirms that heavy rains leading to floods have occurred in northwest India in association with

i) Shifting of the seasonal trough towards foot of the Himalayas

ii) Movement of a low/depression from the east towards north Rajasthan, Punjab and Haryana

iii) Passage of westerly troughs over the area.

3.3 The break-up of the different synoptic situations associated with active to vigorous monsoon conditions for all the sub-divisions of northwest India, is given in Table II.

TABLE - II

Percentage of vigorous and active monsoon days over northwest India associated with specific synoptic situations for the monsoon months (July-August) of 1966 to 1969

Sub-Division	Synoptic situation					
	Depres-sion	low	Monsoon trough	Well-marked seasonal low	Westerly trough	Miscel-laneous
East Rajasthan	10	74	13	3	0	0
West Rajasthan[+]	7	77	10	3	0	2
Punjab Haryana	0	62*	15*	4	19	0
Himachal Pradesh	0	28*	32*	4	36	0
Jammu and Kashmir[+]	0	13*	7*	4	69	7
West Uttar Pradesh hills	0	36*	31*	2	31	0

+ In the case of Jammu and Kashmir and West Rajasthan figures refer to normal monsoon days, as these sub-divisions hardly get any vigorous or active monsoon conditions (refer para 2.1.7.)

* Westerly troughs also present simultaneously with low and monsoon trough on a good number of occasions

The table shows that lows (surface as well as upper air) constitute a large percentage of synoptic situations causing active monsoon, over Rajasthan, Punjab and Haryana. Monsoon depressions affecting northwest India are few in number. Even these move only across Rajasthan. They hardly ever reach the other sub-divisions, as depressions in July and August. The effect of the northward shift of the monsoon trough is most marked in Himachal Pradesh and West Uttar Pradesh hills. Westerly troughs are responsible for active monsoon conditions in the northern sub-divisions of northwest India - conspicuously in Jammu and Kashmir. It may also be borne in mind that some of the lows listed in Col.3 of the Table might have formed under the influence of the troughs in westerlies.

3.4 Monsoon Depressions and Lows

3.4.1 The monsoon depressions that form over head Bay of Bengal usually move westnorthwestwards. After crossing coast they generally weaken, only a small percentage reaching northwest Madhya Pradesh as depressions. During the Southwest Monsoon Season (July-September), on an average, one or two depressions reach northwest Madhya Pradesh and the adjoining areas. The majority of these weaken over that area and only one out of three has a further life and travels into Rajasthan as depression. In July, the depressions have a more westerly to westnorthwesterly track from northwest Madhya Pradesh across north Gujarat State and south Rajasthan. In August, the track is more northwesterly and there is a greater tendency for depressions to move into Rajasthan from West Madhya Pradesh. In September, the tracks become northnorthwest to north or even northnortheast. Thus, the probability of depressions reaching Punjab, Haryana, Himachal Pradesh and West Uttar Pradesh hills is practically nil in July, and maximum in September. Exceptionally heavy amounts of rainfall often occur in Punjab, Haryana, Himachal Pradesh and West Uttar Pradesh hills when monsoon depressions move towards them.

3.4.2 While depressions reaching West Madhya Pradesh are not many, the low pressure areas (surface or upper air) that reach West Madhya Pradesh are almost five times that number. These low pressure areas may be

i) remnants of monsoon depressions which have weakened

ii) lows that have formed over north Bay or even inland and moved westwards

iii) lows that have developed in situ.

In many cases the lows may weaken at sea level and it may hardly be possible to locate them on surface chart; however they may persist in the lower/mid troposphere as well-marked cyclonic circulations and continue to travel west or northwest, causing increased monsoon activity. Thus these weaker systems which follow a track similar to monsoon depressions are also effective in causing heavy rains in northwest India. While the movement of the monsoon depressions is quite regular, that of the low pressure areas and upper air cyclonic circulations is at times erratic and generally sluggish.

3.4.3 It has been found that even while the depression or low is over East Madhya Pradesh (far to the east), if the associated circulation covers a large area and if the zone of convergence to the west of the depression is well-marked over northwest India, rainfall activity may commence over northwest India. A similar sequence of weather over Gujarat State has already been discussed in Sec. 4 of FMU Rep.No. III - 3.1. Further in this connection, results of a study of weather over Jodhpur are reproduced below:-

"So far as the effect on weather over Jodhpur is concerned, there is some difference between a low moving over northeast Madhya Pradesh and neighbourhood from the Bay of Bengal and a low directly appearing over northeast Madhya Pradesh and neighbourhood. The former has mostly a tendency of westnorthwestward movement which contributes to the realisation of weather over Jodhpur, whereas the latter may or may not have tendency of such a movement. In some cases, the low directly appearing over northeast Madhya Pradesh and neighbourhood may shift westnorthwestwards and behave like a low coming from the Bay of Bengal and produce weather over Jodhpur, while in some other cases, it may remain stationery or shift northeastwards, without producing any weather over Jodhpur. In the latter cases the trough line from northeast Madhya Pradesh runs north or northeast instead of westnorthwest."

"It may also be worth mentioning here that when the rainfall occurs at Jodhpur in the afternoon or evening, it is almost invariably accompanied with thunder even in the monsoon period, whereas, if it occurs at other times, it may or may not be accompanied with thunder. When the low moving westnorthwestwards is nearer Jodhpur, rainfall may occur at any time of the day or night and may or may not be accompanied with thunder. But, when the rainfall is caused by the influence of the distant low coming from the Bay of Bengal over northeast Madhya Pradesh and neighbourhood, it occurs in the afternoon or evening and is accompanied with thunder. This is a useful knowledge for forecasting the time of occurrence and the type of weather."

"It would be seen from the foregoing paragraphs that from the point of view of forecasting the weather over Jodhpur, the movement of the low from the Bay of Bengal into northeast Madhya Pradesh and neighbourhood during the monsoon season and the orientation of the associated trough lines in the lower troposphere in the neighbourhood of Jodhpur are noteworthy features, as they have well-marked influence on the weather over Jodhpur in spite of the large intervening distance of the low from Jodhpur."

(From 'Influence of distant monsoon lows over Weather over Jodhpur' by K.L. Sinha - Indian Journal of Meteorology and Geophysics, Vol.9 No.3, July 1958)

3.4.4 On rare occasions monsoon depressions move westwards and emerge into Northeast Arabian Sea. Depressions may also form in Northeast or East Central Arabian Sea particularly early in the monsoon season, and take some northerly track ushering the monsoon into Rajasthan. Statistics of such depressions for the period 1891-1969 are given below; these figures bring out the rarity of these depressions.

TABLE - III

Depressions over Northeast Arabian Sea during the Southwest Monsoon period (1891-1969)

	No.of Depressions	
	moving westwards into Northeast Arabian Sea	moving north from Arabian Sea towards Rajasthan
June	3	8
July	3	5
August	Nil	Nil
September	2	4

3.5 Seasonal Monsoon Trough

3.5.1 The seasonal monsoon trough, being a region of low-level convergence, is associated with rainfall. The distribution and intensity of the rainfall is determined by the location of the monsoon trough as well as the presence or absence of localised cyclonic circulations in the trough. The western end of axis of the seasonal trough runs, in the mean, across north Rajasthan and Haryana. The position varies from day to day. An analysis of nine years' data (1961-1969) shows that the trough over northwest India lies to the north of the normal position most frequently (45% of the occasions) and south of the normal position least frequently (only on 25% of the occasions). It is well-known that during 'break', the axis of the trough shifts to the foot-hills of the Himalayas. On such occasions easterlies over northwest India disappear and westerlies prevail over the area from surface upwards, practically over the whole troposphere. The low level westerlies over northwest India also strengthen considerably. Such occasions are favourable for heavy rains over the Western Himalayas. Sometimes good cyclonic shear due to speed variations occurs in the low level westerlies, leading to heavy rain over the adjoining plains, also.

3.5.2 During the 'break' period which usually lasts for a few days, the rainfall over the submontane regions is not uniformly heavy on all the days. There could be days during 'break', when the monsoon is weak over this area. These fluctuations in rainfall are largely determined by the movement of westerly troughs over the area.

3.5.3 Apart from 'breaks', another type of situation arises when the western end of the axis of the trough is towards Himalayas while the eastern half continues in the normal or even in a more southerly position. On such occasions, the rainfall distribution over northwest India may be similar to 'break' conditions.

3.5.4 When the seasonal trough is somewhat north of the normal position, running over Punjab and Haryana, but not close to the foot-hills, there is often active monsoon conditions over these areas. In such situations, rainfall is found mainly to the north of the seasonal trough in the region of low level southeasterlies; to the south, over Rajasthan, the weather may even be dry, This is in contrast to the occurrence of heavy rains to the south of the trough-line over most parts of north and central India.

3.5.5 There are occasions when the monsoon trough takes a more southerly position, lying over south Rajasthan or even further south. Such situations usually occur when a depression from the Bay takes a more westerly course over the central parts of the country, or when some development takes place over Northeast Arabian Sea or Gujarat State. On such occasions it is mainly south Rajasthan that experiences active monsoon. The rest of northwest India may go dry, particularly if the easterlies to the north of the trough are quite strong in the lower troposphere. Rainfall may occur in the region of easterlies also when cyclonic wind shift is noticed in these easterlies.

3.6 Disturbances in Westerlies

3.6.1 It has already been pointed out in para 2.3.5 that the flow pattern over the country north of Lat. 30°N is one which is favourable for movement of troughs in westerlies affecting the weather over the area. Several workers in India have pointed out the prominent role of the disturbances in westerlies in causing active monsoon conditions over northwest India. The effect of the movement of the westerly troughs may be classified under these following heads:

i) shifting the axis of the seasonal trough to the foot of the Himalayas

ii) causing the monsoon depressions and lows to recurve north or even northeastwards towards the Western Himalayas where they may break up against the mountains and

iii) inducing low pressure areas over West Pakistan and northwest India, which in turn activate the monsoon over these areas.

3.6.2 The passage of the westerly troughs could be traced with extended charts covering the whole of Asia as well as with time sections of key stations, like Tashkent or Srinagar. An examination of the time-sections of Tashkent shows that these troughs extend through a fairly deep layer of the atmosphere. Over Srinagar they are noticeable mostly in the upper troposphere (above 500 mb). A study of the time-sections of Tashkent and Srinagar for the four-year period (1966-69) shows that on an average three to four troughs move across these stations in a month during the Southwest Monsoon period (July-September). 300 mb charts are helpful for locating the troughs and tracing their progress from day-to-day.

3.6.3 A further analysis of the conditions over northwest India and West Pakistan during the period of the passage of the westerly troughs, shows that on most occasions the passage of the trough is associated with the formation of a low/trough at the sea level and/or in the lower troposphere which, while moving in an easterly direction, enhances the monsoon activity over northwest India. When such a low forms over West Pakistan or West Rajasthan it may appear as an intensification of the seasonal low. The pressure changes and departures over West Pakistan and northwest India and changes in low level winds may help to trace the movement of these lows. Unusual convective activity over West Pakistan may serve as another indication of the presence of these lows. Monsoon activity increases over northwest India with the formation of the circulation/low. The lows and the upper troughs move across Western Himalayas, and this favours the shift of the western end of the axis of the seasonal trough towards the foot-hills. Often while the western end moves towards foot-hills, the eastern end remains in the normal or even more southerly position. Although on an average 3-4 troughs per month move across Western Himalayas, the number of occasions of 'break' situation is relatively small. Further work is required to distinguish between the situations when the westerly troughs cause 'breaks' and when they do not.

3.6.4 The shift of the monsoon trough towards the foot-hills during the 'break' monsoon due to westerly trough passage has already been discussed in detail in FMU Report No. IV - 18.3.

3.6.5 The recurvature of the monsoon depressions under the influence of the moving westerly troughs is well recognised. Of the monsoon depressions which have travelled to the west of Long. 80°E, a little less than one half the number recurve towards north or northnortheast in September. Invariably such recurvature occurs under the influence of westerly troughs.

3.6.6 It is also noticed that early in July, the westerly troughs may serve to advance the monsoon into northwest India. Similarly in September the monsoon withdraws from northwest India immediately after the passage of a westerly trough. The withdrawal also generally coincides with a strengthening of the westerlies in the upper troposphere over extreme north of the country. These strong westerlies appear about 3 to 5 days before the withdrawal of the monsoon from northwest India. Srinagar time-section shows that westerlies reach as high as 80-100 kt, just before the withdrawal, and in some years these strong westerlies extend southwards over Punjab and West Uttar Pradesh also.

3.7 Weak Monsoon

3.7.1 Rajasthan: Weak monsoon (including dry days) prevails during nearly two-thirds of the monsoon period in West Rajasthan and about one half of the period in East Rajasthan. Thus, so far as these two sub-divisions are concerned, weak monsoon is the predominent feature of the season. Monsoon activity over these sub-divisions increases only under the influence of some synoptic disturbance as discussed in the earlier paragraphs. The absence of such disturbances together with the presence of the seasonal anticyclonic circulation above 850 mb level over the area indicate weak activity. Weak monsoon conditions also prevail over most of Rajasthan when the seasonal trough shifts either to north of Rajasthan or to the south of the state or when the trough, though in normal position, is shallow and weak. The trough shifts to the south of Rajasthan when a depression or low (surface or upper air) moves across Madhya Pradesh or Gujarat State or develops in situ over these areas. In these cases though the disturbance may not be far away from Rajasthan, the weak monsoon is due to the sub-division being located in sectors of the disturbance unfavourable for large precipitation.

3.7.2 Rest of Northwest India: The frequency of weak monsoon days (including dry days) over the rest of northwest India is about 40-50% except over Jammu and Kashmir where it is nearly 60%. In these areas, weak monsoon often occurs when the monsoon trough has shifted far to the north and general northwesterlies prevail over the region. Such situations obtain in the rear of disturbances in the westerlies - though some heavy rainfall in the hilly region is not ruled out even under such conditions. Some of these cases include typical 'break' situations when the entire monsoon trough had shifted to the foot-hills. Weak monsoon also prevails when the monsoon trough shifts far to the south (viz. towards south Rajasthan or north Gujarat State) and strong easterlies prevail over the region.

3.7.3 Typical synoptic situations of active and weak monsoon conditions in the different meteorological sub-divisions of northwest India are discussed in the following pages.

4. Bay Depressions weakening over Northwest Madhya Pradesh and moving Westnorthwestwards as a Low Pressure Area across south Rajasthan - 12 to 14 August 1964

4.1 The tracks followed by the monsoon depressions and lows which form over North Bay of Bengal and move inland have already been discussed in para 3.4.1. When these disturbances approach northwest Madhya Pradesh and adjoining areas, a strengthening of the monsoon begins over Rajasthan. Further activity over northwest India depends on the course followed by the low pressure system. Monsoon depressions moving across northwest India, are few *in number. Depressions generally weaken into low pressure areas by the time they reach northwest India. In this section the case of a monsoon depression weakening over north* Madhya Pradesh *and moving across* south Rajasthan as a low is dealt with.

4.2 A depression which developed over the North Bay of Bengal on 9 August 1964, intensified into a deep depression by the next day. Moving northwestwards it crossed coast near Chandbali on 10-11th night and lay over north Madhya Pradesh centred near Sagar on the morning of 12th (Fig. 4.1). The system continued to be a deep depression with pressure departures of about -10 mb at the centre and the cyclonic circulation extending upto about 400 mb with a sharp southward tilt above 3.6 km (Fig. 4.2). With the approach of the deep depression, the western portion of the monsoon trough which was earlier (on 10th) running across north Rajasthan shifted south to extreme south Rajasthan. Consequently the southeastern parts of Rajasthan got rain on 12th, while elsewhere over the state only isolated falls were reported.

4.3 The deep depression weakened into a depression by 12th evening. It moved westnorthwestwards into southwest Rajasthan and adjoining Sind by 13th morning, at the same time weakening further into a low pressure area (Fig.4.3). The 24 hour pressure changes were all positive over the entire country and the largest negative pressure departures (-6 mb) were over southwest Rajasthan. Though the upper winds showed the cyclonic circulation upto about 400 mb, there was a southward tilt with height even at 3.0 km (Fig. 4.4), in contrast to the previous day (12th) when the tilt was noticed only above 3.6 km. On this day (13th) the monsoon was active over East Rajasthan and widespread rain with a few heavy to very heavy falls were reported from south Rajasthan. The monsoon was generally weak over the rest of northwest India. It may be noted that widespread rainfall was confined to the south of the trough line on the sea level and in the lower troposphere (upto 0.9 km). The heaviest falls were over north Gujarat State and the adjoining south Rajasthan and West Madhya Pradesh. In the region of low level easterlies the rainfall was isolated.

4.4 The system further weakened and moved away westwards towards south Baluchistan, and the western end of the monsoon trough also shifted abruptly to the north by 14th morning (Figs. 4.5 and 4.6). As a consequence, there was considerable decrease in the rainfall activity over East Rajasthan on 14th. The rainfall over the Western Himalayas began to increase. By 15th, weather became mainly dry over West Rajasthan.

4.5 The hemispherical charts showed that during this period the sub-tropical ridge was quite prominent between 30°N and 35°N and was also north of the normal position. Presumably because of this, the depression/low took a westnorthwestward course upto Baluchistan. The hemispherical charts* for 13th illustrating these features are given in Fig. 4.7 (a and b).

4.6 A point to be noted is that although the deep depression weakened progressively from 12th onwards, it caused an appreciable increase in the rainfall over Rajasthan. The heavy falls in Rajasthan were confined to southeast Rajasthan, which was in the southwestern sector of the disturbance. Over the rest of northwest India this low pressure system did not have any significant effect.

4.7 There are other cases when the depression or low may not travel across Rajasthan, but weaken as it approaches Rajasthan, lose its identity and merge into the seasonal trough/low. In such cases, too, there can be an increase in monsoon activity over Rajasthan. In rare cases, the depression/low may move across south Rajasthan or north Gujarat State and emerge into the Arabian Sea where it may intensify again. The main rainfall belt is then

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* The hemispherical charts in this report are copied from "Synoptic Bulletins of the Northern Hemisphere" published by USSR, except Figs. 5.11 a and b which are from "Daily Weather Maps" of Japan Meteorological Agency.

over Gujarat State and may extend to south Rajasthan. A case of this type has been discussed in Sec. 5 of FMU Rep. No. III - 3.1.

5. Bay Depression weakening over North Madhya Pradesh and recurving northwards - 17 to 22 August 1960.

5.1 In this section we shall discuss the case of a Bay depression which weakened over north Madhya Pradesh and recurved northwards to Punjab causing strong monsoon conditions over northwest India.

5.2 A deep depression which developed over the head Bay of Bengal during 13-14 August 1960, moved westnorthwestwards and, weakening into a depression, lay over northeast Madhya Pradesh centred near Ambikapur on 17th morning (Fig. 5.1). The maximum negative pressure departure was of the order of 6 mb and the cyclonic circulation extended upto 300 mb level (Fig. 5.2). In the lower troposphere, there was a north-south ridge over Rajasthan and the main convergence zone between northeast/easterlies and west/northwesterlies was running at 0.9 km a.s.l. through Jaipur, Jhansi and Umaria. On this day the heavy rainfall was confined to south Madhya Pradesh; Rajasthan was dry except for a few light showers in the southeastern parts.

5.3 The depression moved further westnorthwestwards and was centred near Nowgong on 18th morning (Fig. 5.3). It showed signs of further weakening. The 24 hour pressure changes were positive over the entire country except for a slight fall in the immediate neighbourhood of the centre of the depression. Note the appreciable rise of pressure over northwest India in addition to the steep rise in the rear of the depression. The maximum negative pressure departures (-4 mb) were over northwest Madhya Pradesh. The upper air cyclonic circulation extended at this stage upto 400 mb only (Fig. 5.4). In the lower troposphere the north-south ridge shifted west to Sind and West Rajasthan and the convergence zone at 0.9 km a.s.l. was passing through Ajmer, Jhalawar and Sagar. The rainfall belt extended to East Rajasthan with an isolated heavy fall in southeast Rajasthan. A comparison of the rainfall distribution on 18th with the low-level wind field on the previous day shows that the area of significant rainfall was mainly to the east of the ridge line over Rajasthan and in the neighbourhood of and to the south of the convergence zone at 0.9 km a.s.l.

5.4 The depression continued its westnorthwestward course during the next 24 hours with a slight decrease in its speed of travel and was centred near Sheopurkalan on 19th morning (Fig. 5.5). The other synoptic features were more or less the same as on the previous day. However, the slight fall in pressure during the previous 24 hours to the north of the depression-centre indicated a change in the course of the depression to a northerly direction. The monsoon continued to be strong over East Rajasthan and rainfall extended into West Rajasthan too. The rainfall distribution in relation to the low-level wind flow was as on previous day.

5.5 The depression weakened into a low pressure area and shifted northwards to extreme northeast Rajasthan by 20th morning (Fig. 5.6). There was a significant change in the rainfall pattern on this day. While the rainfall decreased appreciably over southeast Rajasthan, it increased over northeast Rajasthan towards which the depression had been moving. West Rajasthan also had fairly widespread rain. The upper air cyclonic circulation now extended only upto about 600 mb (Fig. 5.7).

5.6 The low shifted further north to Haryana and neighbourhood on 21st (Fig. 5.8). Although it continued to be well-marked on surface chart, the upper air circulation had weakened and was seen mainly as a trough extending upto about 300 mb (Fig. 5.9). The heavy rainfall on this day was confined to Haryana and Punjab where falls upto 16 cm were recorded. Rainfall decreased over Rajasthan.

5.7 The system weakened further as it moved towards the foot-hills on 22nd (Fig. 5.10). Rainfall now became confined to the Western Himalayas and adjoining plains where a few heavy falls were also reported. Rainfall decreased further over Rajasthan; weather became practically dry, except in the extreme northern districts.

5.8 As in the case discussed in Sec. 4, the deep depression in the present case also weakened over north Madhya Pradesh; but instead of continuing to move westnorthwestwards it recurved northwards. A probable indication of the change in the course of the depression was given by the 24 hour pressure changes on 19th to which we have alluded earlier. Another indication was the absence of deep easterlies in the upper troposphere over the area of the depression/low; actually the flow was southeast/south during this period. It is interesting to note the differences in upper tropospheric flow in this case and in the situation discussed in Sec. 4 where over the depression area the easterlies prevailed in the entire upper troposphere. The monsoon activity increased in the present case over Jammu and Kashmir, Himachal Pradesh, Punjab, Haryana and West Uttar Pradesh hills between 16th and 19th, as a trough in the middle latitude westerlies moved across the extreme north of the country. Immediately following, another trough passed across between 21st and 23rd. The low also by this time moved into Haryana and was well-marked. Under the combined influence of the upper trough and the lower tropospheric low, the monsoon became strong to vigorous in Himachal Pradesh, Punjab, Haryana and West Uttar Pradesh between 21st and 23rd. The upper air circulation associated with the low over northwest India and the westerly trough merged together to form an extended westerly trough on 21st with its axis at 500 mb running from 50°N 70°E to northeast Rajasthan (Fig. 5.11).

5.9 An important point about the rainfall pattern was that so long as the depression was moving westnorthwestwards, the main rainfall area was confined to the southern sector but when it started recurving north the main rainfall area changed to the northern sector. The heavier falls in Himachal Pradesh, Punjab, Haryana and hills of West Uttar Pradesh between 21st and 23rd were largely due to the influence of the westerly trough.

6. Monsoon Depression recurving northnortheastwards over Rajasthan causing Strong/Vigorous Monsoon over Northwest India – 4 to 9 September 1966.

6.1 We have seen that monsoon depressions take a westerly to northwesterly course in July and August and at best affect only Rajasthan. But, during the late stage of the monsoon period, particularly in September, depressions recurve northwards over northwest India and West Uttar Pradesh and reach more northerly latitudes causing an increase in the monsoon activity over these areas. The rainfall is invariably heavy on such occasions resulting in serious floods. One such case is described in this section.

6.2 A depression which formed over northwest Bay of Bengal on 2 September, 1966 moved westwards and was over south Orissa on the morning of 4th (Fig. 6.1). Widespread rainfall extended westwards upto south Madhya Pradesh. Over northwest India, there was only scattered light rain but over the hills of West Uttar Pradesh rainfall was widespread; this was not directly associated with the depression. Pressures registered a fall upto southeast Rajasthan and a marked rise further north. The upper air cyclonic circulation associated with the depression was extending into southeast Rajasthan (Fig. 6.2) where a zone of convergence between easterlies and westerlies was seen upto 0.9 km a.s.l. The depression moved westwards and was centred near Kanker on 5th morning (Figs. 6.3 and 6.4). In addition to the widespread rainfall in the southwest sector of the depression, there was light to moderate rainfall to the northwest, over southeast Rajasthan. The other parts of northwest India received only isolated light showers.

6.3 The subsequent movement and activity of the depression appears to have been considerably influenced by the upper air flow to the north of India, which is described in this paragraph. On the 3rd, a well-marked trough in the upper westerlies was extending across central USSR southwestwards upto Afghanistan and Iran (Fig. 6.5 a). On the 4th the northern portion of the trough moved eastwards while the southern portion was nearly stationery. A cut-off low formed in the trough with centre near 40°N, 65°E (Fig. 6.5 b). It showed little movement during the next two days. However, on the 6th the associated trough extended southwards upto the Mekran coast (Fig. 6.5 c). Under its influence the upper tropospheric flow was one of deep southerlies over northwest India/ West Pakistan. Moving slowly across West Pakistan and northwest India during the next 5 days, it reached west Tibet by 11th (Fig. 6.5 d). The vertical time-sections of Tashkent and Srinagar showing the passage of the deep westerly trough are presented in Figs. 6.5 (e and f). The satellite nephanalysis for the period 3 to 7 September, 1966 delineating the cloud systems associated with the westerly trough and the monsoon depression are shown in Figs. 6.6 a to e*. The recurvature of the monsoon depression over Madhya Pradesh, its movement towards Western Himalayas, as also the vigorous monsoon activity over northwest India were largely due to this perturbation in the middle latitude westerlies.

6.4 Reverting to the discussion on the depression, it moved northwestwards to West Madhya Pradesh and was centred near Hoshangabad on 6th morning (Fig. 6.7 and 6.8). There was a general increase of cloudiness over northwest India with a few stations in Rajasthan reporting 'present-weather rain'. Yet, the largest negative pressure changes were over north Gujarat State. However, with the westerly trough continuing to be well-marked with scarcely any movement, there was no marked change in the upper air flow and the northwestward movement of the depression was maintained during the next 24 hours.

6.5 The depression was centred near Nimach on 7th morning (Fig. 6.9) and moderate to rather heavy rainfall had occurred in Rajasthan particularly in the eastern parts. An isolated very heavy fall of 26 cm was reported from

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* Figs. 6.6 a to e are copied from Catalog of Meteorological Satellite Data - KMRD No. 5.311.

Bhilwara, close to the depression centre. The rain belt also extended northwards upto Kashmir. The main heavy rainfall region associated with the depression was however over Gujarat State where the pressures had been falling the previous day. On this day (7th), the pressure falls were to the north and the westerly trough also moved slightly eastwards to about 70°E (Fig. 6.10). The depression began to move northwards from 7th evening onwards.

6.6 On 8th morning the depression was centred near Sikar and monsoon was active to vigorous in all the sub-divisions of northwest India and also hills of West Uttar Pradesh (Fig. 6.11). The largest pressure falls (of the order of 5 mb) were over Himachal Pradesh and adjoining Punjab. Rainfall increased considerably over the area to the north of 30°N - Dalhousie reported 14 cm and Amritsar 9 cm. There were also a few very heavy falls on this day in Rajasthan - Mount Abu 24 cm, Erinpura Road 14 cm. In the middle and upper troposphere, the circulation associated with the depression merged into the westerly trough (Fig. 6.12).

6.7 The system rapidly weakened during the night, and on 9th morning the low could hardly be located (Fig. 6.13). The pressures also started rising everywhere. On this day the monsoon was vigorous in Himachal Pradesh, Haryana, Punjab and Jammu and Kashmir and active in the hills of West Uttar Pradesh and northeast Rajasthan. There was considerable decrease of rainfall elsehwere in Rajasthan. The very heavy amounts were, Dalhousie 41 cm, Dharamsala 18 cm, Quazigund 16 cm and Amritsar 9 cm. The upper wind chart for this day is shown in Fig. 6.14.

6.8 The westerly trough began to move eastwards after 9th and, with the axis of the monsoon trough close to the foot-hills, monsoon activity was restricted to the Western Himalayas and there was no rain over the plains of northwest India. Even in the sub-montane regions, the amounts decreased considerably after the 9th, as the surface low weakened and the westerly trough also moved eastwards.

6.9 To sum up, the strong monsoon activity over northwest India on 8th and 9th was due to the Bay depression recurving and moving across the area. The recurvature of the depression took place under the influence of the deep westerly system moving slowly across West Pakistan and northwest India. The increased monsoon activity in and near the Western Himalayas due to the depression appears to have been further enhanced by the deep westerly trough, resulting in phenomenal rain and consequent floods.

7. Low Pressure Area from the East moving to Punjab and adjoining West Pakistan - 16 to 21 July 1962.

7.1 Apart from depressions, weaker systems like lows (surface and/or upper air) move from east towards the seasonal low; they are common during July and August. They also cause widespread rain over northern and central India; sometimes the rainfall amounts may be as high as in the case of depressions. A few of them move as far west as Rajasthan, Punjab and Haryana. In this section we describe the case of one such low.

7.2 A low pressure area moving from the east across central Burma and north Bay of Bengal lay over Bihar Plateau and neighbourhood on 16 July 1962 (Fig.7.1). The axis of the monsoon trough was running across north Rajasthan on sea level chart. The 24 hour pressure changes were -3 to -4 mb over northern divisions of West Pakistan where the pressure departures were also maximum (negative), indicating that a low was over the area. The upper winds also indicated a possible cyclonic circulation in the lower troposphere and a trough in westerlies in the middle troposphere (Fig. 7.2).

7.3 The low over Bihar Plateau moved westnorthwestwards to northwest Madhya Pradesh and adjoining parts of Uttar Pradesh and East Rajasthan on the next day. Though the system was hardly detectable on the surface chart, the associated cyclonic circulation extended nearly upto 500 mb level without much tilt with height (Figs. 7.3 and 7.4). The large pressure rise and positive pressure departures over the northern divisions of West Pakistan with negative changes and departures to the east indicated that the disturbance in the north was moving away eastwards across Kashmir. The middle tropospheric trough was also moving across Jammu and Kashmir and Punjab. There was scattered to fairly widespread rainfall practically over the whole of northwest India. The moderate to heavy falls were over West Madhya Pradesh and East Rajasthan, where rainfall as high as 14 cm was recorded. The vigorous monsoon activity over East Rajasthan was caused by the low approaching the sub-division from the east, whereas the rainfall north of latitude 30°N was apparently caused by the system in the westerlies. Note the development of the marked convergence between the easterlies and westerlies over Rajasthan on this day, in the lower troposphere.

7.4 The low moved slowly northwestwards to northeast Rajasthan and southwest Uttar Pradesh by 18th morning (Fig. 7.5). The associated upper air cyclonic circulation continued to be well-marked extending at least upto about 500 mb (Fig. 7.6). The westerly trough was also probably moving across Western Himalayas. The monsoon was vigorous in East Rajasthan, where rainfall amounts of the order of 14 to 17 cm were recorded. The monsoon was also active in West Rajasthan, Himachal Pradesh and hills of West Uttar Pradesh.

7.5 The low lay over north Rajasthan on 19th (Fig. 7.7). The associated upper air cyclonic circulation continued to be well-marked (Fig. 7.8). Rainfall was widespread over northwest India with the heaviest amounts over Rajasthan, as on the previous day. Monsoon continued to be vigorous in East Rajasthan and active over West Rajasthan and Himachal Pradesh. The low moved slightly north and lay over extreme north Rajasthan and adjoining Haryana on the 20th (Fig. 7.9). In the upper air, the circulation was seen only upto about 700 mb, and aloft there was probably only a trough (Fig. 7.10). The monsoon became active in Punjab and Haryana and continued to be vigorous in

East Rajasthan and active in West Rajasthan and Himachal Pradesh. The low moved further northnorthwest into West Pakistan on 21st (Fig. 7.11) and was weakening by 22nd. As a result, the monsoon activity decreased over the whole of northwest India after the 20th.

7.6 Though the system as seen on the surface charts was only a low pressure area, it caused active to vigorous monsoon conditions over a large tract of the country - particularly north Madhya Pradesh, northwest India and West Uttar Pradesh. The system was better marked in the upper air than on the surface chart and extended upto the middle troposphere, a feature which was noticeable almost throughout the life-history of the low. The low was also characterised by an unusually long life. During the monsoon, low pressure areas often weaken as they travel across north India. It may be difficult to locate them on the surface chart after they have weakened. However, in the upper air (lower and middle troposphere) lows maintain their intensity and may travel further, activating the monsoon along their path.

7.7 The low moved from north Madhya Pradesh to Punjab (Pakistan) - a distance of about 800 km in four days i.e. with an average speed of only about 5 kt. Such sluggish movement is characteristic of the low pressure areas over north India during the monsoon. The slow movement of the low coupled with its effective rain-producing capacity causes prolonged spells of wet weather in contrast to the shorter spells of active monsoon associated with monsoon depressions moving relatively fast.

7.8 In the beginning of the period (i.e. between 16th and 18th) active monsoon conditions prevailed over and near the Western Himalayas as a disturbance in westerlies moved across the area. The rainfall belt along and near the Western Himalayas was separated from the one (due to the low from the east) over south Rajasthan by a distinct area of little or no rain in between; particularly on 17th and 18th.

7.9 By the end of the period, a rather deep westerly trough was present over Russian Turkistan, Afghanistan and West Pakistan and the upper tropospheric winds over northwest India became southerly (Fig. 7.12). This upper flow pattern was presumably responsible for the northward movement of the low.

8. Disturbances in Middle Latitude Westerlies

8.1 So far we have dealt with cases of disturbances that form in the monsoon trough and move from east towards northwest India. We have also referred to the influence of the troughs in the middle latitude westerlies in some cases. Disturbances in the middle latitude westerlies sometimes cause increased monsoon activity over northwest India, even without any low approaching the area from the east. They travel from west to east as opposed to the monsoon depressions and lows. They may either be troughs in the middle latitude westerlies which extend to the Indo-Pakistan area or lows/troughs that form over these areas under the influence of the westerly troughs moving further to the north. Quite often the formation of a low over northwest India and West Pakistan could be detected in association with the passage of the westerly trough.

8.2 The effect of the westerly system is normally confined to the northern portion of northwest India. Sometimes these systems may extend southwards and affect Gujarat and south Rajasthan. In this section we shall discuss two cases - illustrative of the effect of the westerly troughs over the monsoon in northwest India - one where a low was induced over the northern parts of northwest India by a westerly trough and another where an induced low formed over Sind and south Rajasthan.

8.3 Movement of a Westerly Trough across Northwest India and formation of a Low over Haryana-Punjab - 4 to 10 July 1967

8.3.1 In 1967 the monsoon advanced into northwest India about a week earlier than normal, so that by 2nd July the monsoon had covered the whole country. However, by the end of the first week of July, a general weakening of the monsoon set in.

8.3.2 On the morning of 4th a well-marked low pressure area lay over Gujarat State and the western half of the axis of the seasonal trough was much to the south of the normal position. The axis was running on the surface chart through Saugor Island, Agra, Ajmer, Jodhpur and thence southwestwards towards the centre of the low (Fig. 8.1). A trough in westerlies had just moved across the Western Himalayas on 3rd. Another was to the west of India on 4th and was well-marked extending from Aral Sea area southsoutheastwards towards north Baluchistan (Fig. 8.2).

8.3.3 By 5th, the trough moved eastwards and was running from east of Aral Sea to Punjab-Haryana (Fig. 8.3). Fig. 8.4 gives the satellite picture showing the extensive clouding associated with the trough. Apparently, under the influence of the trough, a sea level low also formed over Haryana and adjoining areas where pressures were falling (Fig. 8.5). The associated cyclonic circulation was also well-marked in the lower troposphere. The low over Gujarat State was weakening as may be inferred from the large pressure rise. The axis of the seasonal trough was tending to shift north. The monsoon was strong to vigorous in south Rajasthan, Himachal Pradesh, Punjab, Haryana and West Uttar Pradesh. Very heavy rains of the order of 10-14 cm occurred in Punjab-Haryana.

8.3.4 On 6th the westerly trough moved to Western Himalayas; but the low level circulation persisted over Punjab, Haryana and neighbourhood (Fig. 8.6) and was clearly noticeable in the APT picture (Fig. 8.7). The low over Gujarat State weakened further. Except over northwest India, the axis of the seasonal trough had shifted to the foot of the Himalayas (Fig. 8.8). The rainfall decreased over northwest India; while over Rajasthan monsoon became quite weak, it continued to be strong in Punjab-Haryana. However, there were no heavy falls.

8.3.5 On 7th the westerly trough moved to western Tibet (Fig. 8.9). The cyclonic circulation over Punjab - Haryana was weakening and was seen as a trough. The monsoon trough also shifted north to near about 30°N over northwest India, while it continued along the foot of the Himalayas, further east (Fig. 8.10). Thus the shift was complete in the eastern half, whereas in the western half the trough was still over the plains. The 24 hour pressure change and pressure departure charts showed characteristics of typical break monsoon with large negative values in the north and positive values to the south. The monsoon was strong in Punjab and Haryana, normal in West Rajasthan and weak over rest of northwest India. The sub-tropical ridge at 200 mb level abruptly shifted southward between 6th and 7th and was near about 28°N on the 7th.

8.3.6 By 8th the western half of the monsoon trough also shifted to the foot-hills and the winds were everywhere westerlies right upto the foot of the Himalayas (Fig. 8.11 and 8.12). Winds in the lower troposphere also strengthened to 30-35 kt over Rajasthan and the pressure gradient became steep over Rajasthan and adjoining Gujarat State. Strong dust-raising winds or dust in suspension prevailed over West Rajasthan on this day. However, the rainfall pattern remained more or less the same as on the previous day, with generally weak monsoon conditions except in Punjab, Haryana and East Rajasthan where monsoon activity was normal. The upper tropospheric trough was roughly along 85°E at 300 mb and the sub-tropical ridge line at 200 mb shifted further south to about 25°N.

8.3.7 On 9th there was no appreciable change in the surface chart (Fig.8.13). The pressure gradient continued to be strong over Rajasthan where strong dust-raising winds still prevailed. But pressures were falling all over the country, although the largest negative pressure departures from normal were over north India along the foot of the Himalayas. With the strong westerlies continuing in the lower troposphere over northwest India, the rainfall was now confined to the Western Himalayas with a few heavy falls of 12-25 cm in the hills of West Uttar Pradesh. Weather remained mostly dry over the rest of the area. The westerly trough at 300 mb did not show any movement but remained along about 85°E (Fig. 8.14). The sub-tropical ridge continued to be near 25°N.

8.3.8 The synoptic features on 10th were almost the same as on 9th. However, the upper westerly trough showed signs of weakening and the sub-tropical ridge line at 200 mb moved slightly northward to 27°N (Fig. 8.15). Also the surface pressure registered a slight rise over north India. These, together with some development occurring over North Bay of Bengal, indicated the possibility of monsoon trough moving southwards. By the same evening, the western end of the monsoon trough shifted to the plains and the winds in the lower troposphere had weakened considerably with easterlies appearing at some stations near the foot-hills.

8.3.9 To summarise the salient features, this situation illustrates how westerly troughs initially enhance the rainfall over northwest India and subsequently restrict the rainfall to the submontane regions. As the deep westerly trough approached northwest India it induced a well-marked low over Punjab, Haryana and neighbourhood. The vertical time-sections of Srinagar and Tashkent for this period are given in Fig. 8.16. As mentioned in para 3.6.2 these time sections are very helpful in tracing the passages of the westerly troughs and locating the levels through which they extend. The low together with the westerly trough caused vigorous monsoon over these areas. It is a point worth noting that on the 5th the plains had heavier amounts of rainfall than the submontane regions. As the westerly trough progressively moved eastwards into Tibet the low also weakened, the monsoon trough shifted to the foot-hills and strong westerlies extended upto the Himalayas in the lower troposphere This led to an abrupt weakening of the monsoon over the plains, the rainfall being confined to the submontane districts. The steep pressure gradient that built up over Rajasthan in the wake of these developments caused strong dust-raising winds over West Rajasthan for 2 or 3 days as in the pre-monsoon period. During this epoch the sub-tropical ridge line also was to the south of its normal position and the middle latitude westerly regime extended well to the south over northwest India. Though this has not been called a 'break' in the departmental weather reports presumably because rainfall activity did not completely cease over the plains, the synoptic conditions were similar to 'break' situation in many respects.

8.4 Formation of a Low over southeast Baluchistan and Sind and its eastward movement to Rajasthan - 24 to 25 July 1967.

8.4.1 A typical case of this kind has been described in Sec. 7 of FMU Report No. III - 3.1 in so far as it affected Gujarat State. The same system caused active monsoon in Rajasthan also and will be dealt with briefly in this section. For more details FMU Report No. III - 3.1 may be referred to.

8.4.2 On 22 July 1967, the western half of the monsoon trough shifted northwards compared to its position on the previous day and was running on sea level chart across Ferozepur, Agra, Sidhi and Calingapatnam (Figs. 8.17 and 8.18). The 24 hour pressure changes and pressure departures from normal were maximum (negative) over West Uttar Pradesh, Haryana and Himachal Pradesh. On 23rd July* a low was over the northern parts of West Pakistan and another was forming over southeast Baluchistan and Sind. An upper air cyclonic circulation was also noticed over the area upto about 500 mb level. Rainfall on this day was confined to northeast Rajasthan due to the monsoon trough there; over the rest of Rajasthan, it was mainly dry.

8.4.3 By 24th morning, under the influence of the low developing over Sind and adjoining areas, the western end of the seasonal trough shifted southwards to south Rajasthan where there was a marked increase in rainfall and the monsoon was active. The system was at its peak intensity on 24th evening and 25th morning. The low became unimportant by 26th. Under the influence of this low, rainfall was scattered over Rajasthan on 25th and 26th. An isolated

* Charts for this and subsequent days are included in Fig. 7 series in FMU Rep. No. III - 3.1 and are not reproduced here.

heavy fall of 15 cm was recorded at Mount Abu on 25th. Considering the normal low frequency of occurrence of rainfall over most of Rajasthan, even this scattered rainfall is significant. The rainfall over the Western Himalayas during this period was apparently due to the main trough in westerlies in the upper troposphere moving across the area. The low pressure area that affected Rajasthan formed first over Sind and Baluchistan and moved slightly eastwards and remained practically stationery over Sind, Rajasthan and adjoining Gujarat State from 24th to 26th. During this period it intensified and caused strong monsoon conditions over south Rajasthan on 24th and 25th.

8.4.4 In respect of westerly systems causing weather, it is generally noticed that they produce rainfall in Punjab, Haryana, Himachal Pradesh and West Uttar Pradesh hills. Whenever their influence extends to a more a southerly latitude, Gujarat State gets spells of good rain. However, over Rajasthan the rainfall associated with these westerly systems is less compared to the rainfall occurring either to the south or north of Rajasthan.

9. Bay Depression moving westwards along a more southerly latitude and causing Weak Monsoon over most parts of Northwest India – 29 to 30 July 1967.

9.1 In Sec. 3.7 the common synoptic situations leading to weak monsoon conditions over northwest India have been discussed. The significant feature of the weak monsoon is the absence of any synoptic disturbance. The 'break' in monsoon is a typical situation leading to weak monsoon in many parts of northwest India. Even without a 'break', the western end of the monsoon trough may shift far to the north and the prevalence of strong west/northwesterly winds over northwest India may lead to weak monsoon conditions over the plains. The situation on 9 July 1967 discussed in Sec. 8 is a case of this kind.

9.2 A typical case when the monsoon trough was far to the south, over extreme south Rajasthan and north Gujarat State, leading to weak monsoon over most of northwest India will be discussed in this section.

9.3 A depression was developing over the Northwest Bay of Bengal on 26 July 1967. It moved westnorthwestwards to Orissa the next morning (27th) and was centred near Keonjar (Fig. 9.1). The rainfall associated with the depression extended upto West Madhya Pradesh. Rainfall activity was mainly over and near the Western Himalayas. There was a marked convergence between easterlies and westerlies in the lower troposphere upto 850 mb level over southeast Rajasthan (Fig. 9.2). The depression moved fast to central Madhya Pradesh by 28th morning and was centred near Chhindwara (Fig. 9.3). The APT picture of the depression is given in Fig. 9.4 (note the heavy overcast to the south and the well-defined cumuliform bands to the north). The rainfall belt now covered southeast Rajasthan also; over the remaining parts of Rajasthan there was hardly any rain. Over the rest of northwest India rainfall was isolated and very light, except over the West Uttar Pradesh hills.

9.4 The depression was centred near Ratlam on 29th morning (Fig. 9.5). Even though it was so close to Rajasthan, it did not cause any heavy rains there, as the centre of the depression was to the south of Rajasthan. There were only a few light to moderate showers in the extreme southern parts of Rajasthan. The Western Himalayas continued to get some rainfall. Monsoon was weak over the remaining parts of northwest India. The upper winds were all easterly and quite strong (about 30 kt) in the lower troposphere over northwest India south of Lat. 31°N (Fig. 9.6).

9.5 The depression weakened into a low pressure area and lay over southwest Rajasthan and adjoining Sind on 30th morning. Later it merged with the seasonal low. On 30th also the rainfall was confined to extreme south Rajasthan and was only light to moderate. Scattered rainfall continued over Western Himalayas. Subsequently the western end of the monsoon trough which was much to the south of its normal position began to shift northwards and Rajasthan received increased rainfall.

9.6 In Secs. 4 to 6 of this report we saw that the monsoon depressions moving to East Rajasthan or recurving north to Punjab caused active monsoon over northwest India. In contrast, the depression in the present case proceded along a more southerly track than normal (across the extreme northern parts of Gujarat State) and failed to give any significant rainfall over Rajasthan except over the extreme southern parts. Even though the system was quite close to the area in question, the upper winds were uniformly easterly resulting in practically dry weather over major parts of Rajasthan. The main monsoon activity was confined to Gujarat State, in the southern sector of the depression. However, later, as the monsoon trough began to shift northwards across Rajasthan, there was an increase in rainfall over the state.

9.7 The rainfall activity over Western Himalayas appears to have been associated with a westerly trough which was feebly intruding into the extreme northern parts of India (Fig. 9.7). The sub-tropical ridge in the upper troposphere was prominent and did not shift southwards, with the result that the influence of the westerly trough on the weather over India was limited. Another significant feature is the pronounced ridge over the central parts of USSR (between two well-marked troughs/lows) in the middle and upper troposphere, particularly on the 29th (Fig. 9.8). The satellite picture for the day shows this feature clearly (Fig. 9.9).

10. Conclusion.

10.1 Northwest India is the region where the southwest monsoon reaches last and from which it withdraws first. Therefore, the duration of the monsoon rains over northwest India is short, being only one and a half to two months over West Rajasthan.

10.2 The rainiest parts of the region are the areas close to the Western Himalayas, while the driest part is the western districts of West Rajasthan. West Rajasthan is semi-arid and is susceptible to high variability of rainfall.

Another noteworthy feature is that the southwest-monsoon period is not the principal rainy season in the northern parts of Jammu and Kashmir. Perhaps the orography of the region is responsible for preventing the southwest monsoon current extending beyond Jammu.

10.3 The synoptic disturbances that cause heavy rains in northwest India are predominently low pressure areas (either in the surface or upper air). In the earlier part of the monsoon period monsoon depressions affect only Rajasthan. However, late in the season, they may affect more northerly sub-divisions as well. Other important synoptic systems causing active monsoon conditions over the area, particularly the northern parts are the disturbances in the middle latitude westerlies. Hence for successful anticipation of weather over northwest India it is essential to study the flow patterns and weather to the north of India too. This is also a region where there is a profound interaction between systems in westerlies moving from west to east and the systems to the south, moving from east to west. Satellite pictures are very helpful in locating the disturbances to the northwest of India over regions from where observations are not regularly available. Weak monsoon conditions are usually associated with absence of synoptic disturbances.

* * * *

APPENDIX

Specifications for the strength of Monsoon over land areas

(Taken from DDGF's Technical Circular No.23)

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

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

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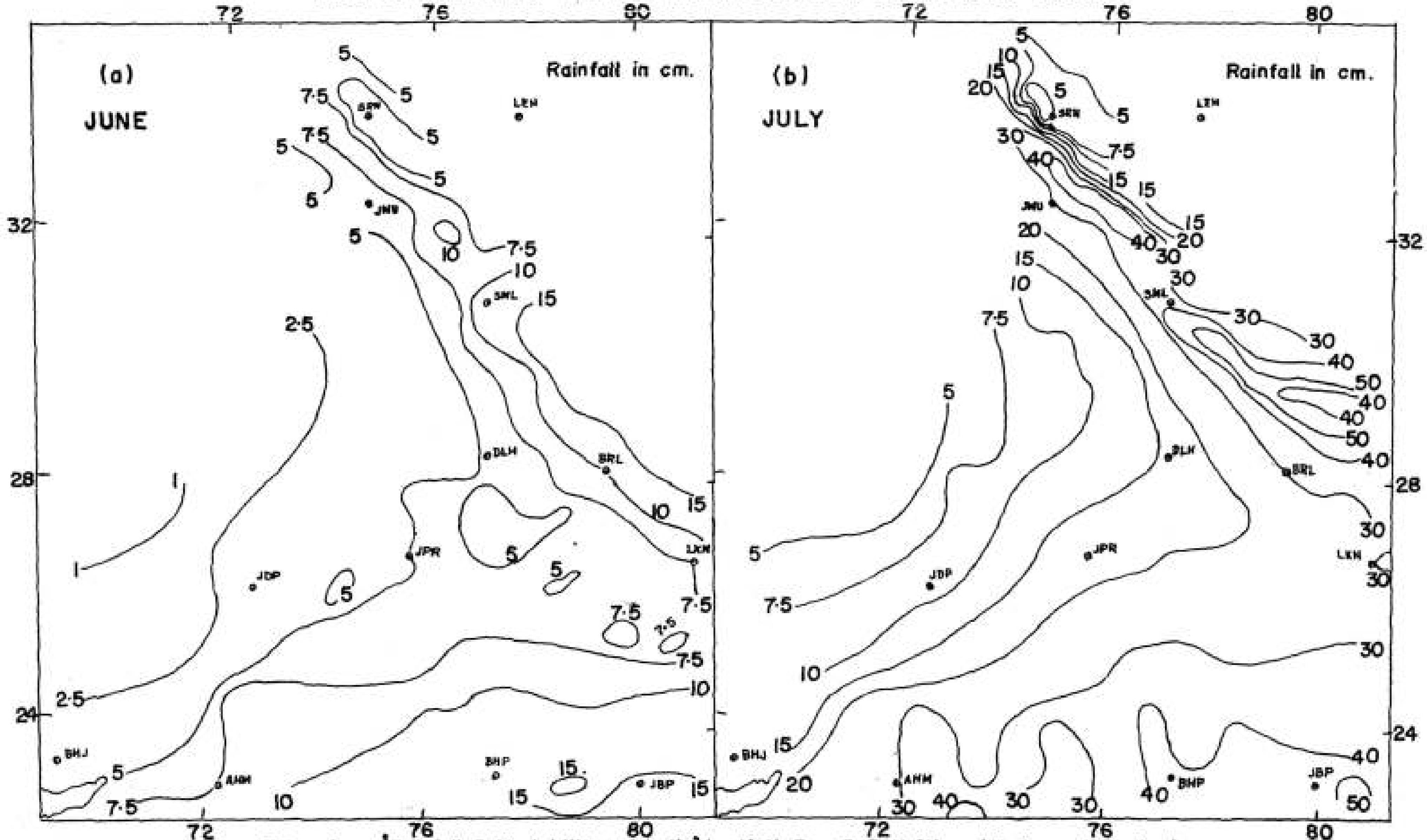
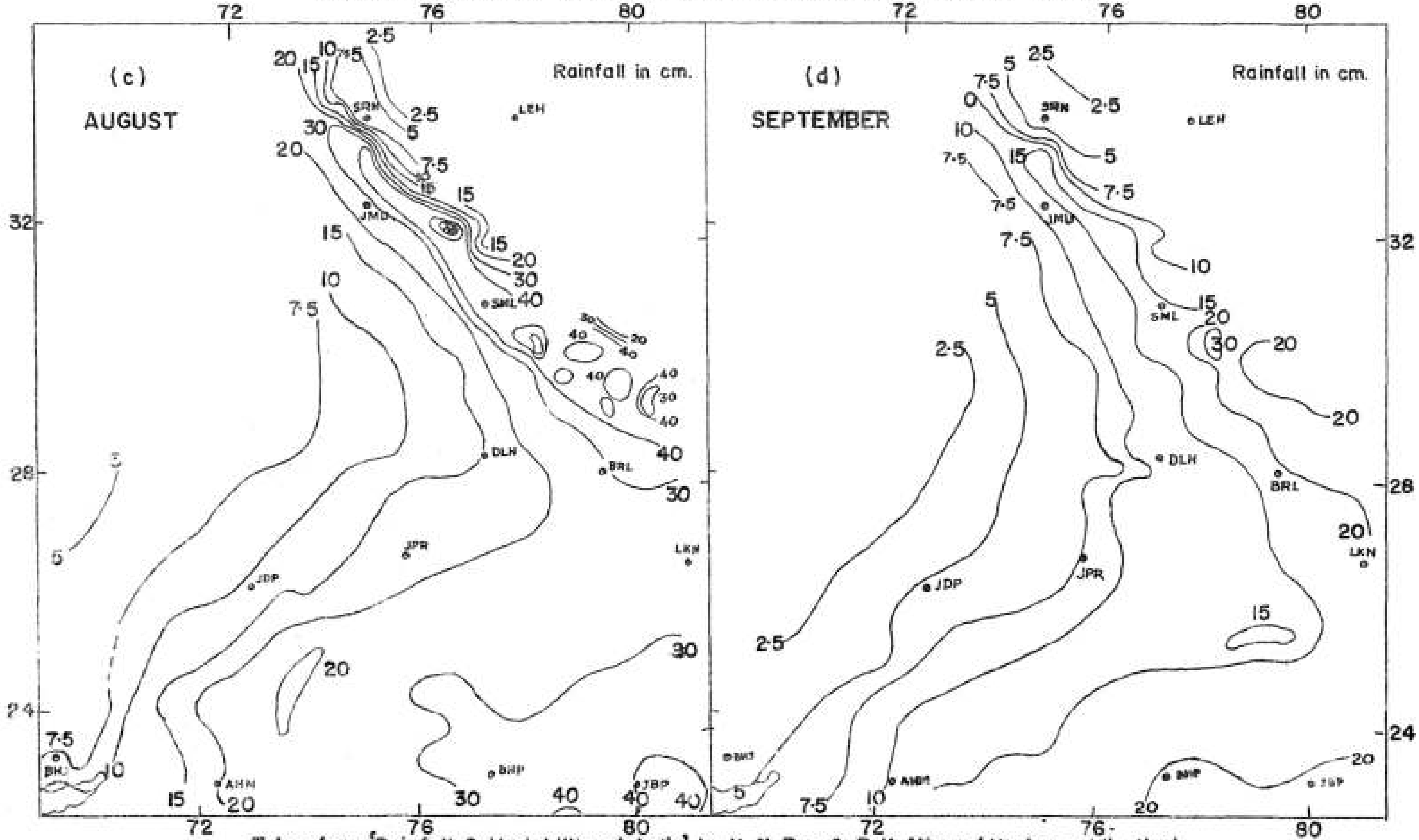
DIAGRAMS

FIG. 2·1 MONTHLY MEAN RAINFALL OVER NORTHWEST INDIA



Taken from 'Rainfall & Variability of India' by K. N. Rao & R. K. Misra (Under publication)

FIG. 2·1 MONTHLY MEAN RAINFALL OVER NORTHWEST INDIA



Taken from 'Rainfall & Variability of India' by K. N. Rao & R. K. Misra (Under publication)

FIG. 2·2 VERTICAL PROFILES OF MONTHLY MEAN UPPER WINDS

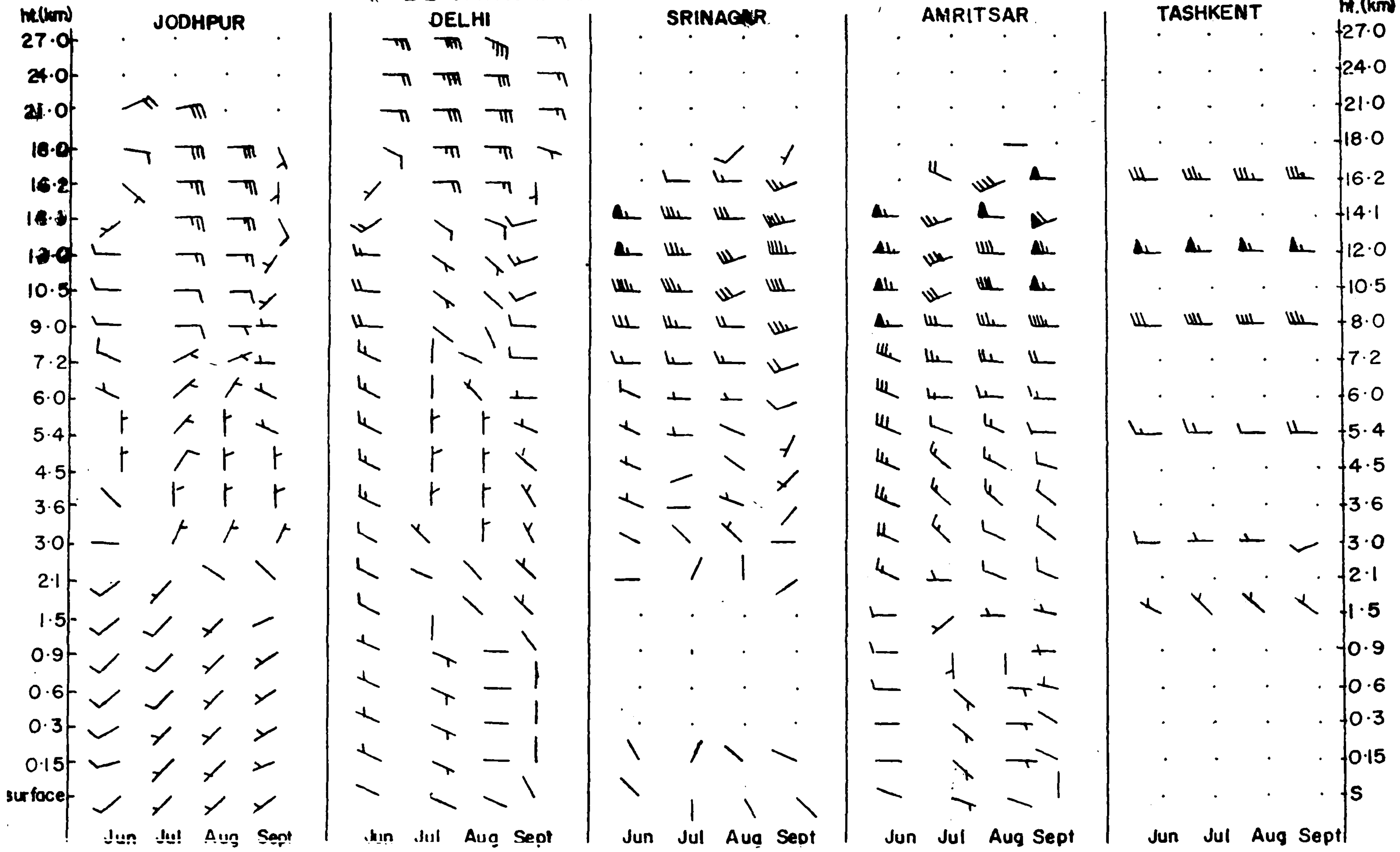


FIG. 2·3 (a) MEAN TEPHIGRAM FOR JODHPUR

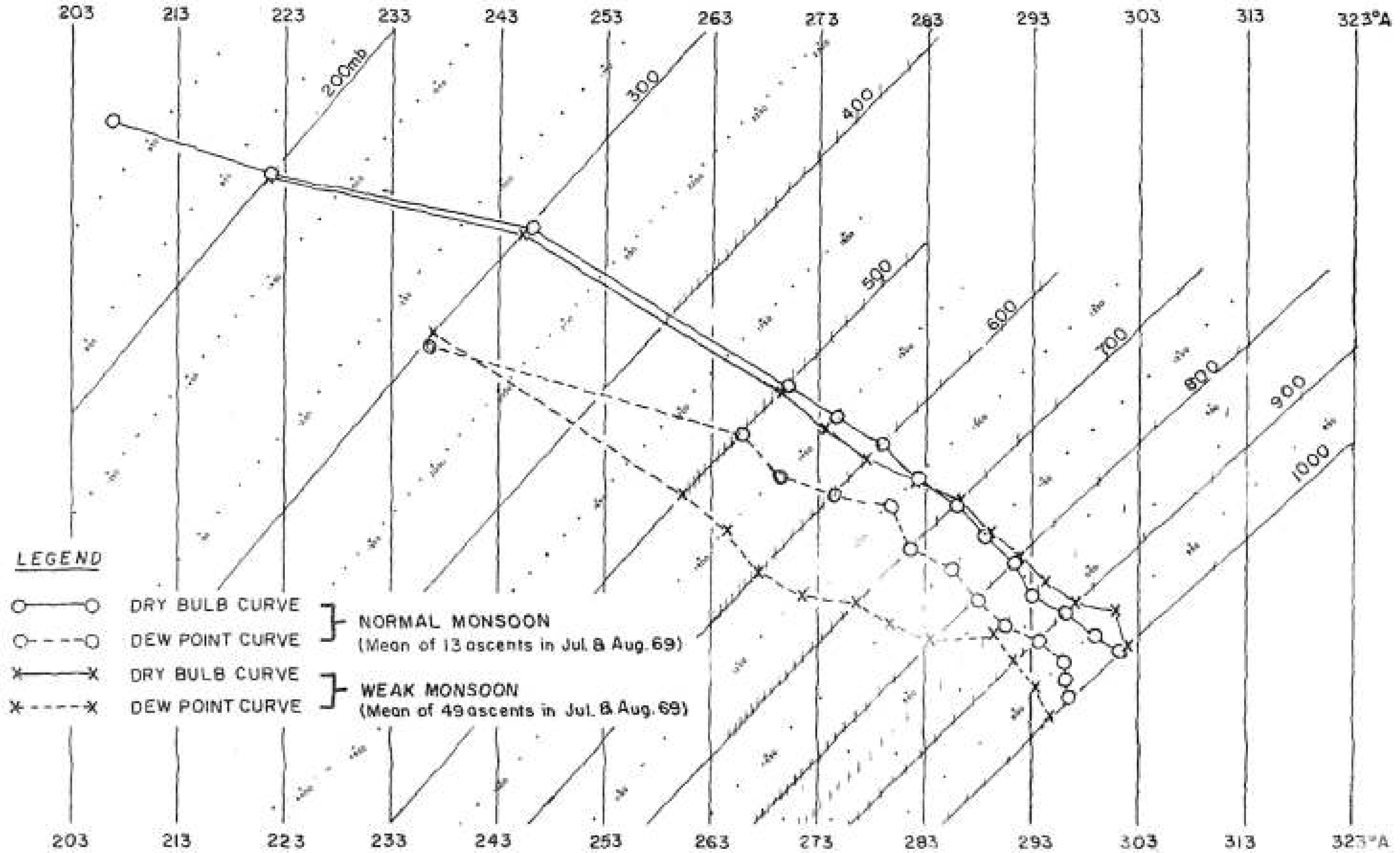


FIG. 2·3 (b) MEAN TEPHIGRAM FOR NEW DELHI

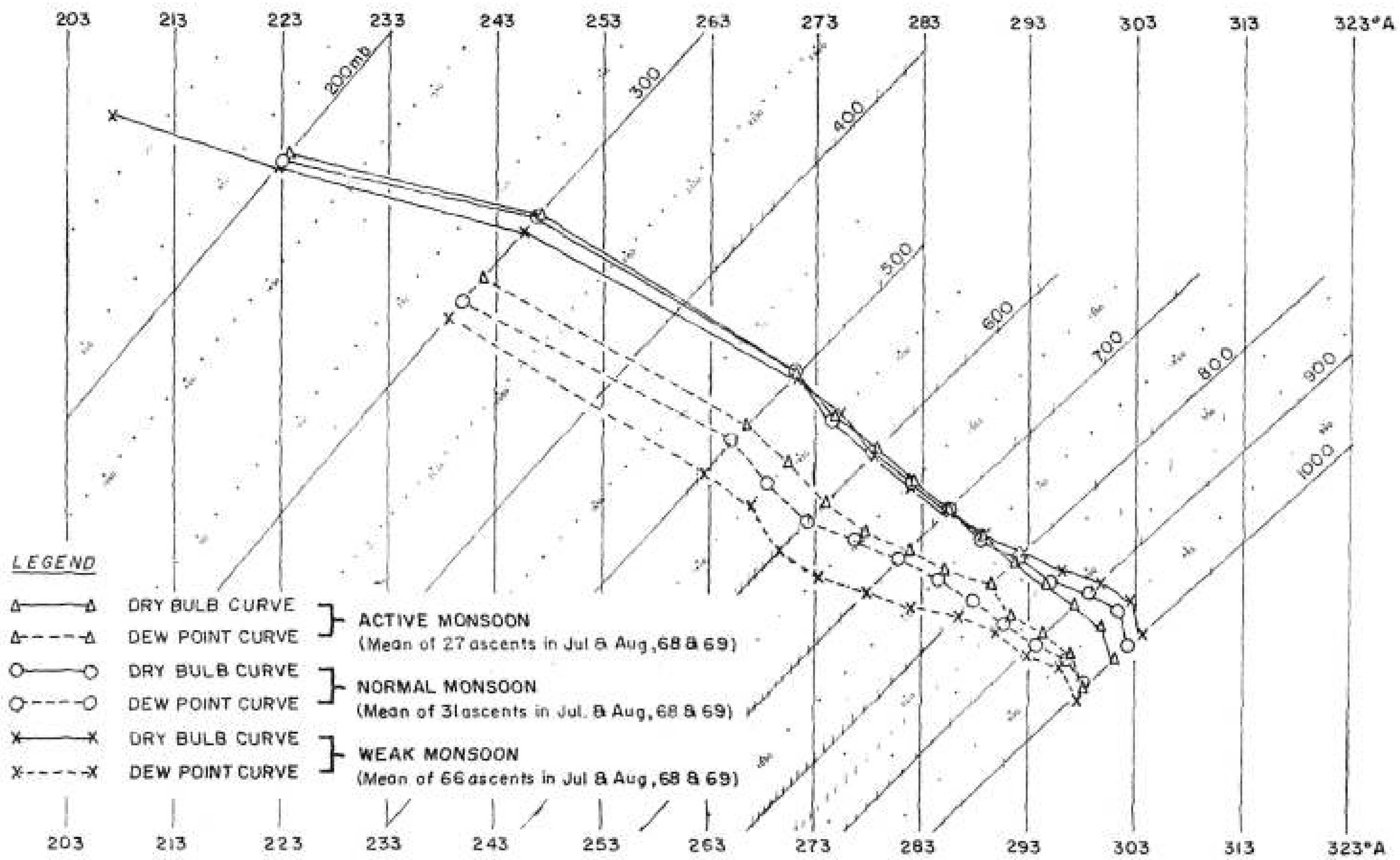


FIG. 2·4 TYPICAL TEPHIGRAM FOR NEW DELHI

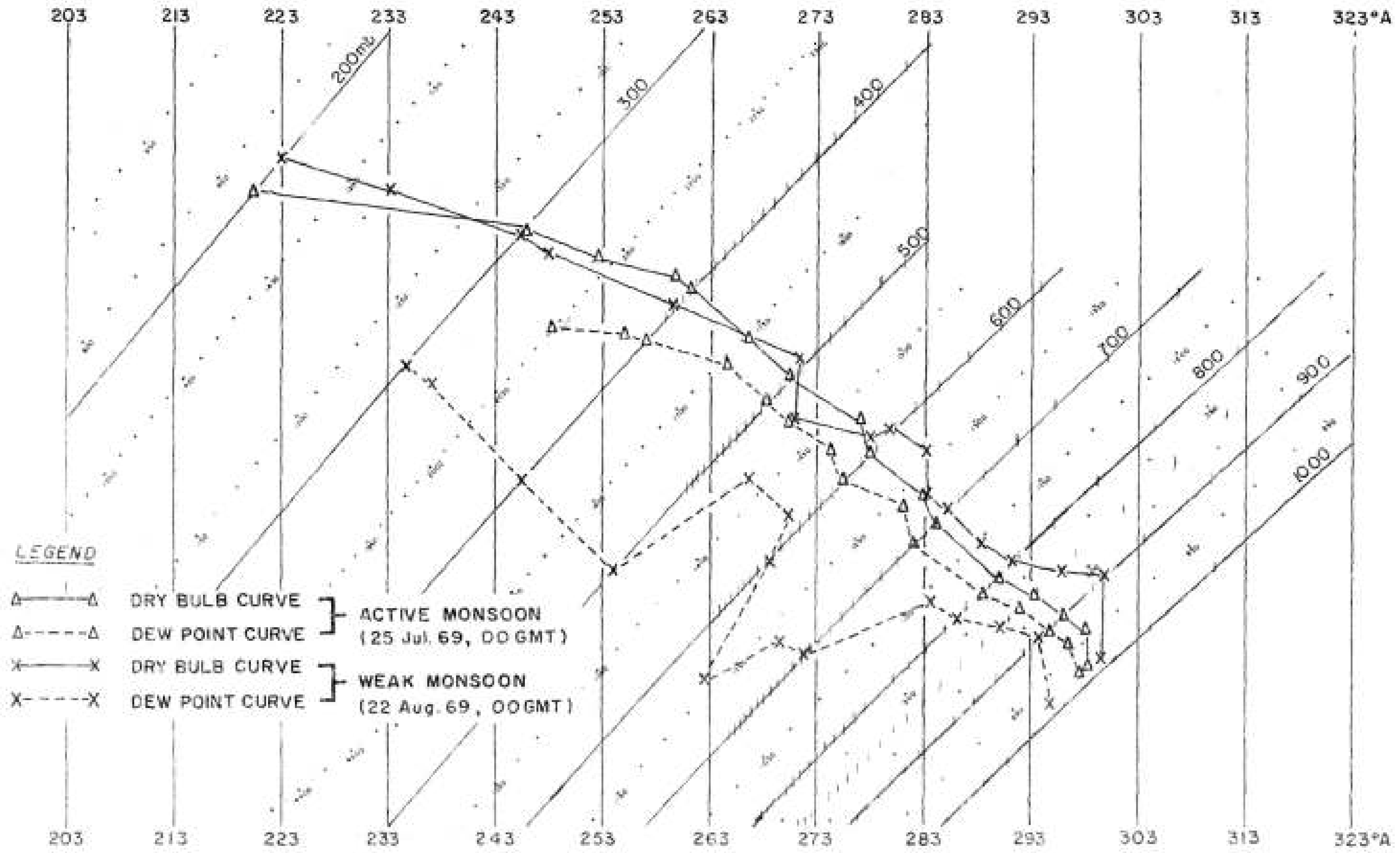


FIG. 4·1 SYNOPTIC CHARTS 0300 GMT 12 AUG. 64

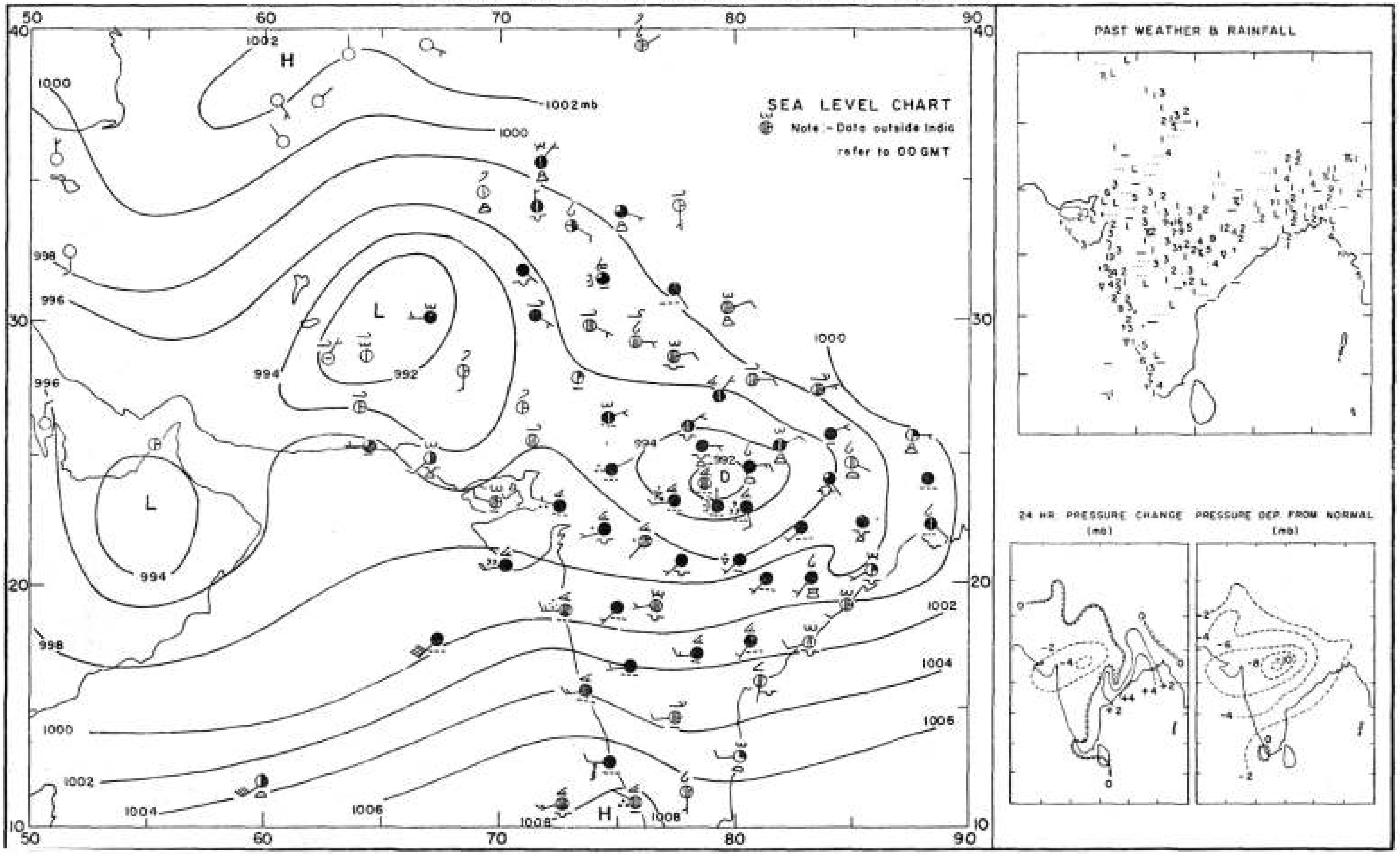
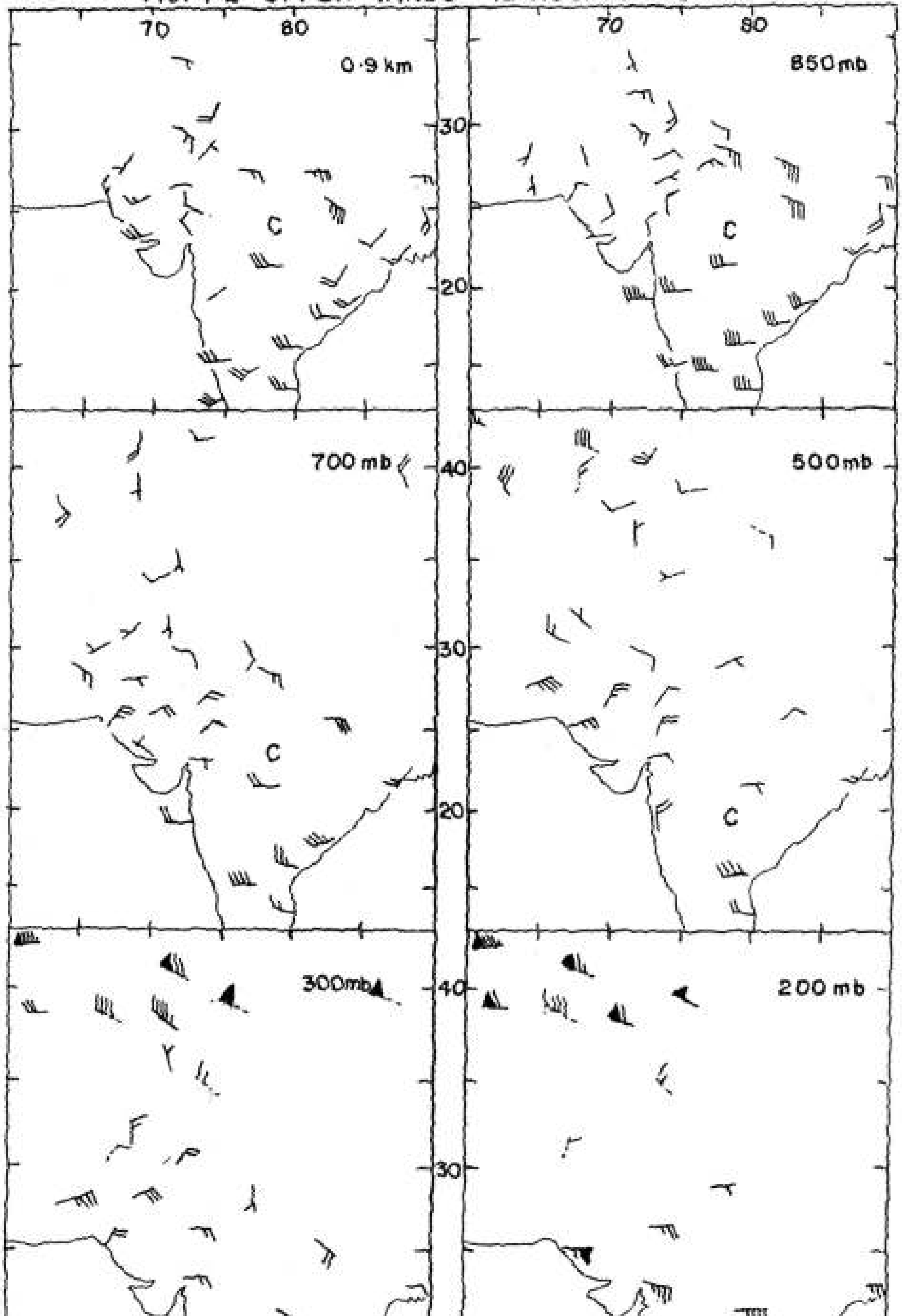


FIG. 4·2 UPPER WINDS 12 AUG. 64 00 GMT



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

FIG. 4·3 SYNOPTIC CHARTS 0300 GMT 13 AUG. 64

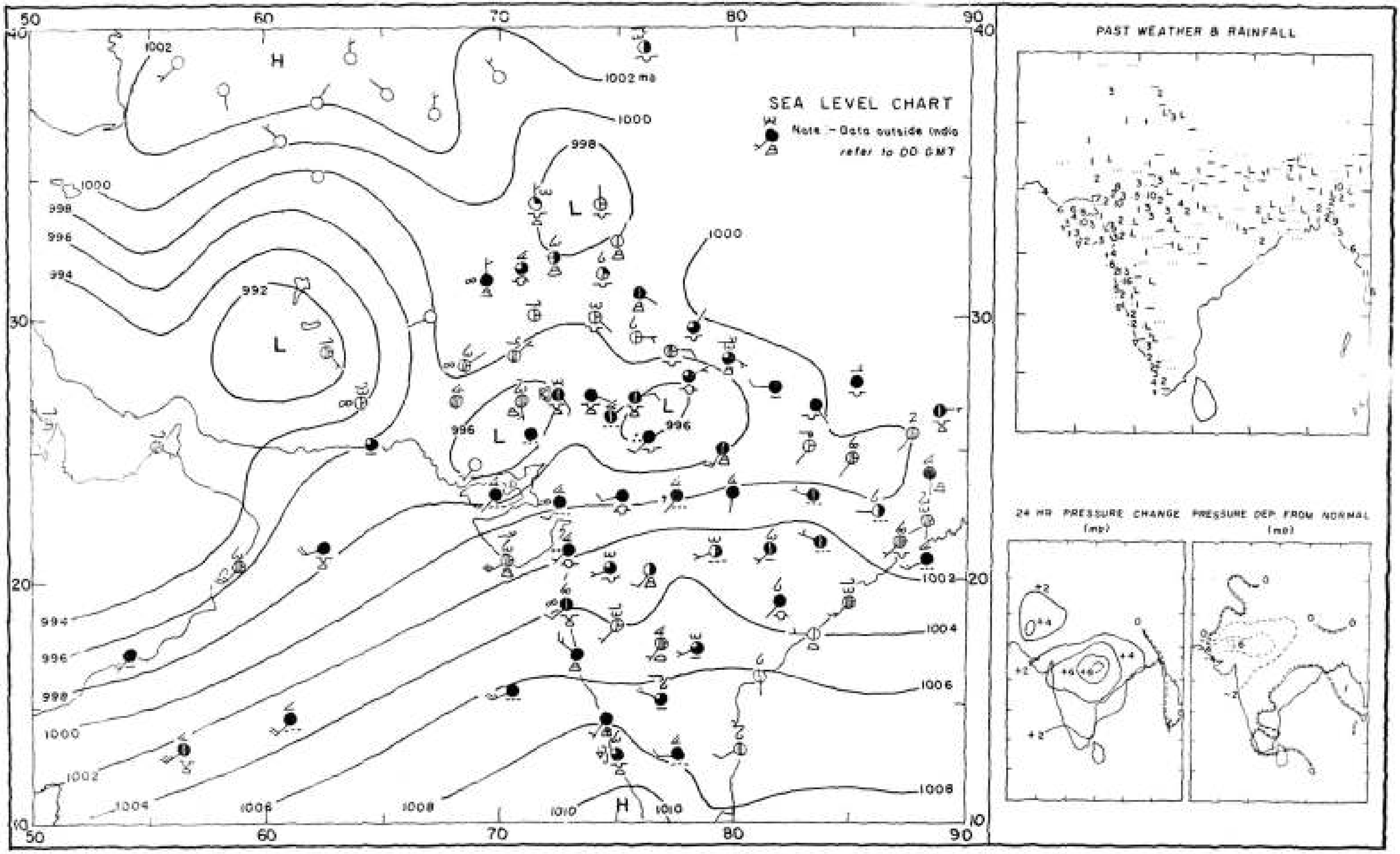
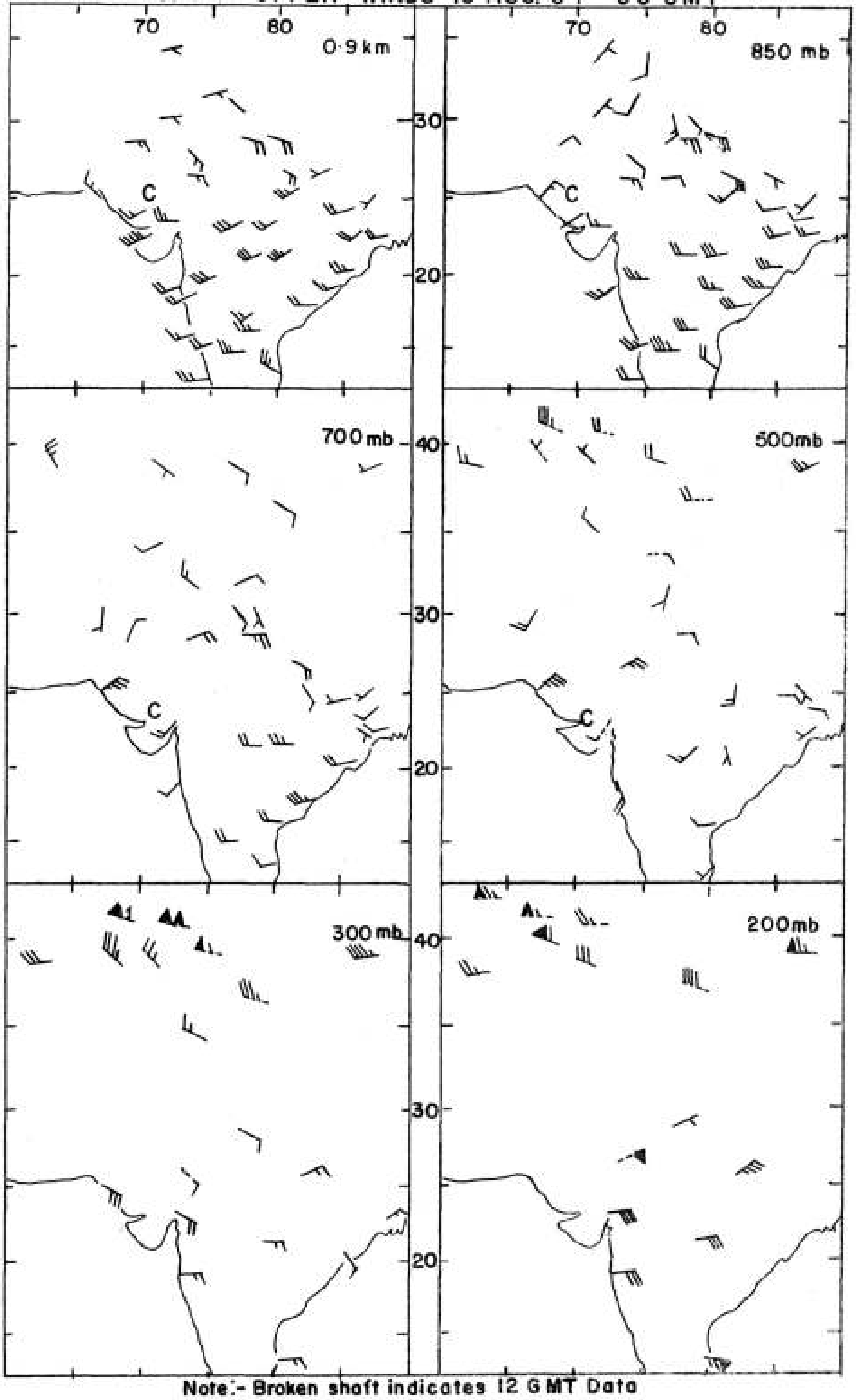


FIG. 4·4 UPPER WINDS 13 AUG. 64 00 GMT



Note:- Broken shaft indicates 12 GMT Data
C - Centre of cyclonic circulation

FIG. 4·5 SYNOPTIC CHARTS 0300 GMT 14 AUG. 64

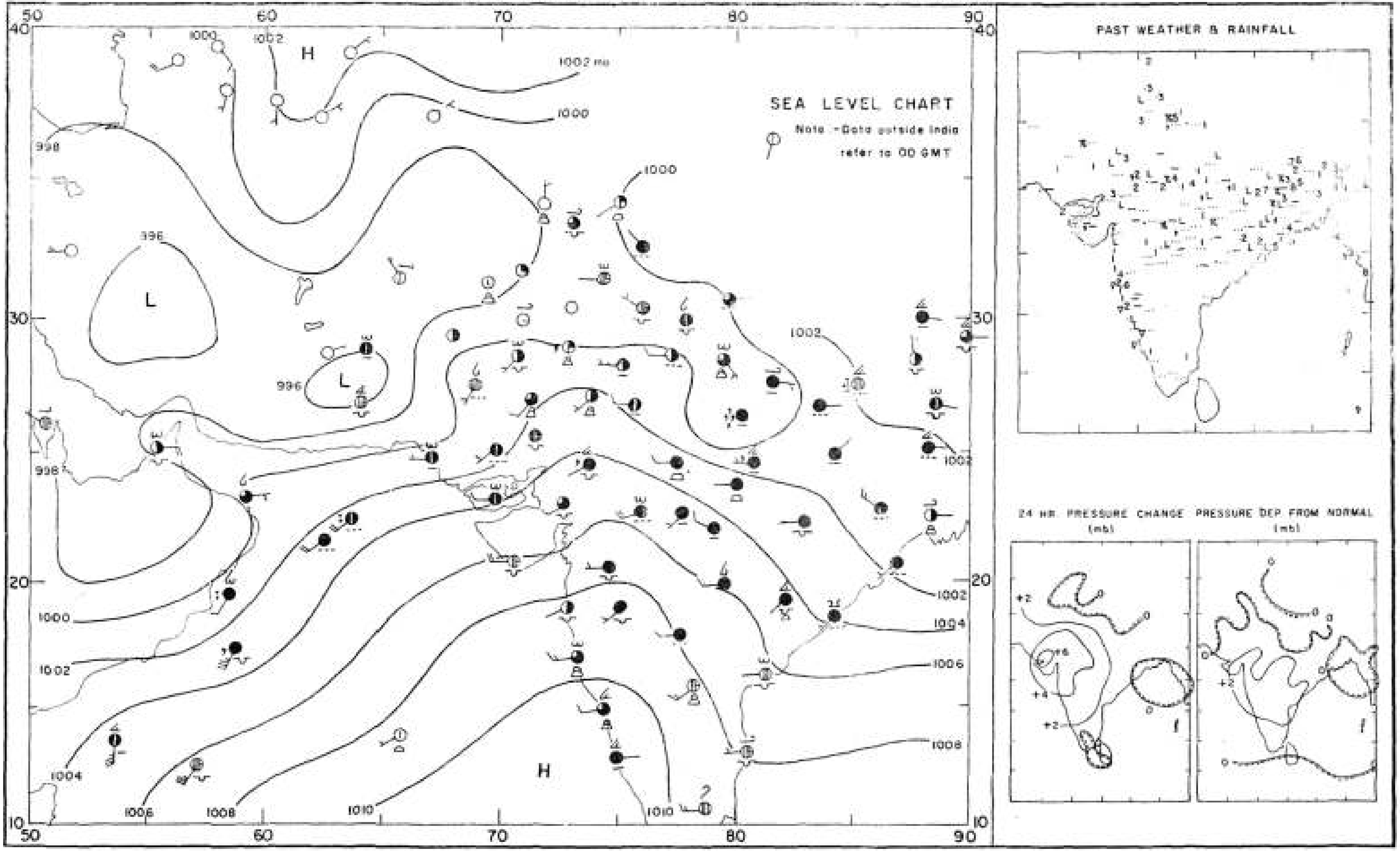
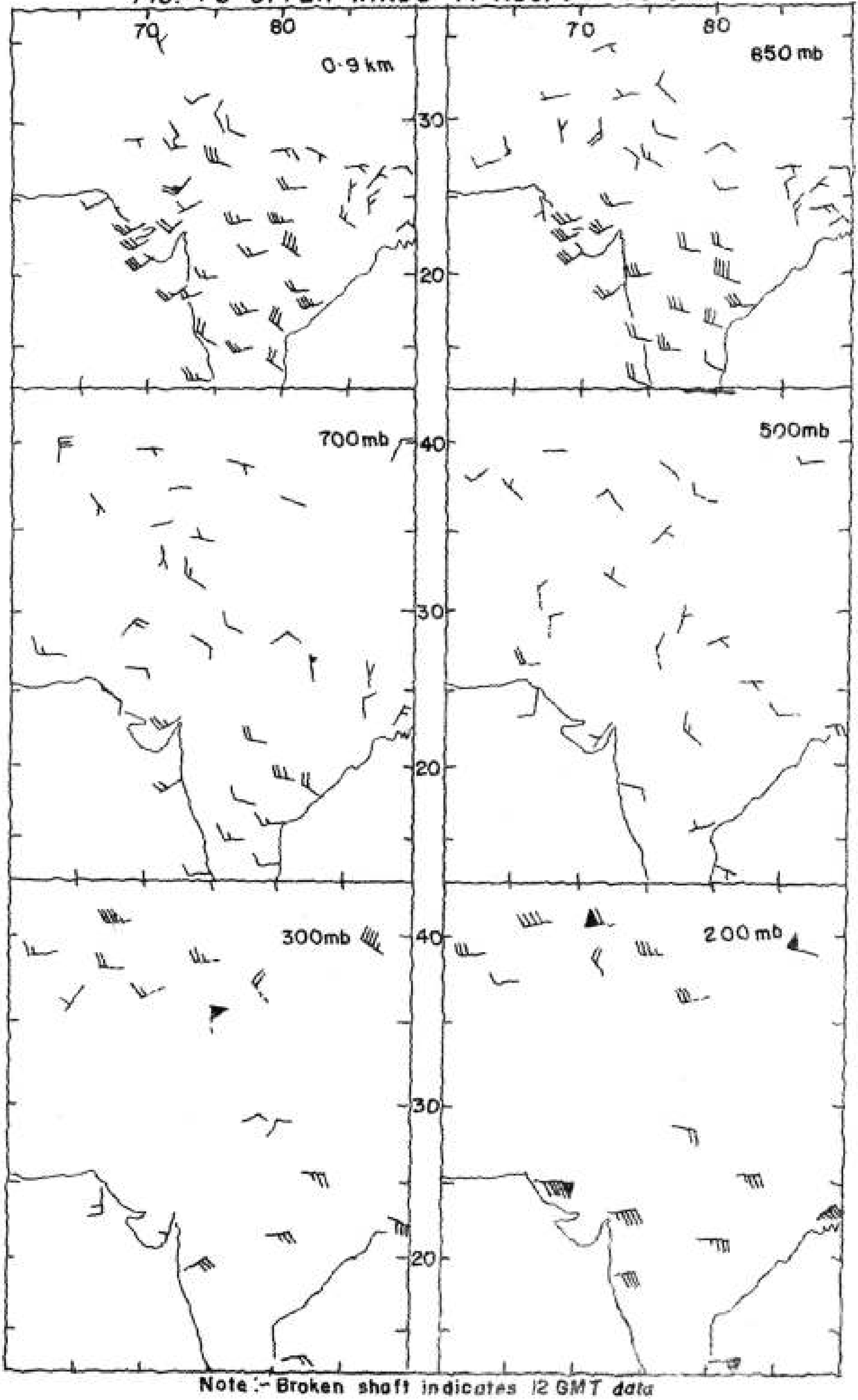


FIG. 4·6 UPPER WINDS 14 AUG. 64 00 GMT



Note :- Broken shaft indicates 12 GMT data

FIG. 4·7 (a) UPPER AIR CHART 13 AUG. 64 00 GMT 500 mb

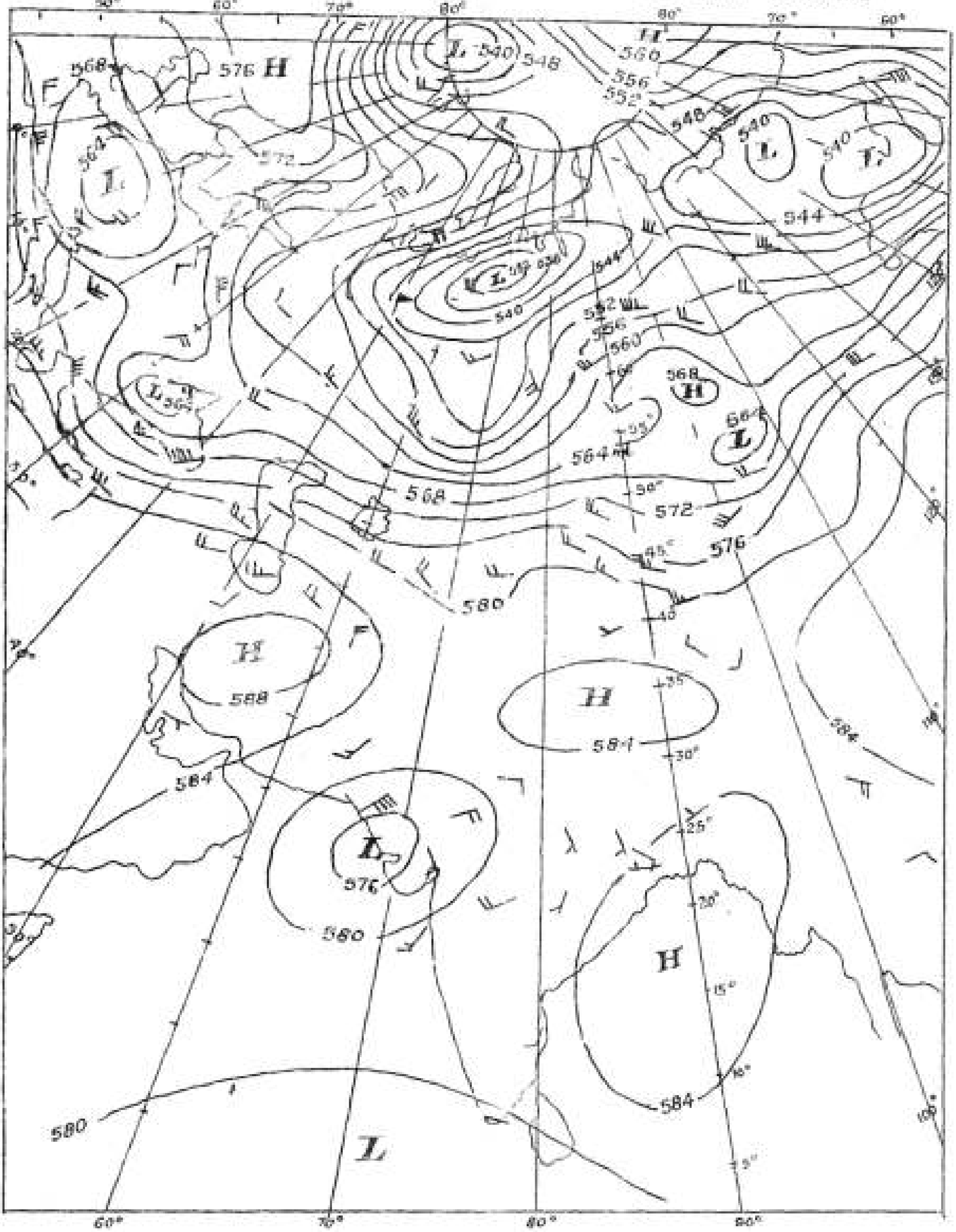


FIG. 4·7 (b) UPPER AIR CHART 13 AUG. 64 00 GMT 300 mb

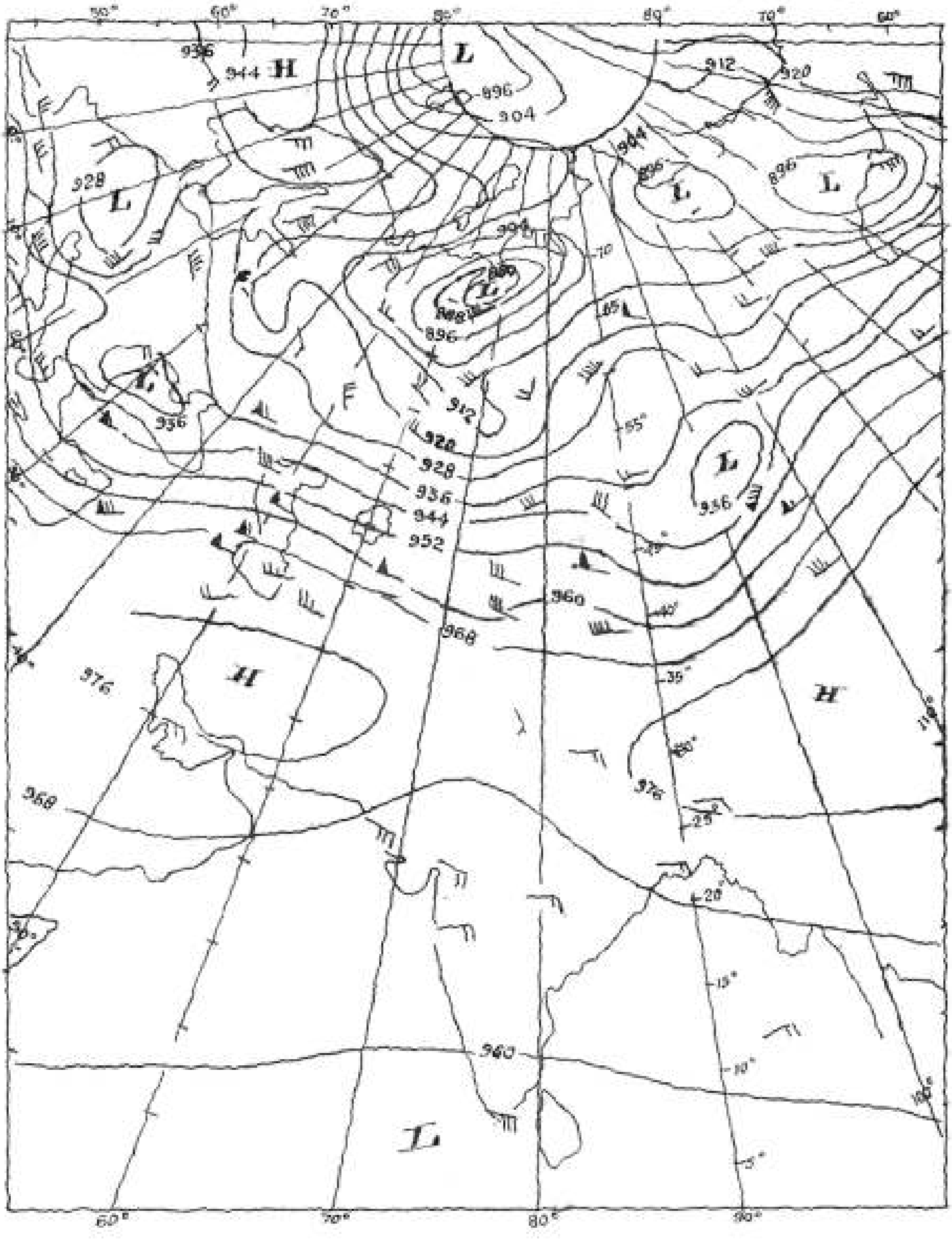


FIG. 5·1 SYNOPTIC CHARTS 0300 GMT 17 AUG. 00

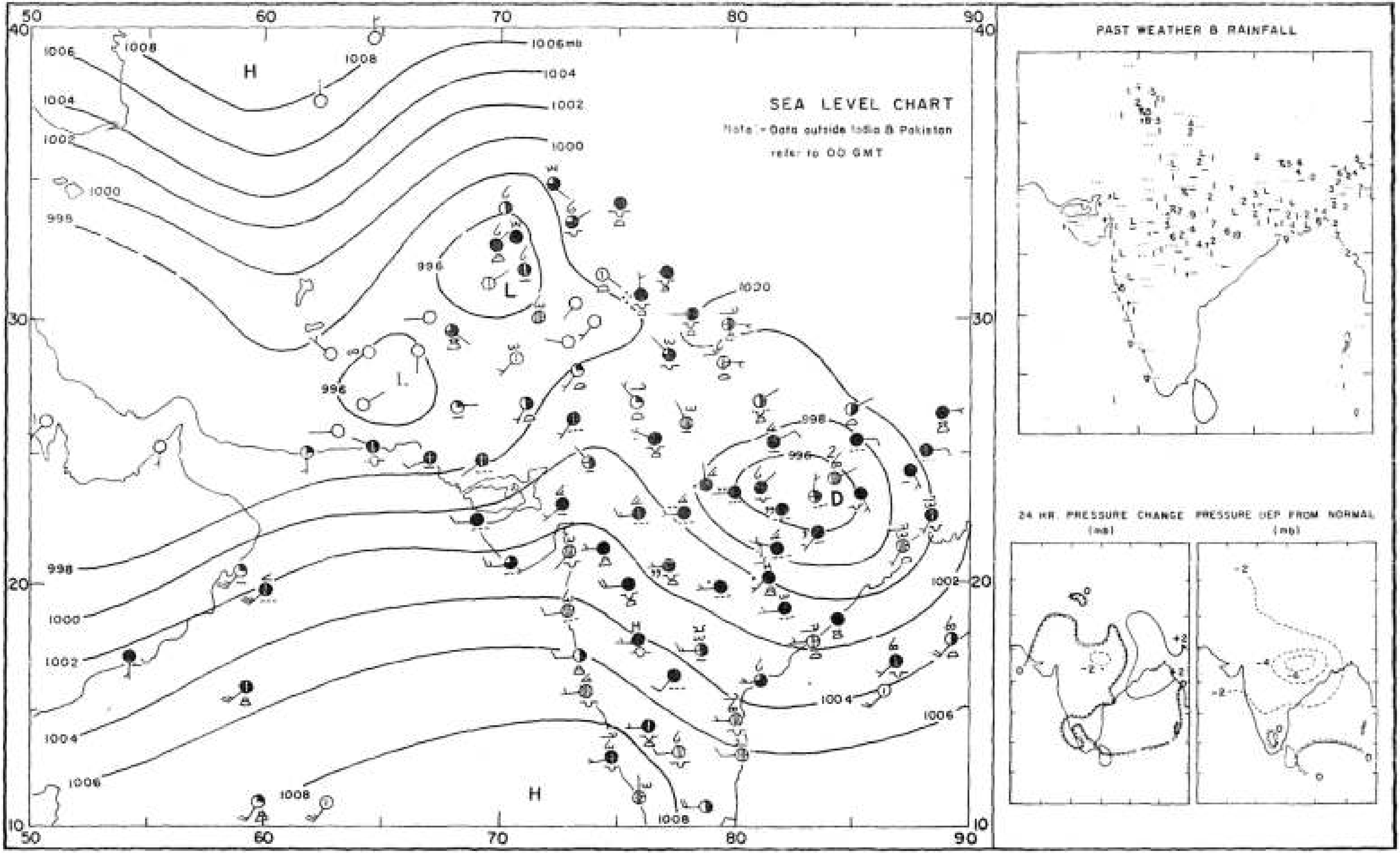
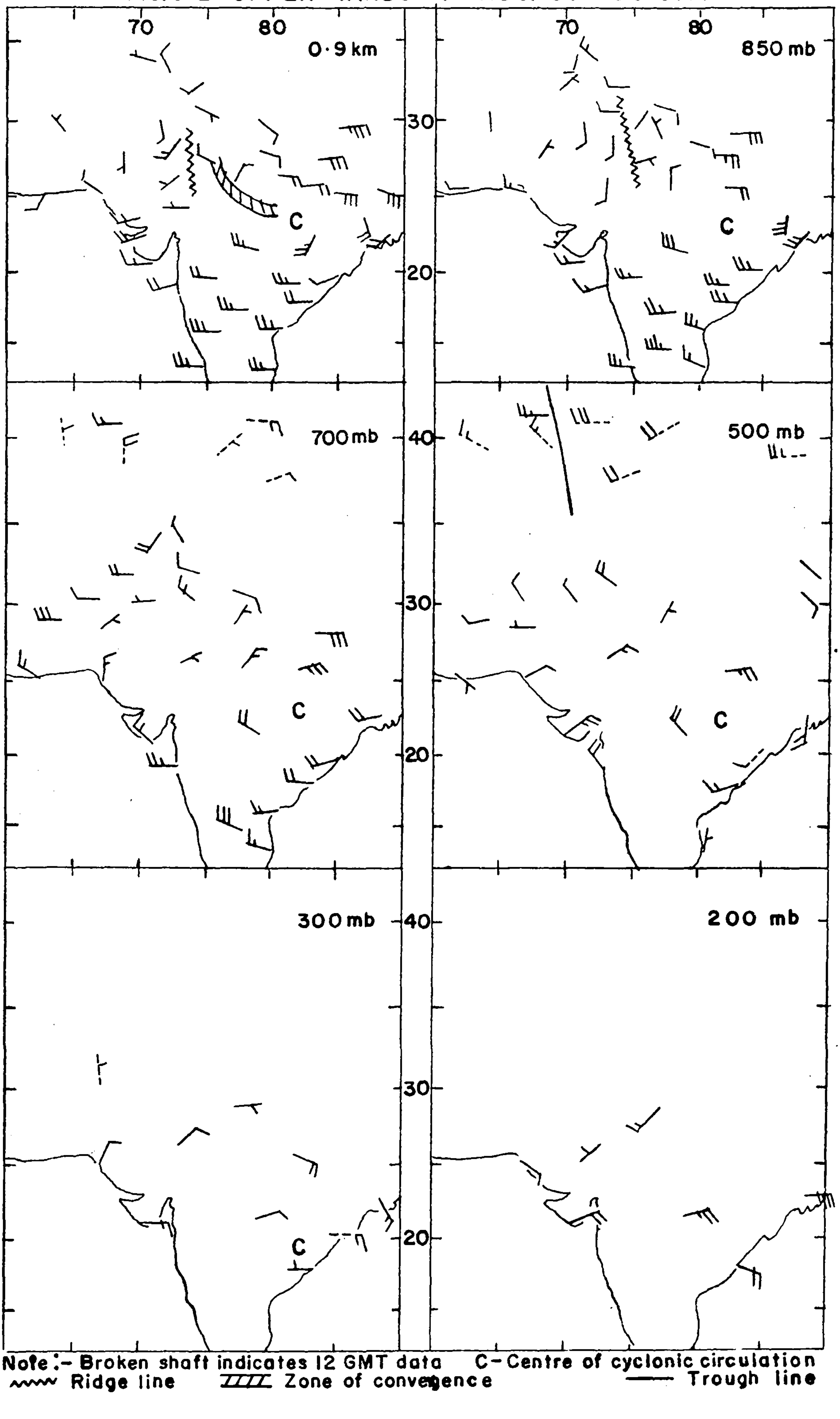


FIG. 5·2 UPPER WINDS 17 AUG. 60 00 GMT



Note :- Broken shaft indicates 12 GMT data C-Centre of cyclonic circulation
Ridge line Zone of convergence Trough line

FIG. 5-3 SYNOPTIC CHARTS 0300 GMT 18 AUG. 60

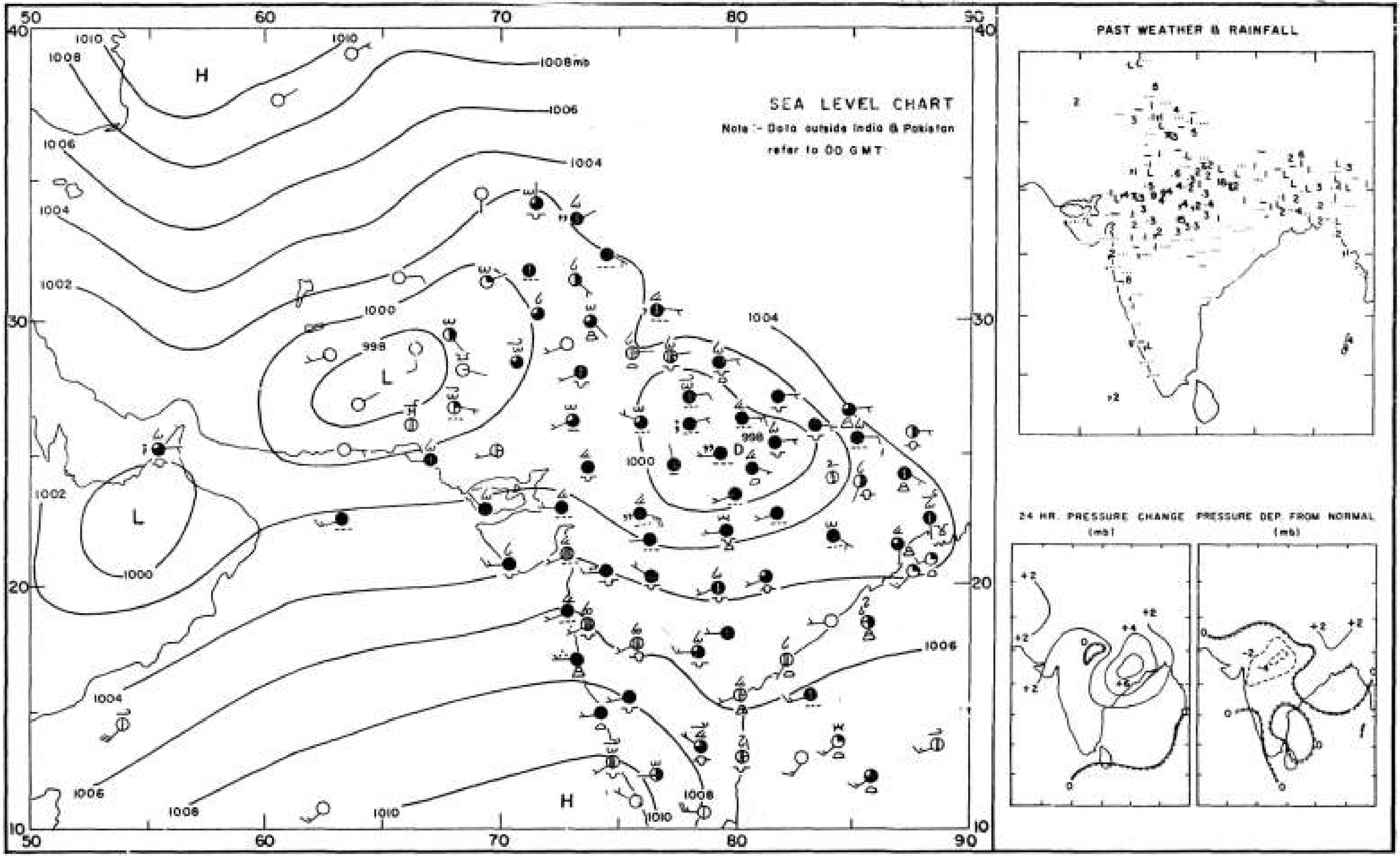
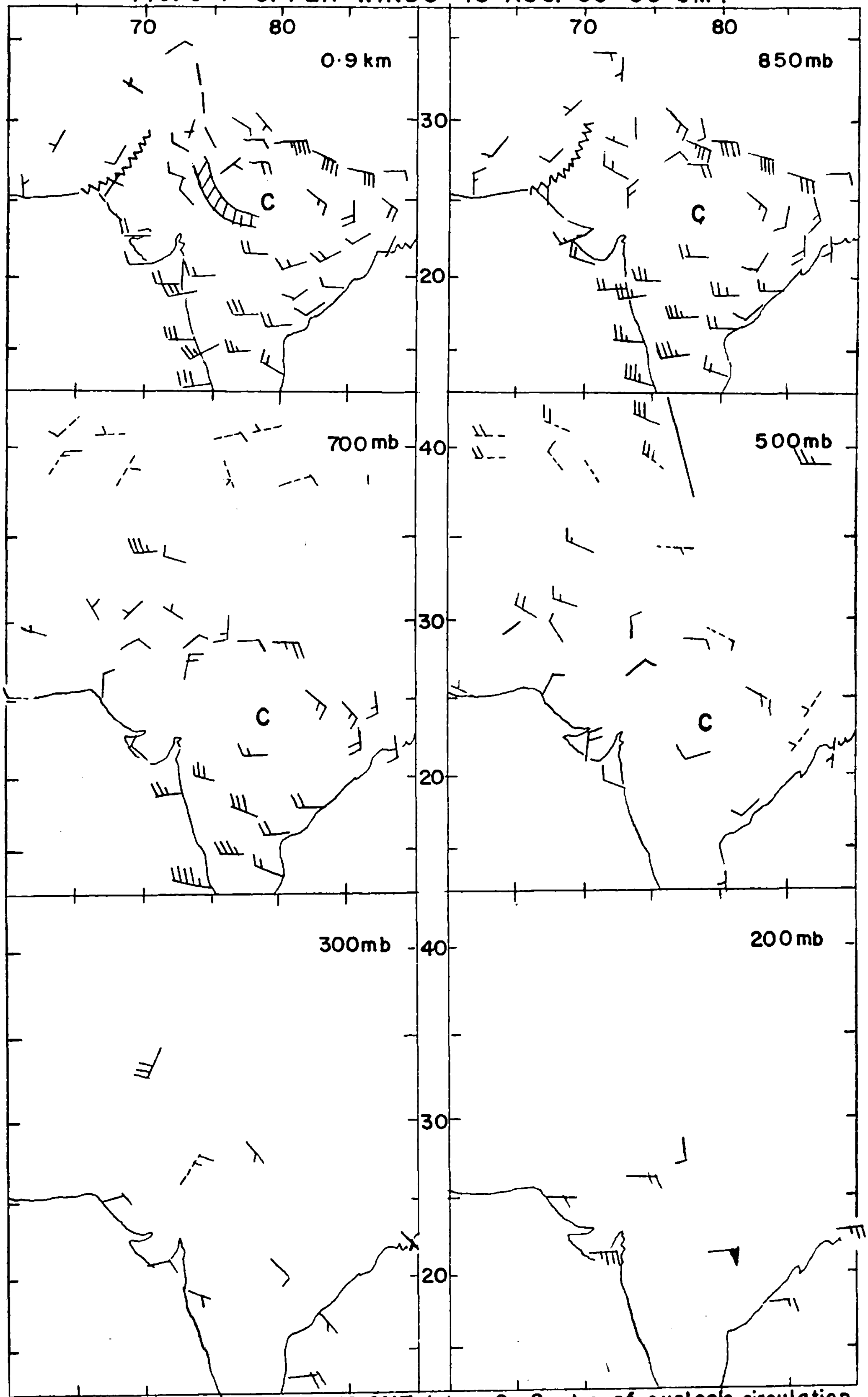


FIG. 5·4 UPPER WINDS 18 AUG. 60 00 GMT



Note :- Broken shaft indicates 12 GMT data C - Centre of cyclonic circulation
Ridge line Zone of convergence Trough line

FIG. 5-5 SYNOPTIC CHARTS 0300 GMT 19 AUG. 60

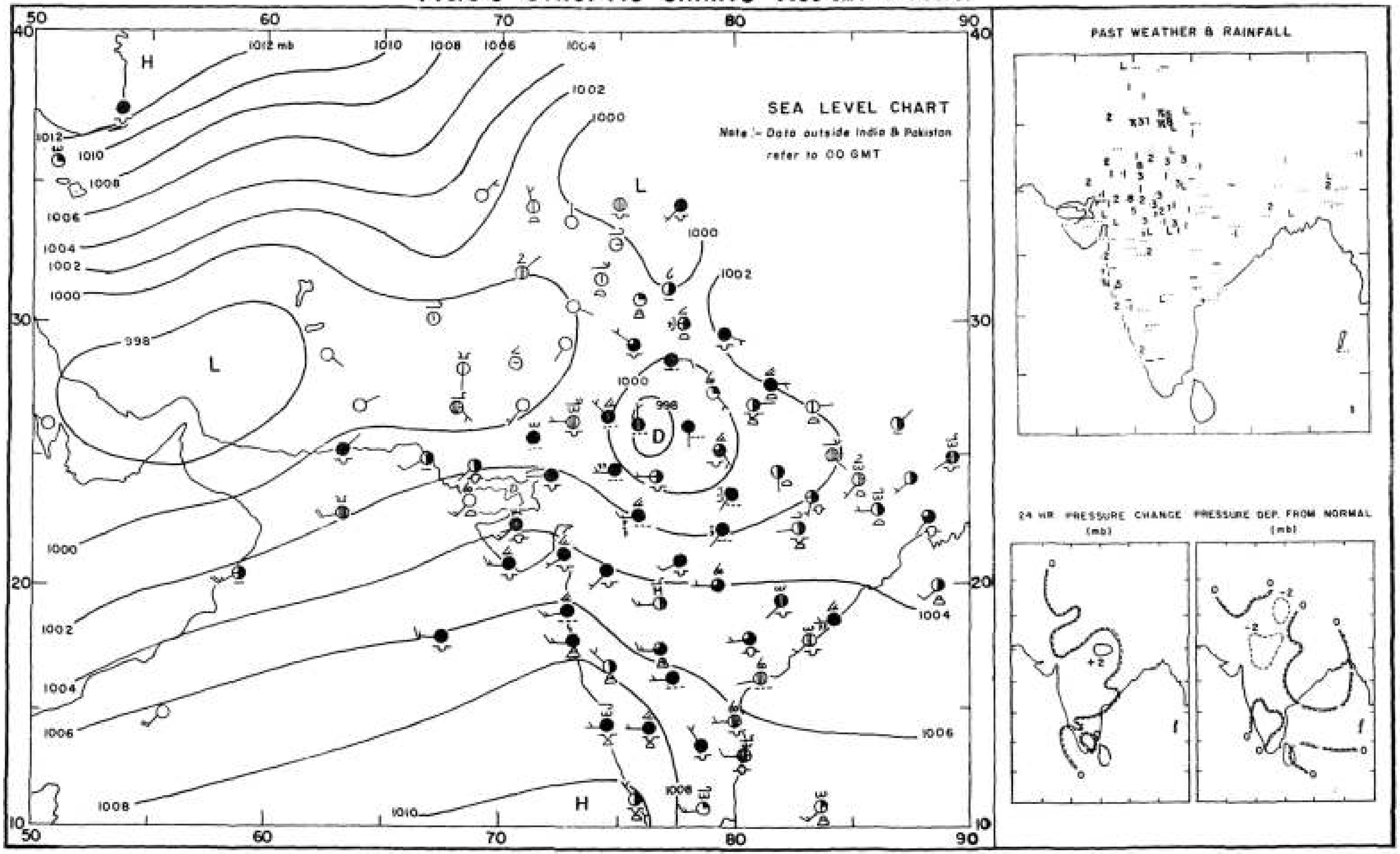


FIG. 5·6 SYNOPTIC CHARTS 0300 GMT 20 AUG. 60

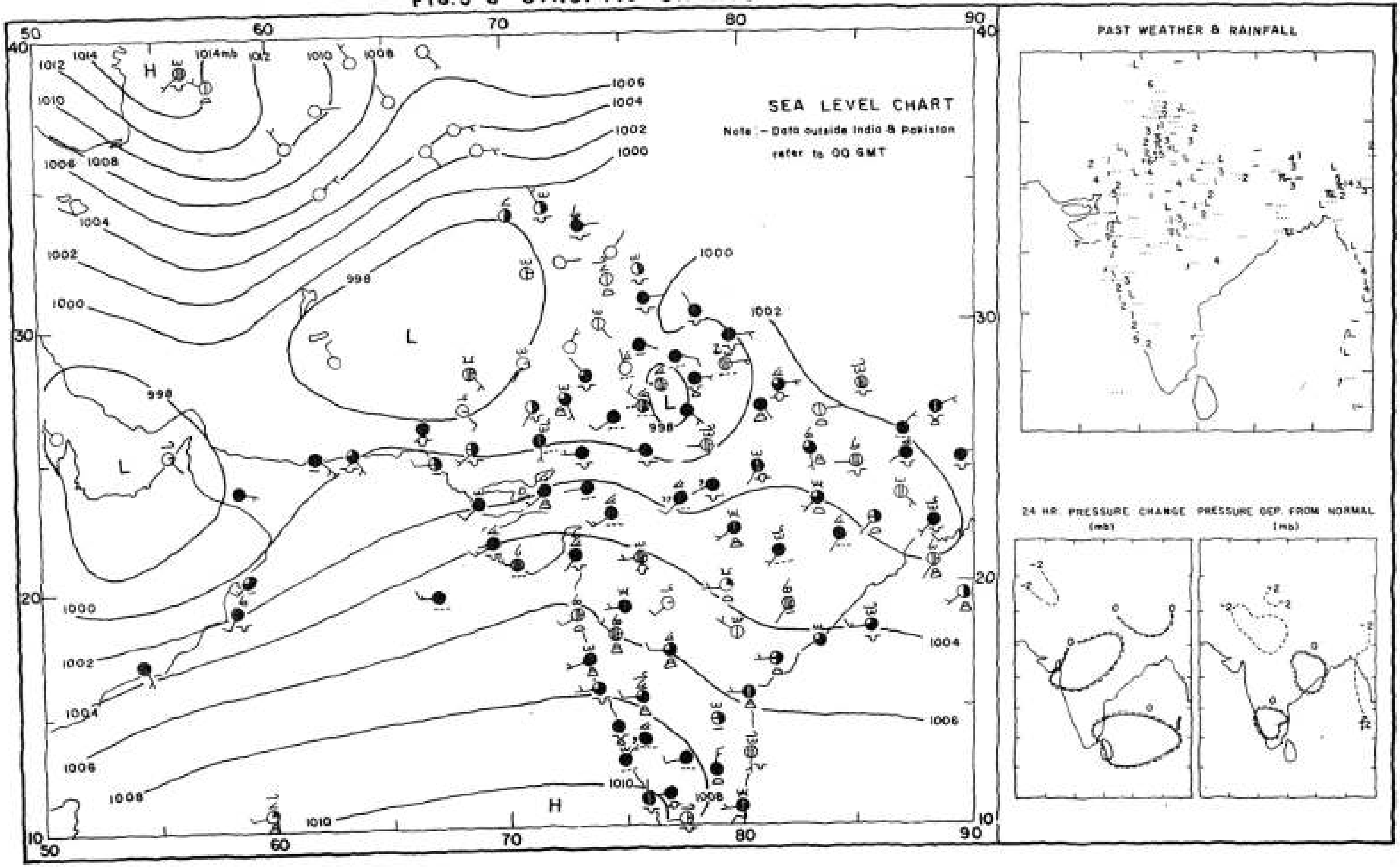
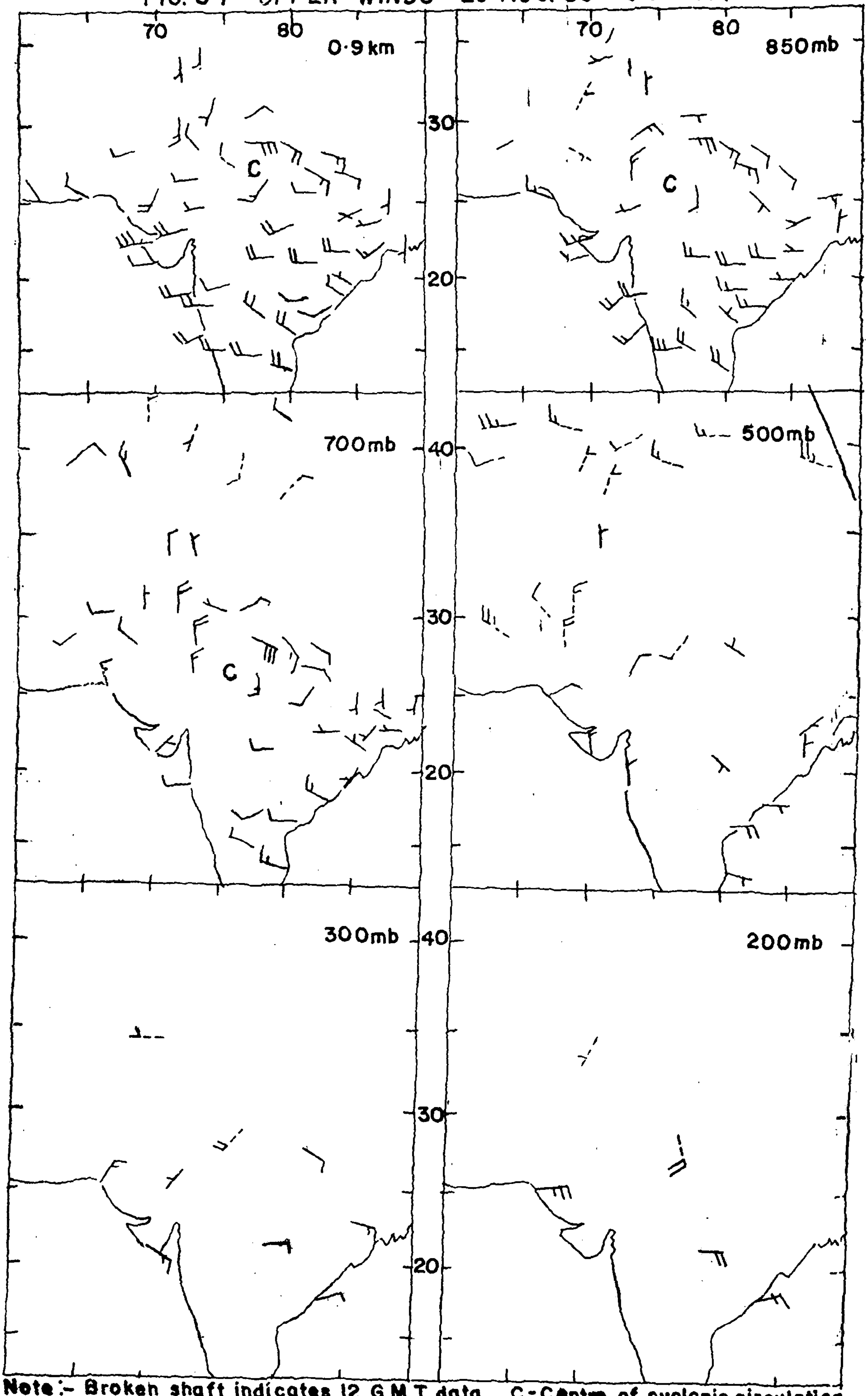


FIG. 5·7 UPPER WINDS 20 AUG. 60 00 GMT



Note :- Broken shaft indicates 12 G M T data C-Centre of cyclonic circulation
——— Trough line

FIG. 5·8 SYNOPTIC CHARTS 0300 GMT 21 AUG. 60

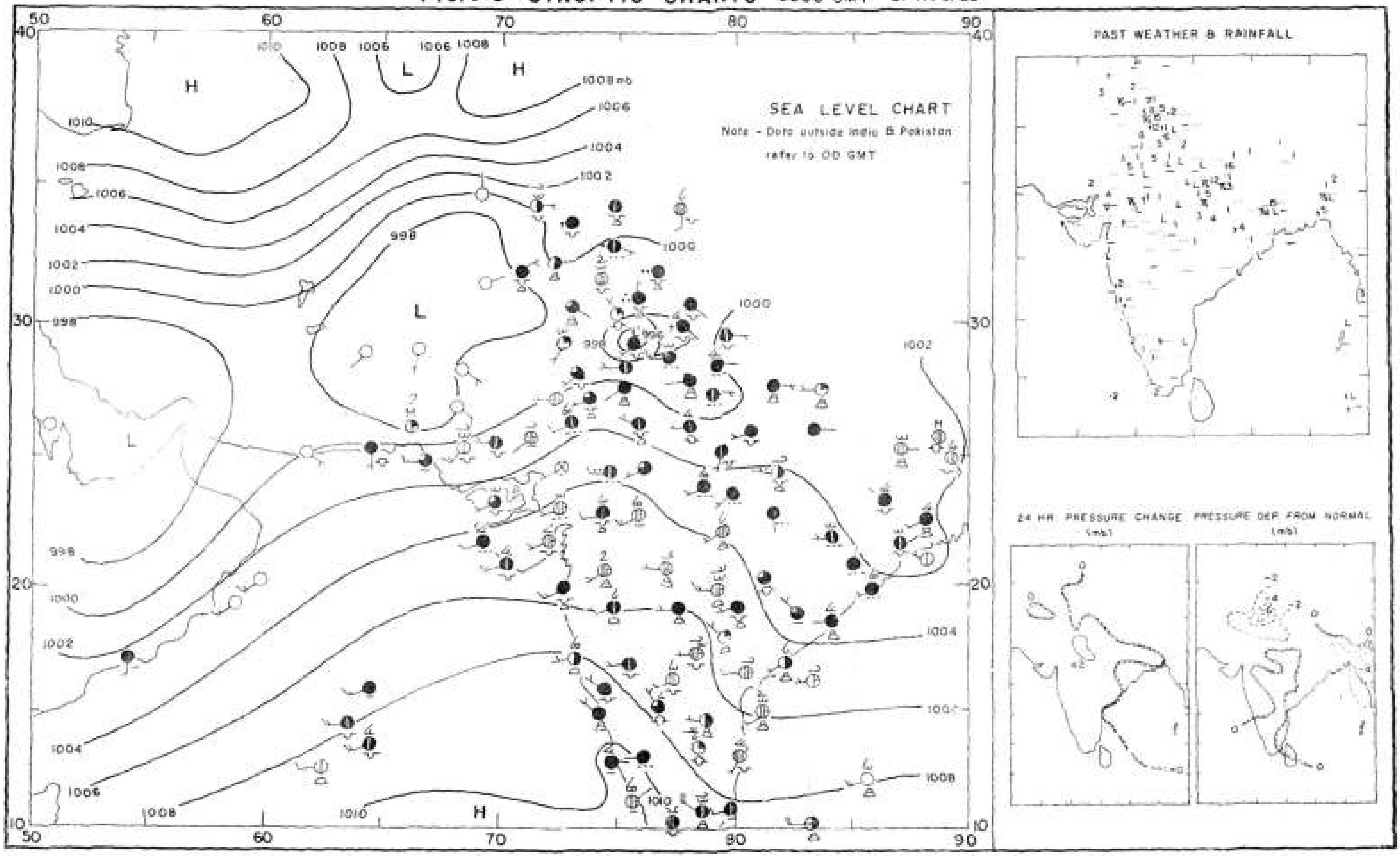
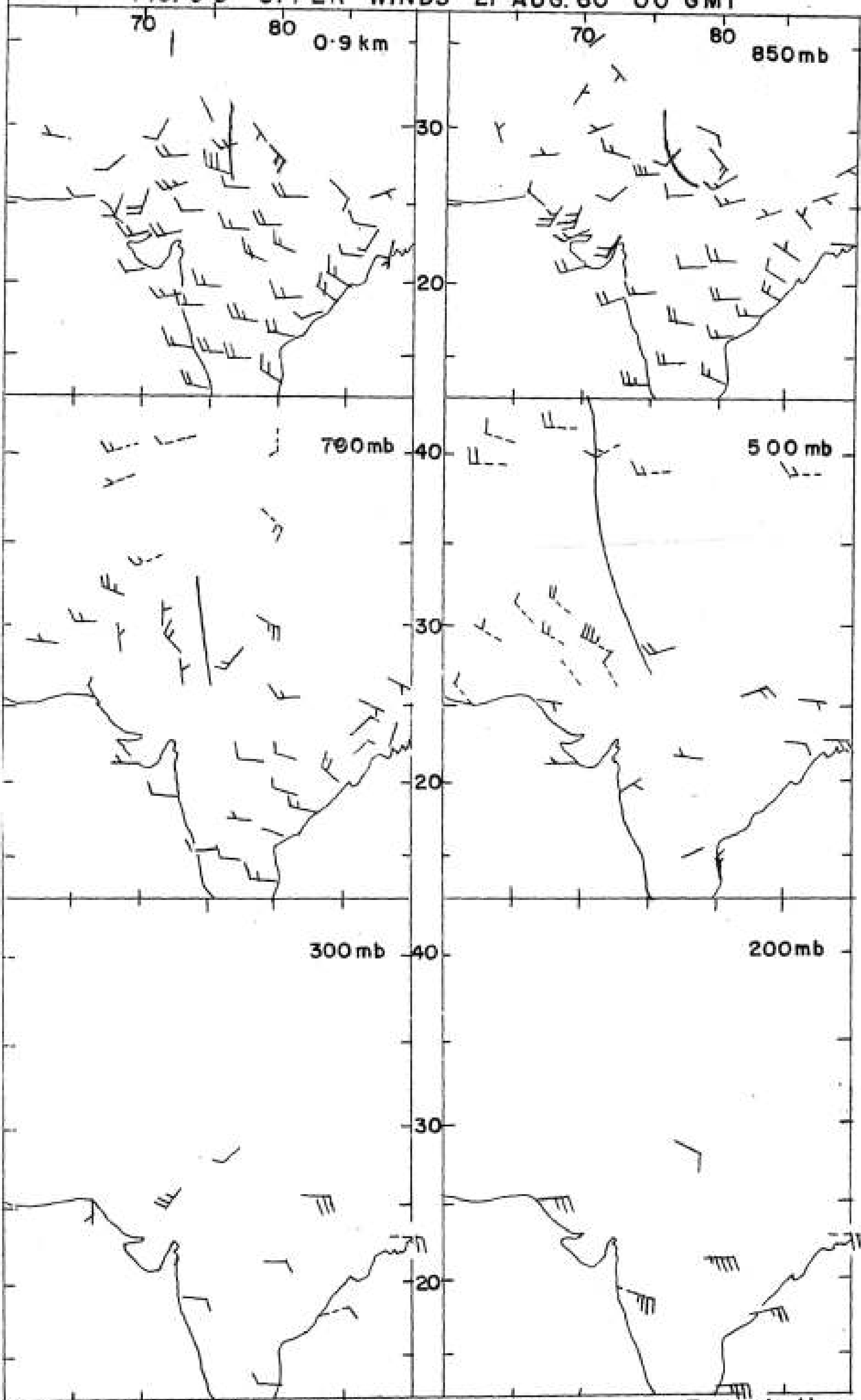


FIG. 5·9 UPPER WINDS 21 AUG. 60 00 GMT



Note :- Broken shaft indicates 12 GMT data — Trough line

FIG. 5·10 SYNOPTIC CHARTS 0300 GMT 22 AUG. 60

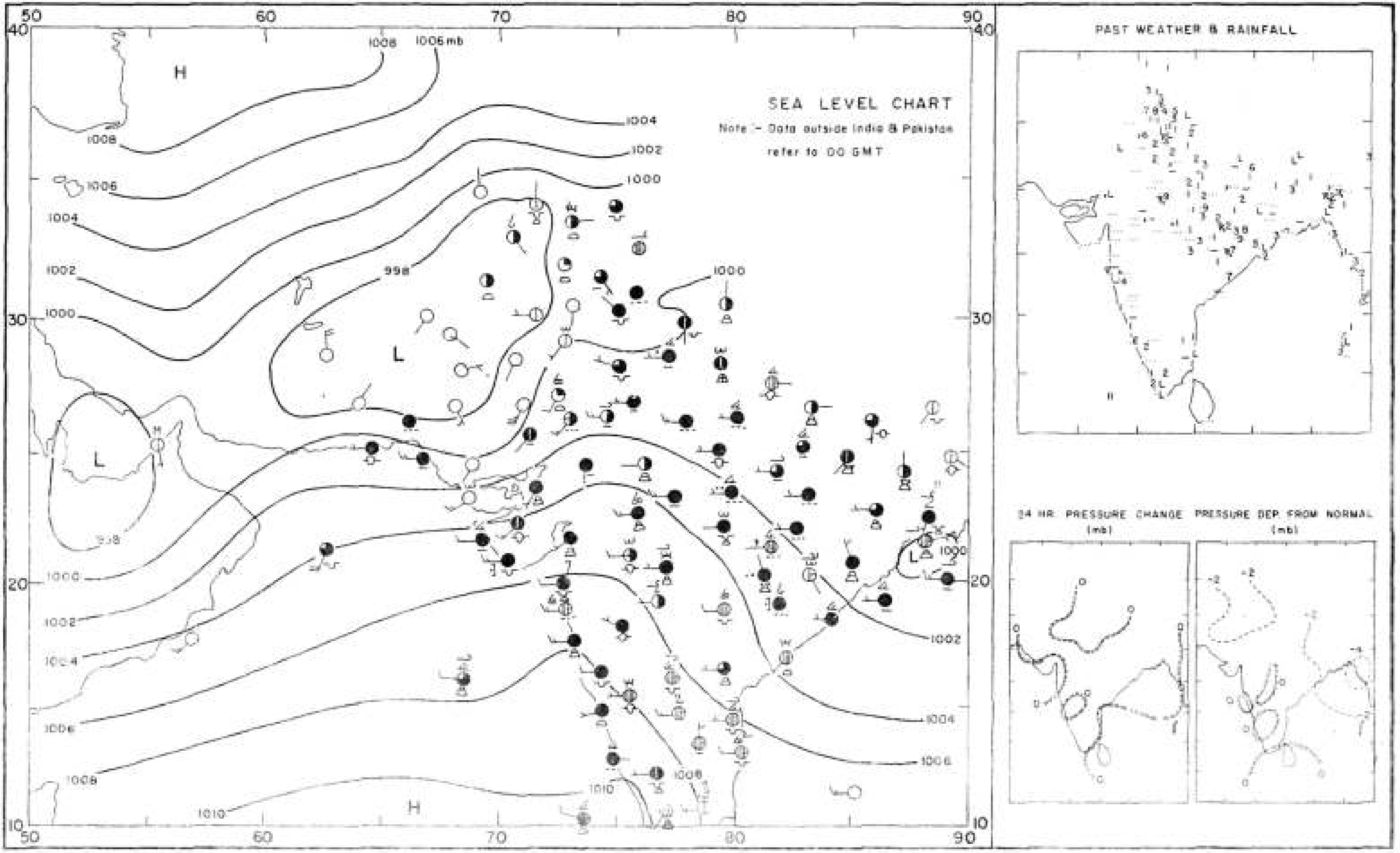


FIG. 5·11 (a) UPPER AIR CHART 20 AUG. 60 12 GMT 500 mb

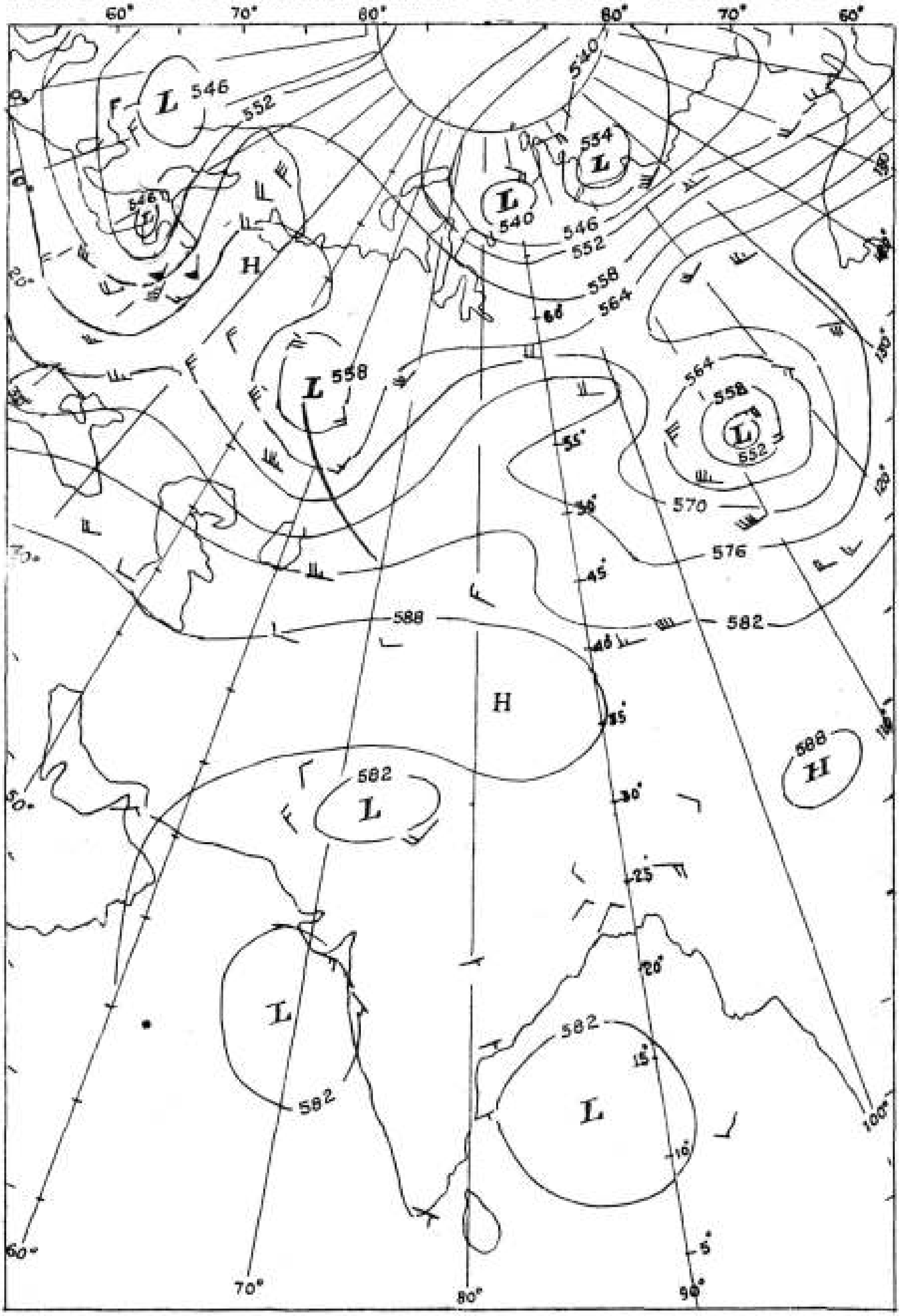


FIG. 5·11 (b) UPPER AIR CHART 21 AUG. 60 12 GMT 500 mb

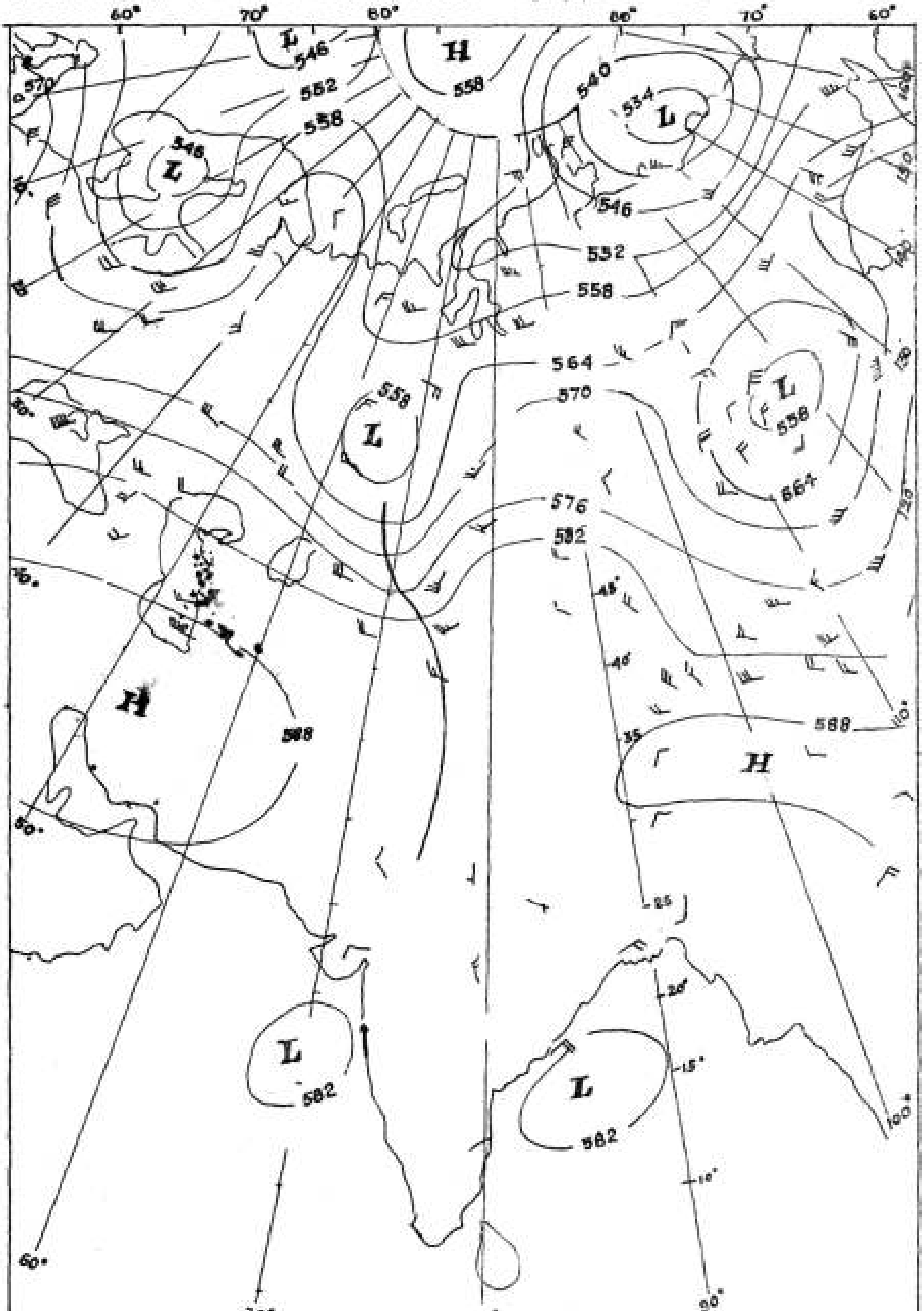


FIG. 6·1 SYNOPTIC CHARTS 0300 GMT 4 SEPT 66

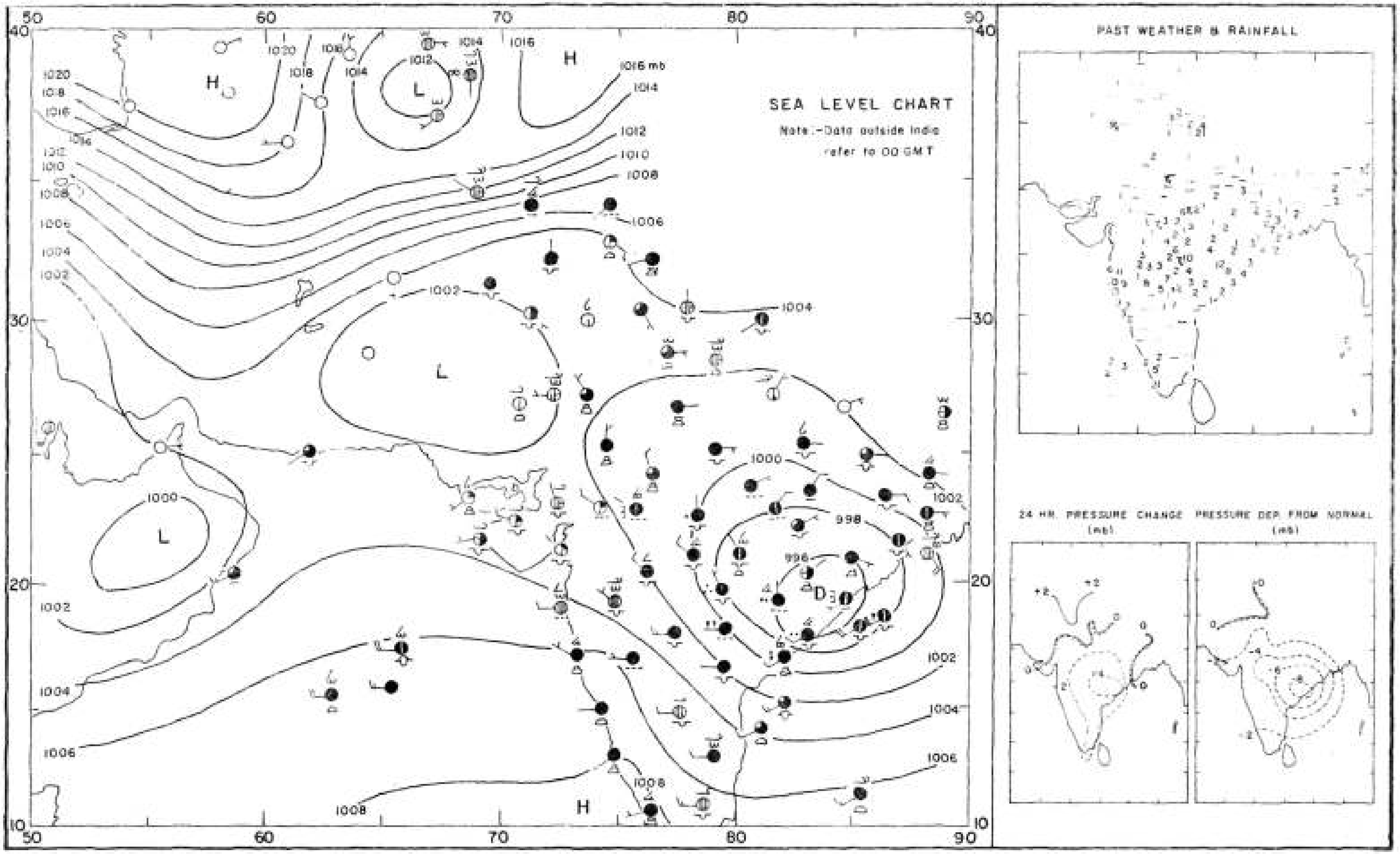
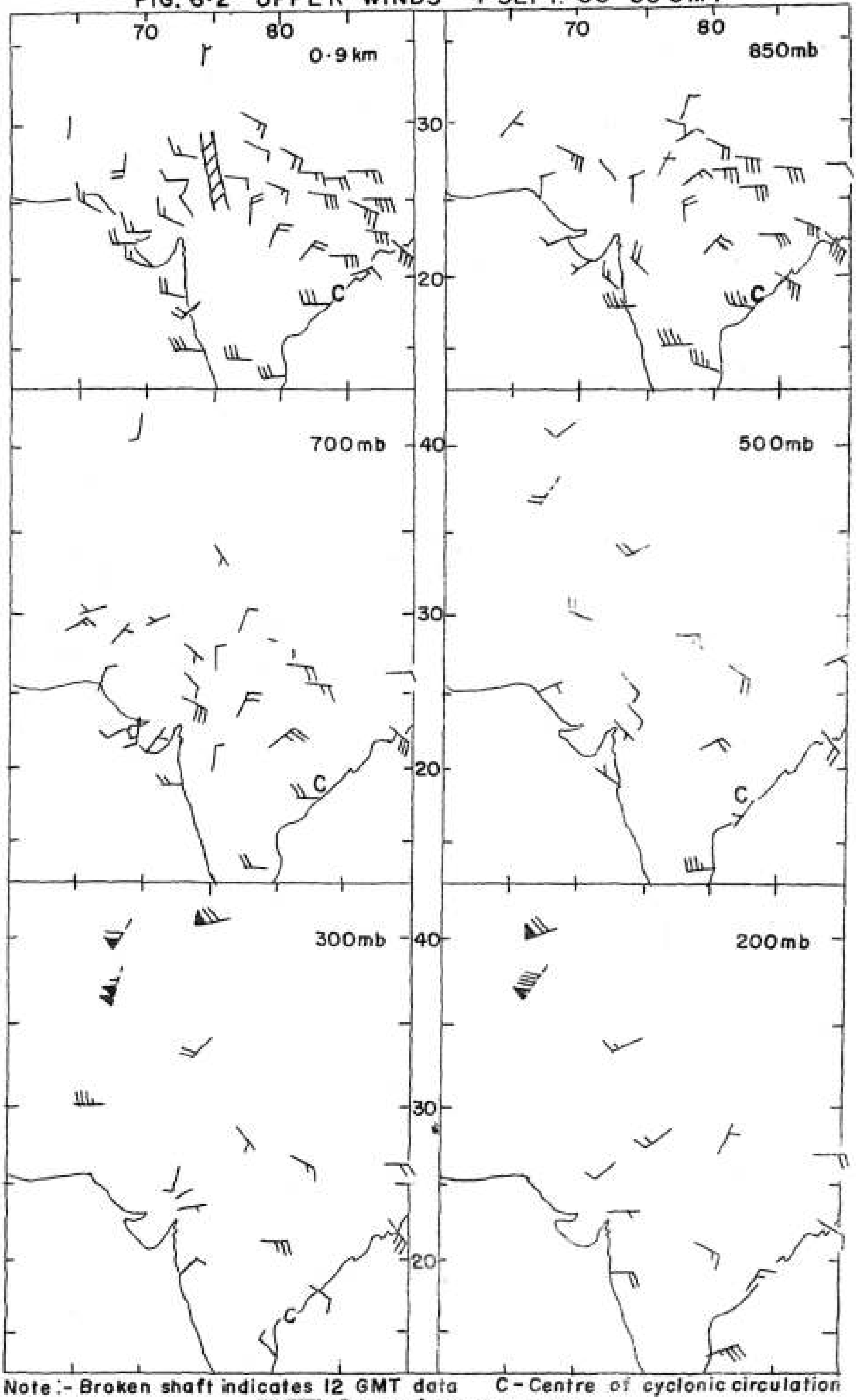


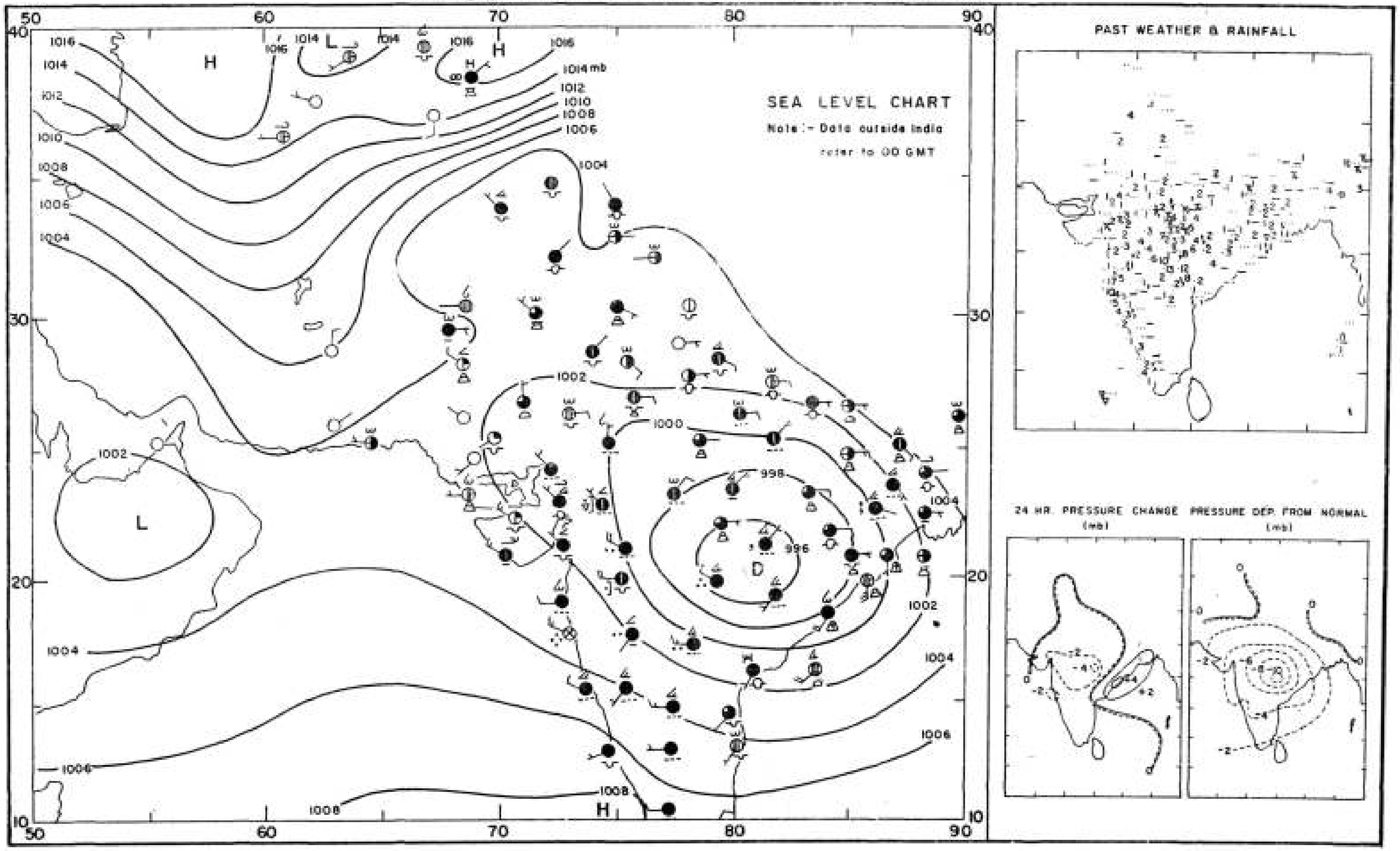
FIG. 6·2 UPPER WINDS 4 SEPT. 66 00 GMT



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

77777 Zone of convergence

FIG. 6·3 SYNOPTIC CHARTS 0300 GMT 5 SEPT. 66



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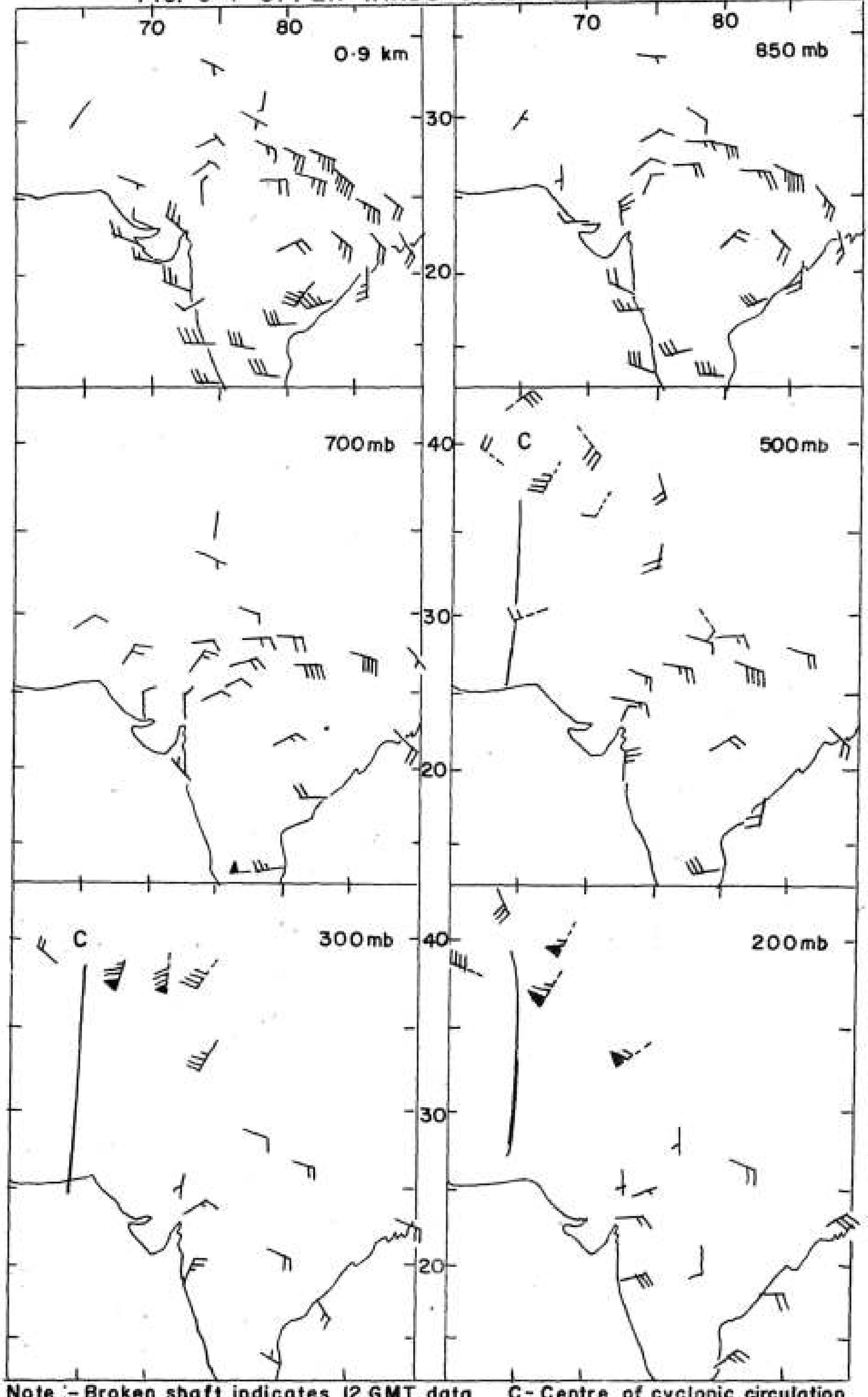


Note :- Broken shaft indicates 12 GMT data   C- Centre of cyclonic circulation
Trough line

FIG. 6·5 (a) UPPER AIR CHART 3 SEPT. 66 00 GMT 300 mb

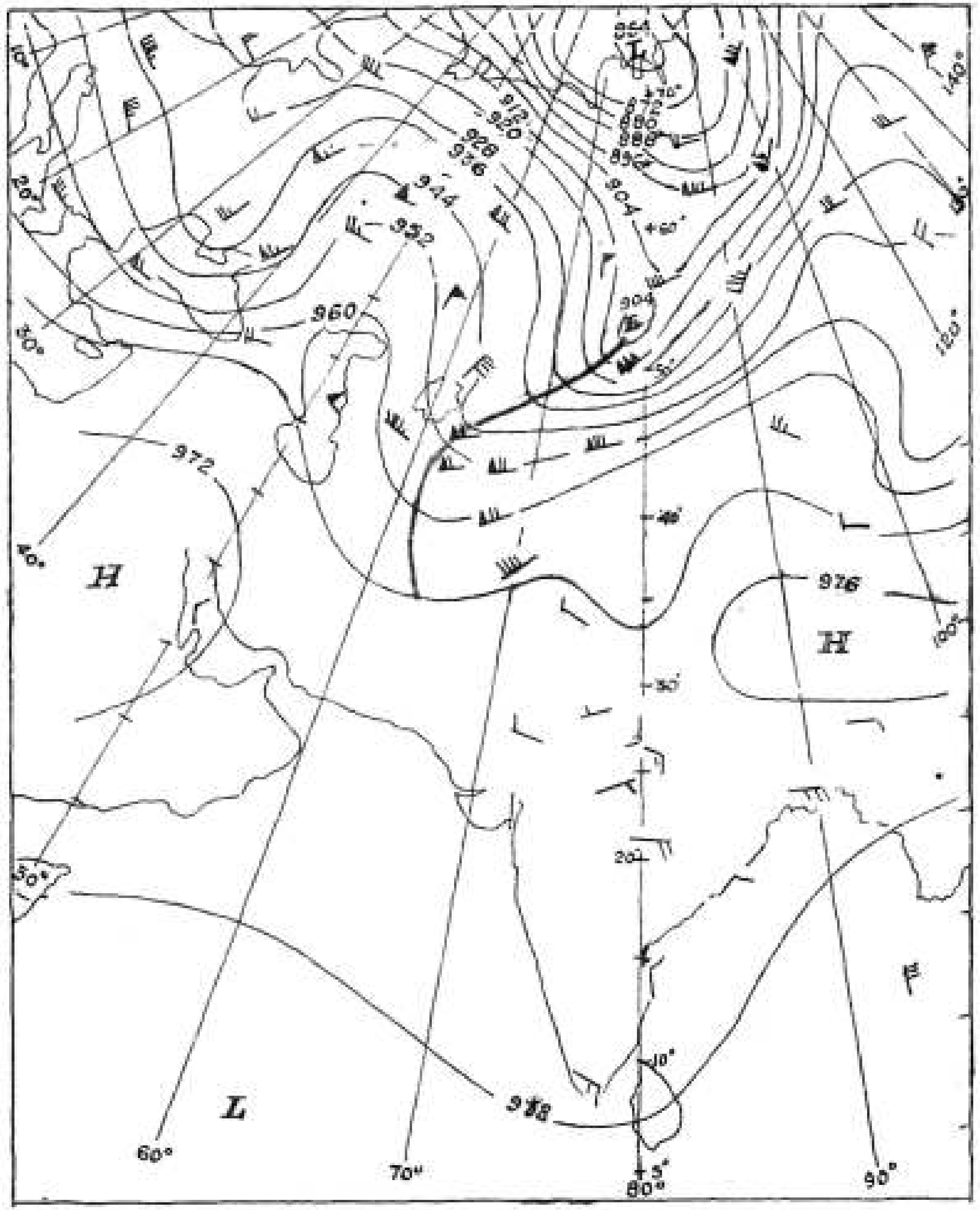


FIG. 6·5 (b) UPPER AIR CHART 4 SEPT. 66 00 GMT 300 mb

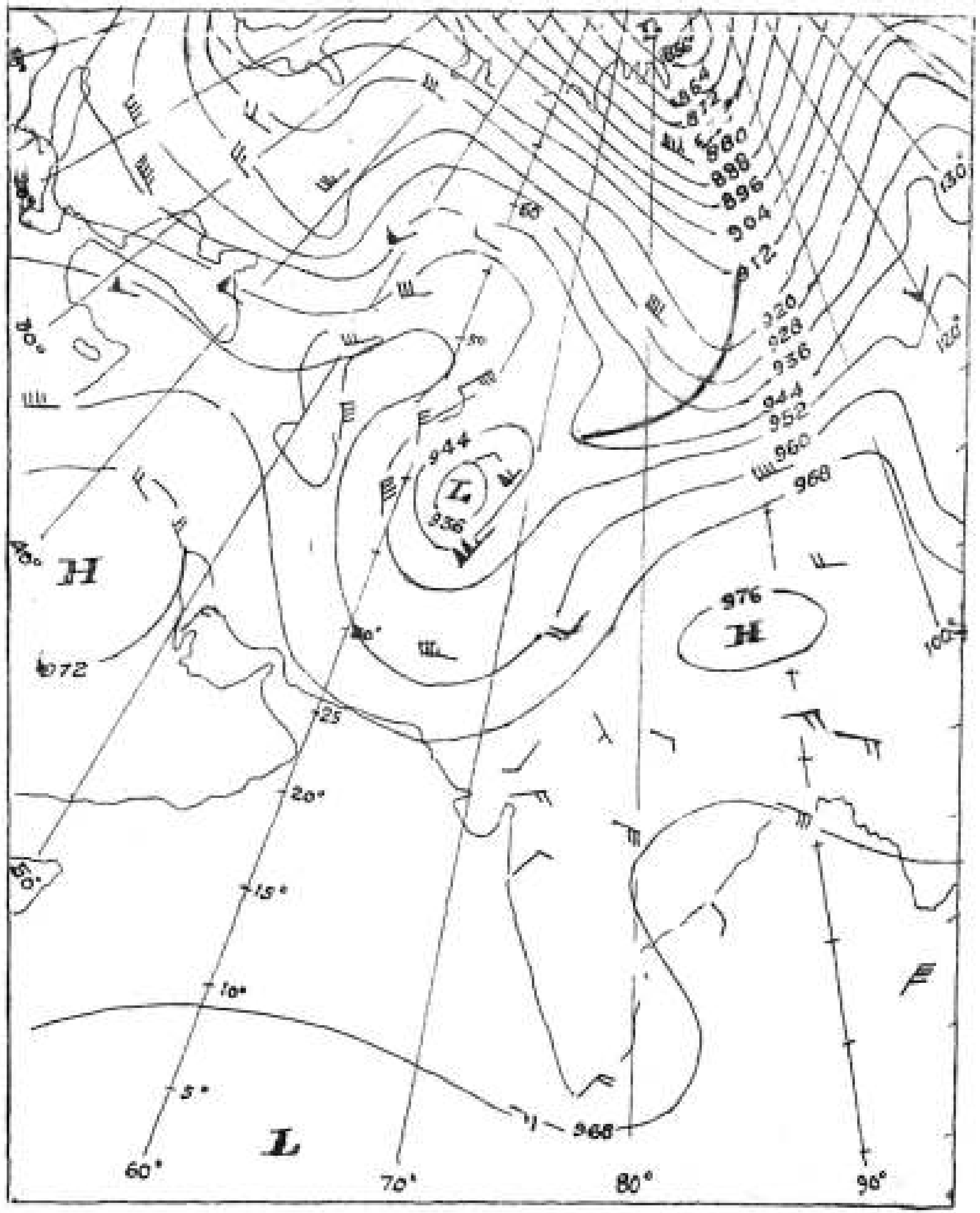


FIG. 6·5 (c) UPPER AIR CHART 6 SEPT. 66 00 GMT 300 mb

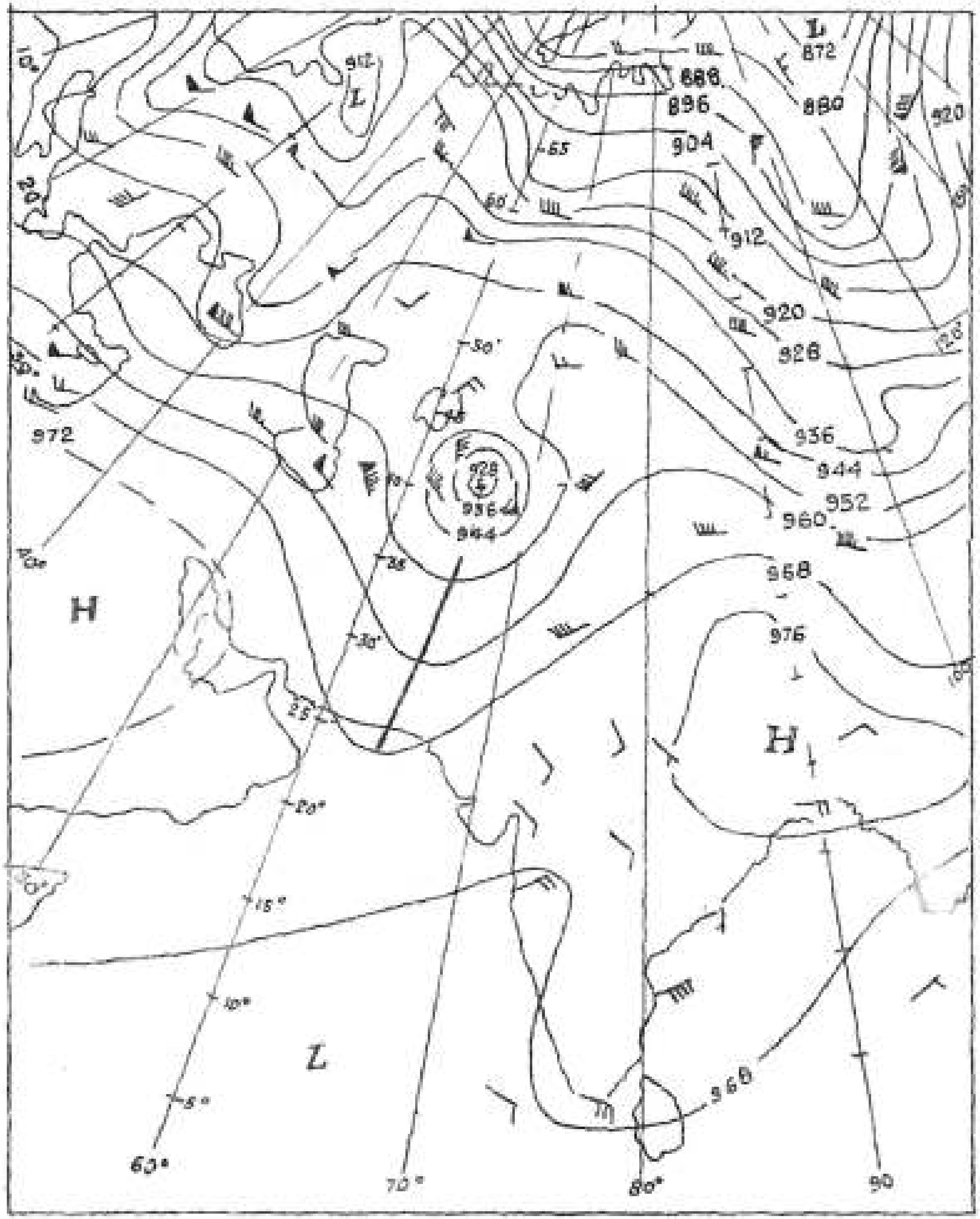


FIG. 6·5 (d) UPPER AIR CHART 11 SEPT. 66 00 GMT 300 mb

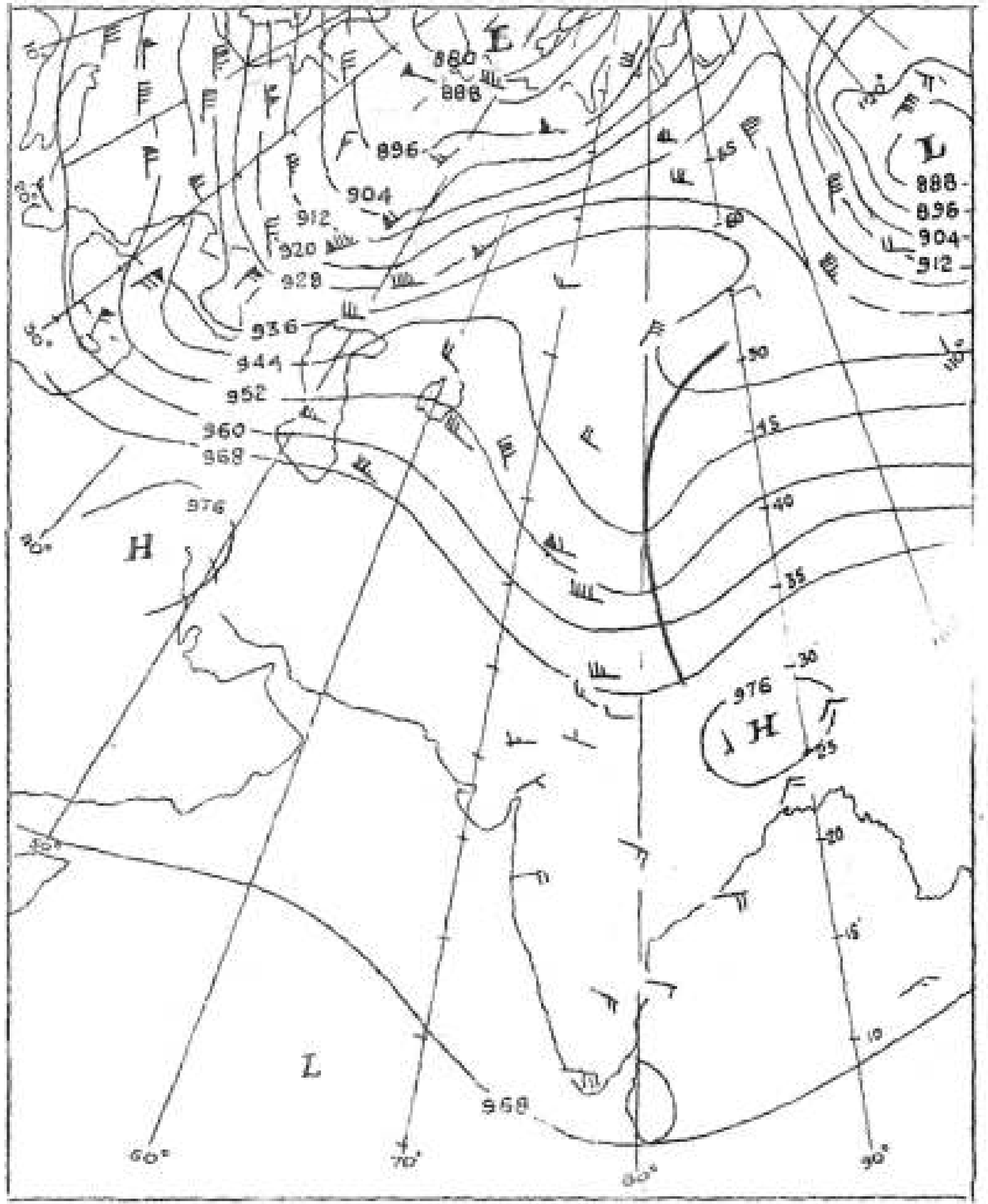
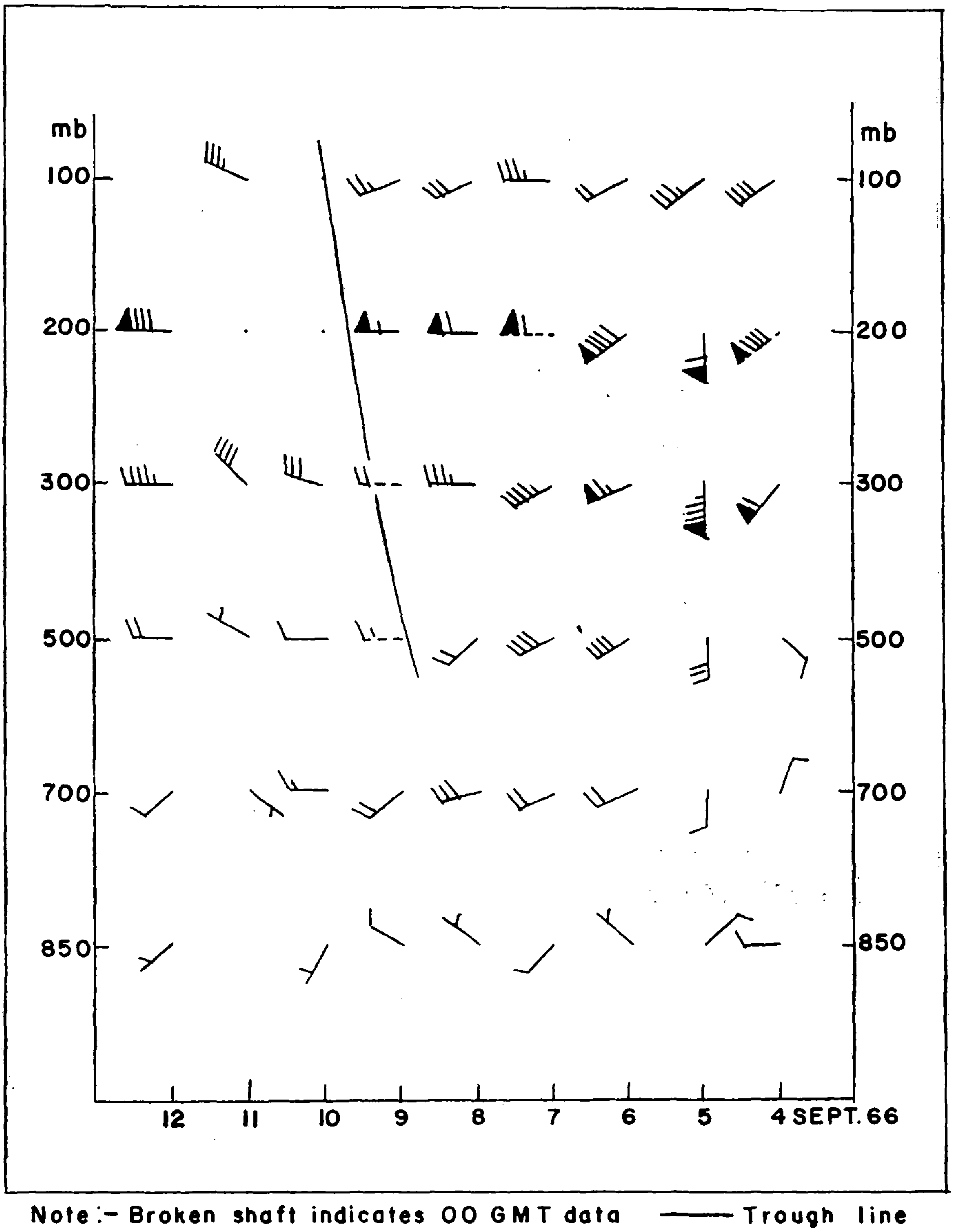


FIG. 6·5 (e) VERTICAL TIME SECTION

TASHKENT

4 – 12 SEPT. 66   12 GMT

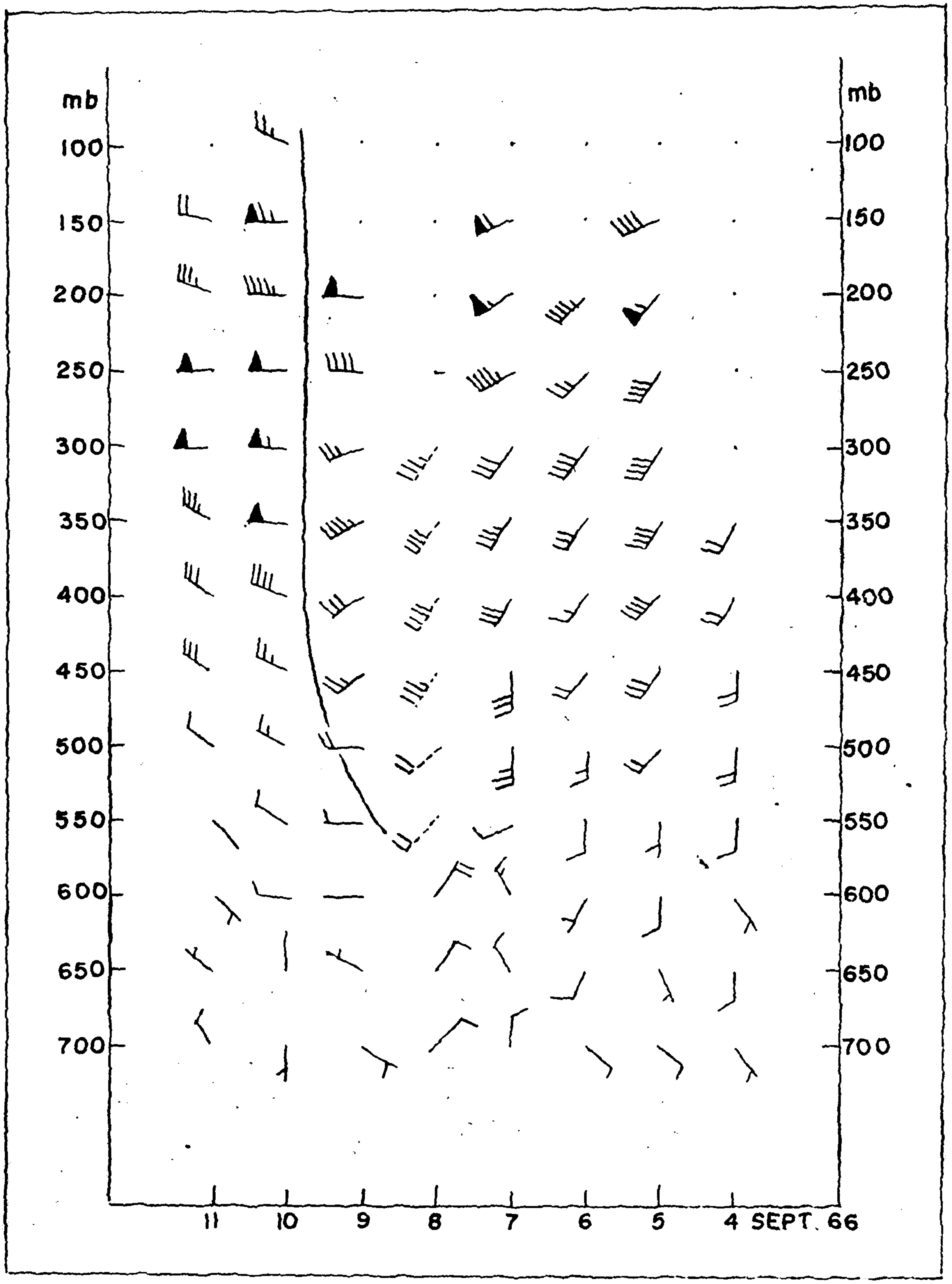


Note :– Broken shaft indicates 00 GMT data   ——— Trough line

FIG. 6·5 (f) VERTICAL TIME SECTION

SRINAGAR

4 – 11 SEPT. 66. 12 GMT



Note:- Broken shaft indicates 00 GMT data ———— Trough line

FIG. 6·6 (a) SATELLITE NEPHANALYSES 3 SEPT. 66

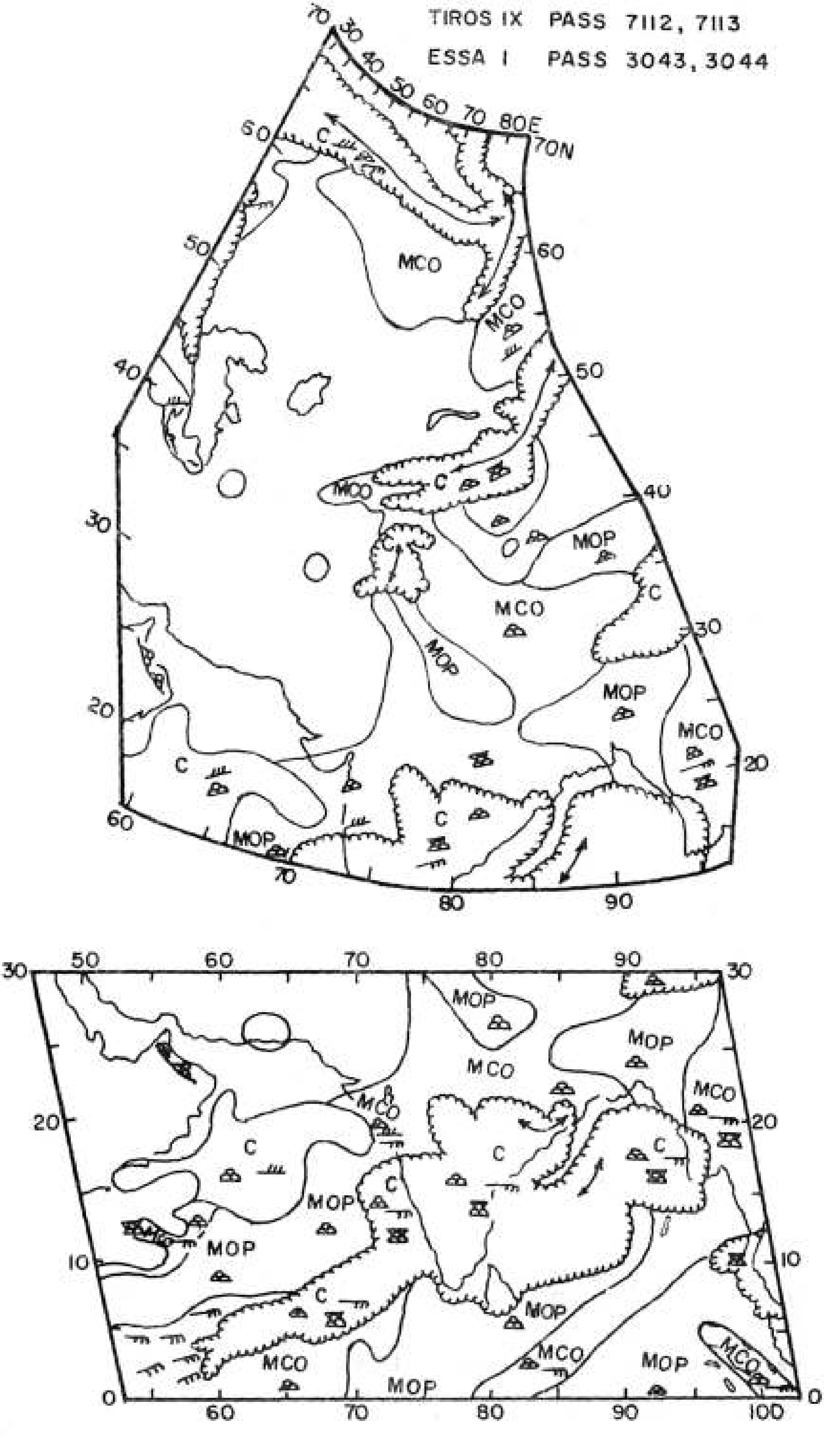
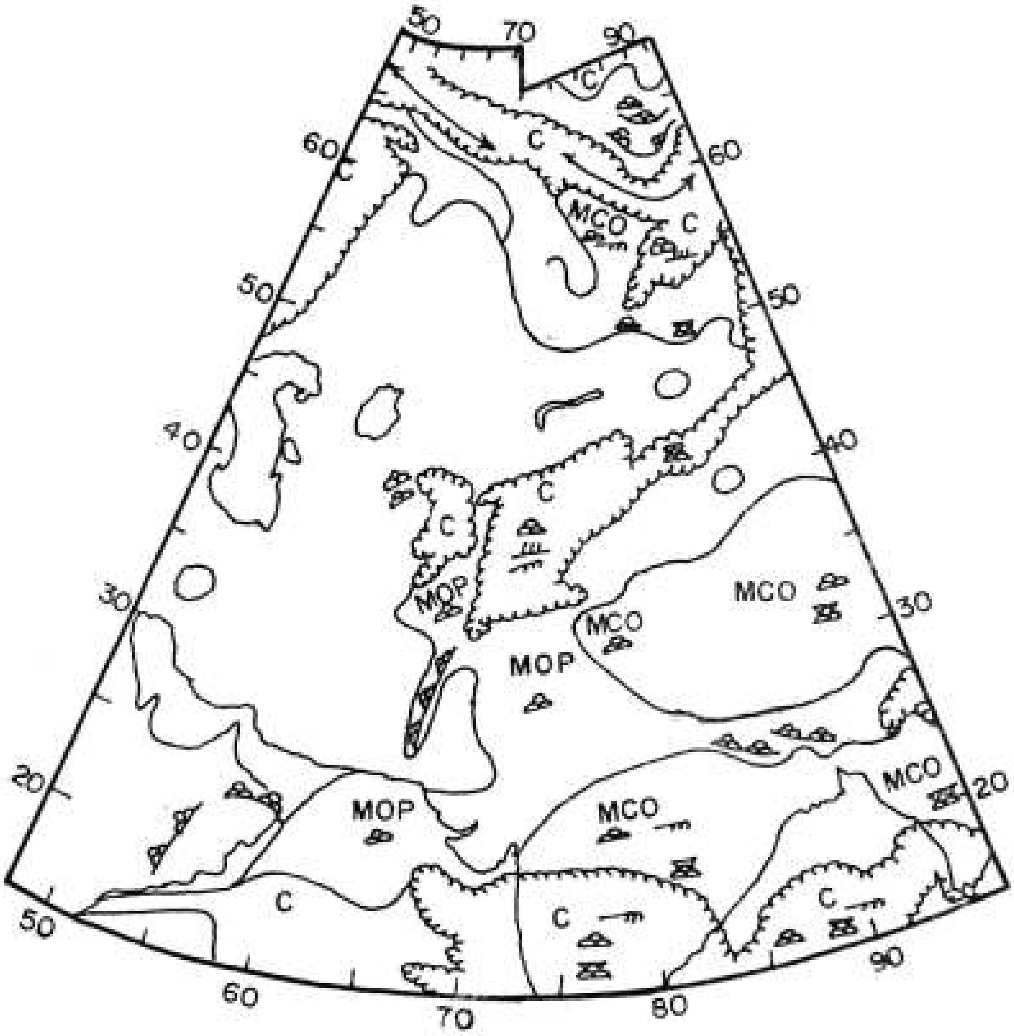


FIG 6·6(b) SATELLITE NEPHANALYSES 4 SEPT. 66

TIROS IX PASS 7125

ESSA I PASS 3058, 3059



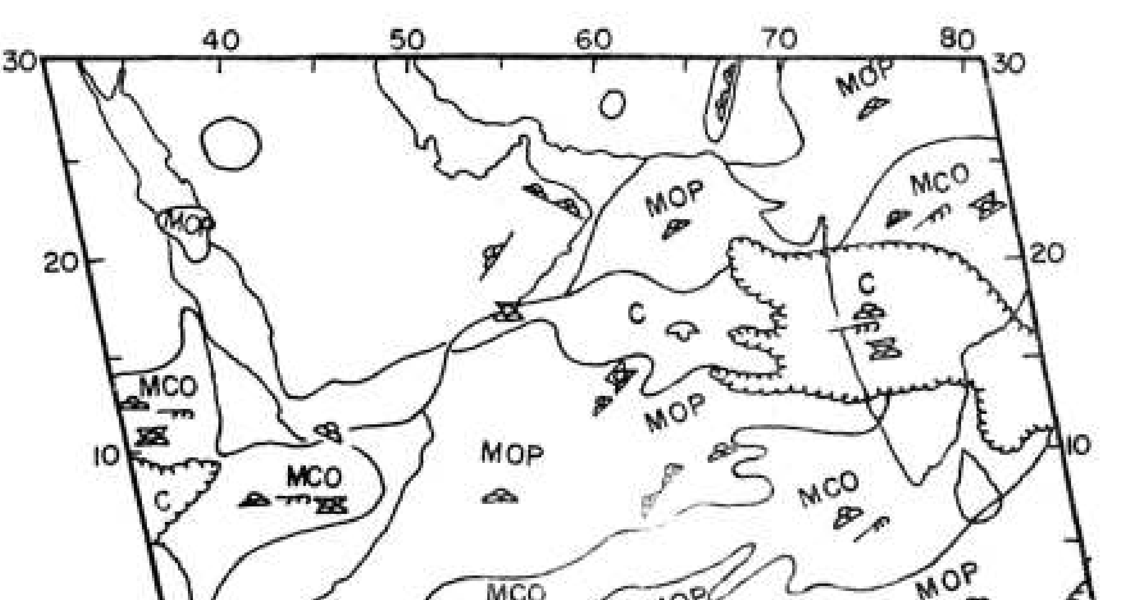


FIG. 6·6(c) SATELLITE NEPHANALYSES 5 SEPT. 66

TIROS IX PASS 7136

ESSA I PASS 3072, 3073

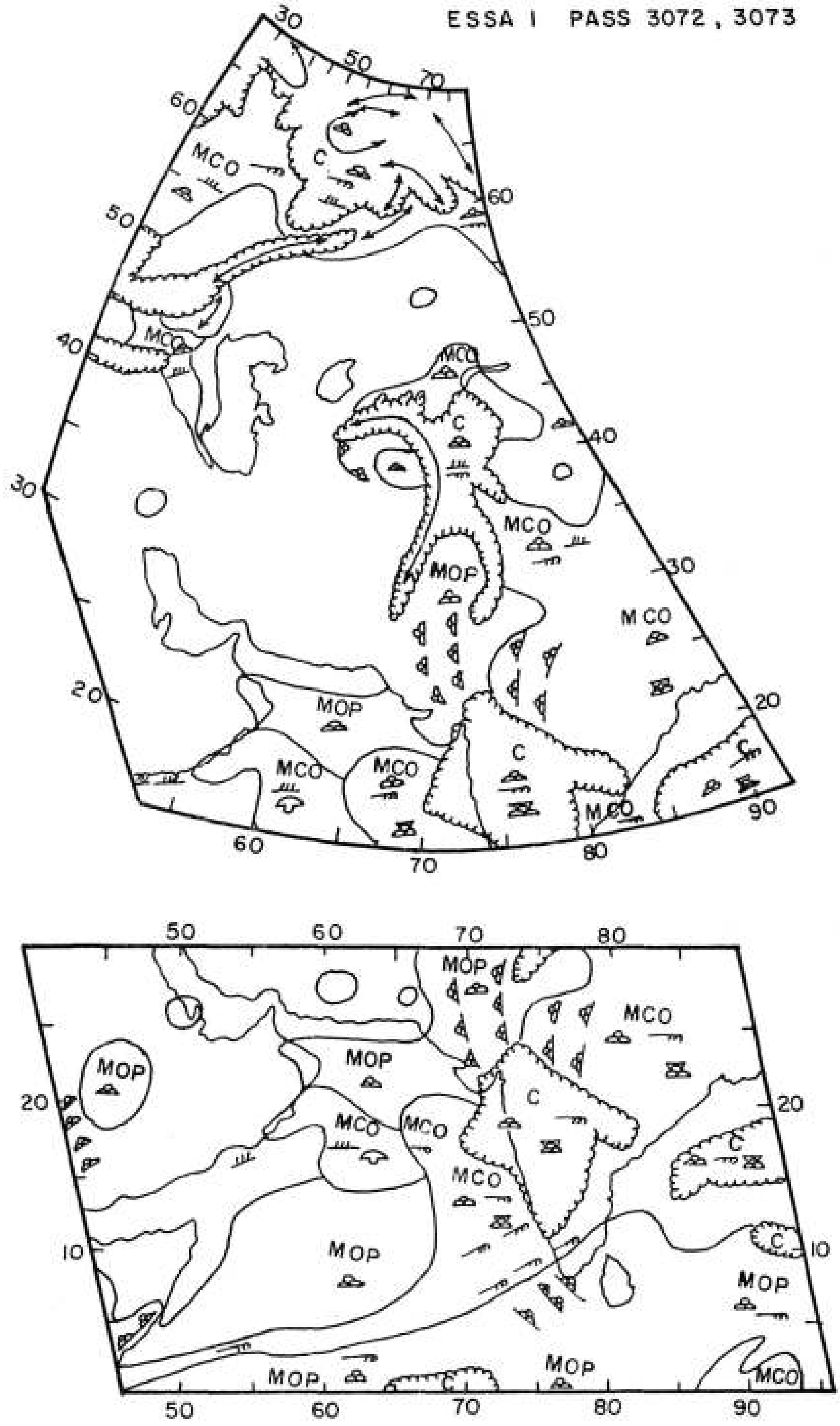


FIG. 6·6(d) SATELLITE NEPHANALYSES 6 SEPT. 66

TIROS IX PASS 7148

ESSA I PASS 3086, 3087

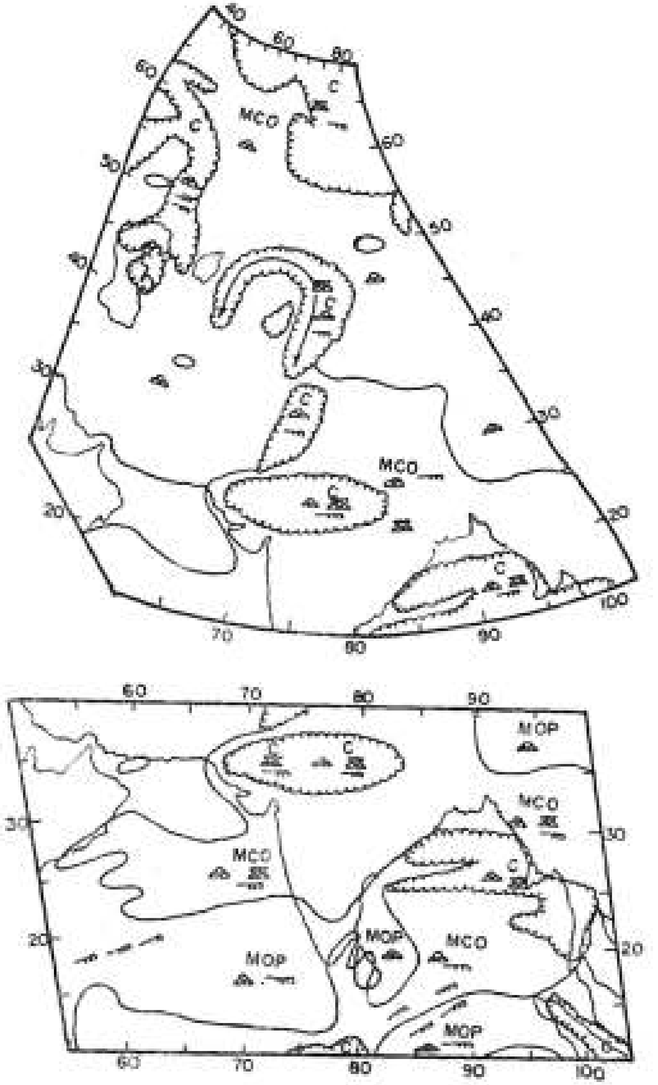


FIG. 6·6(e) SATELLITE NEPHANALYSES 7 SEPT 66

TIROS IX PASS 7160

ESSA I PASS 3102, 3103

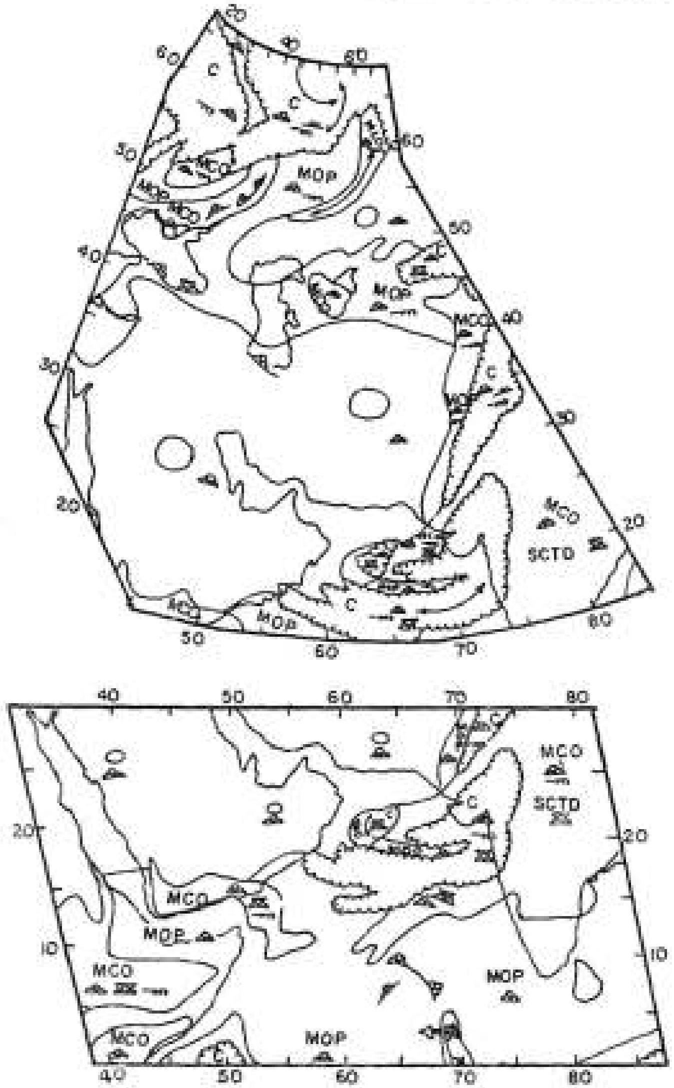


FIG. 6·7 SYNOPTIC CHARTS 0300 GMT 6 SEPT. 66

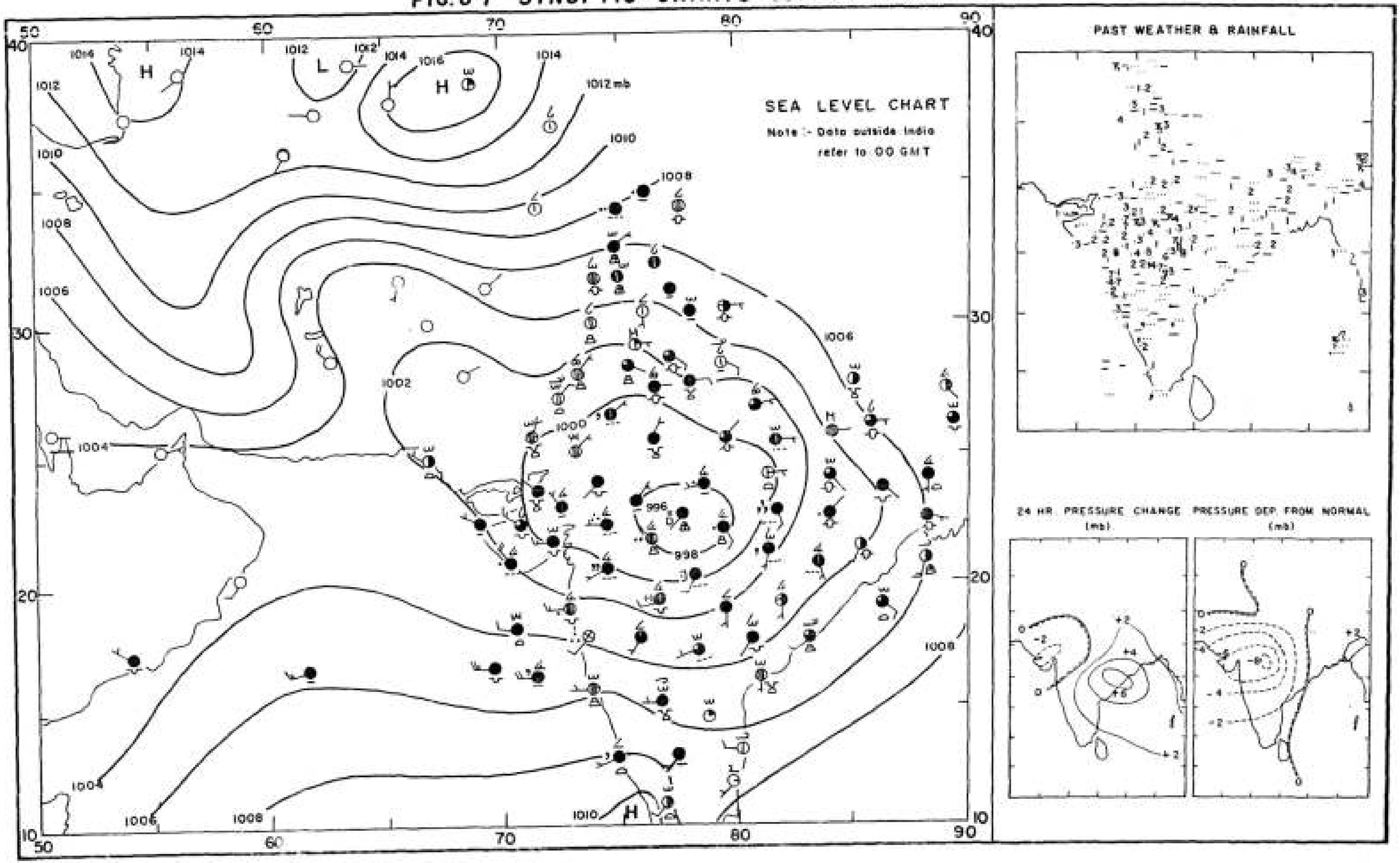
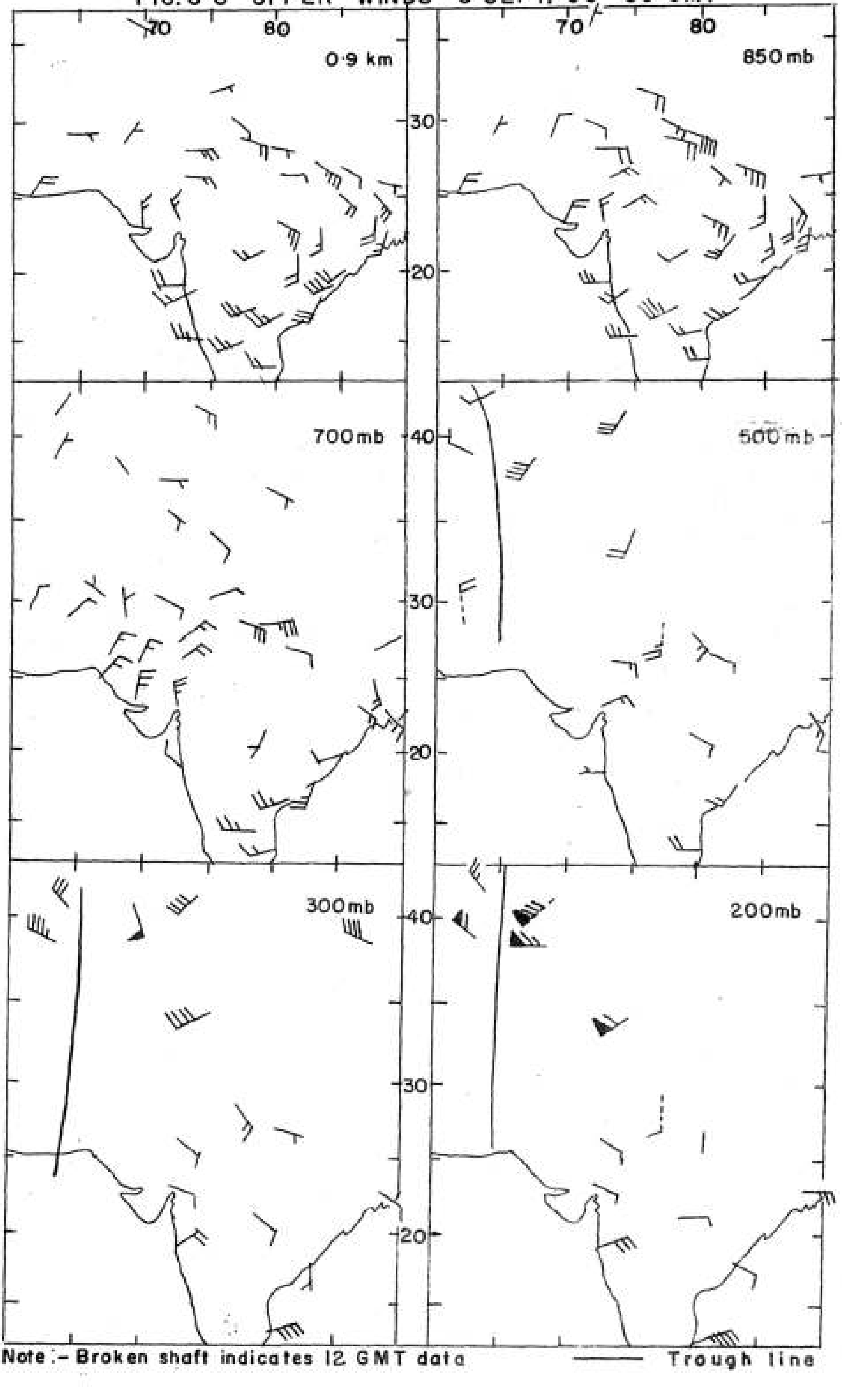


FIG. 6·8 UPPER WINDS 6 SEPT. 66 00 GMT



Note :- Broken shaft indicates 12 GMT data

FIG. 6·9 SYNOPTIC CHARTS 0300 GMT 7 SEPT. 66

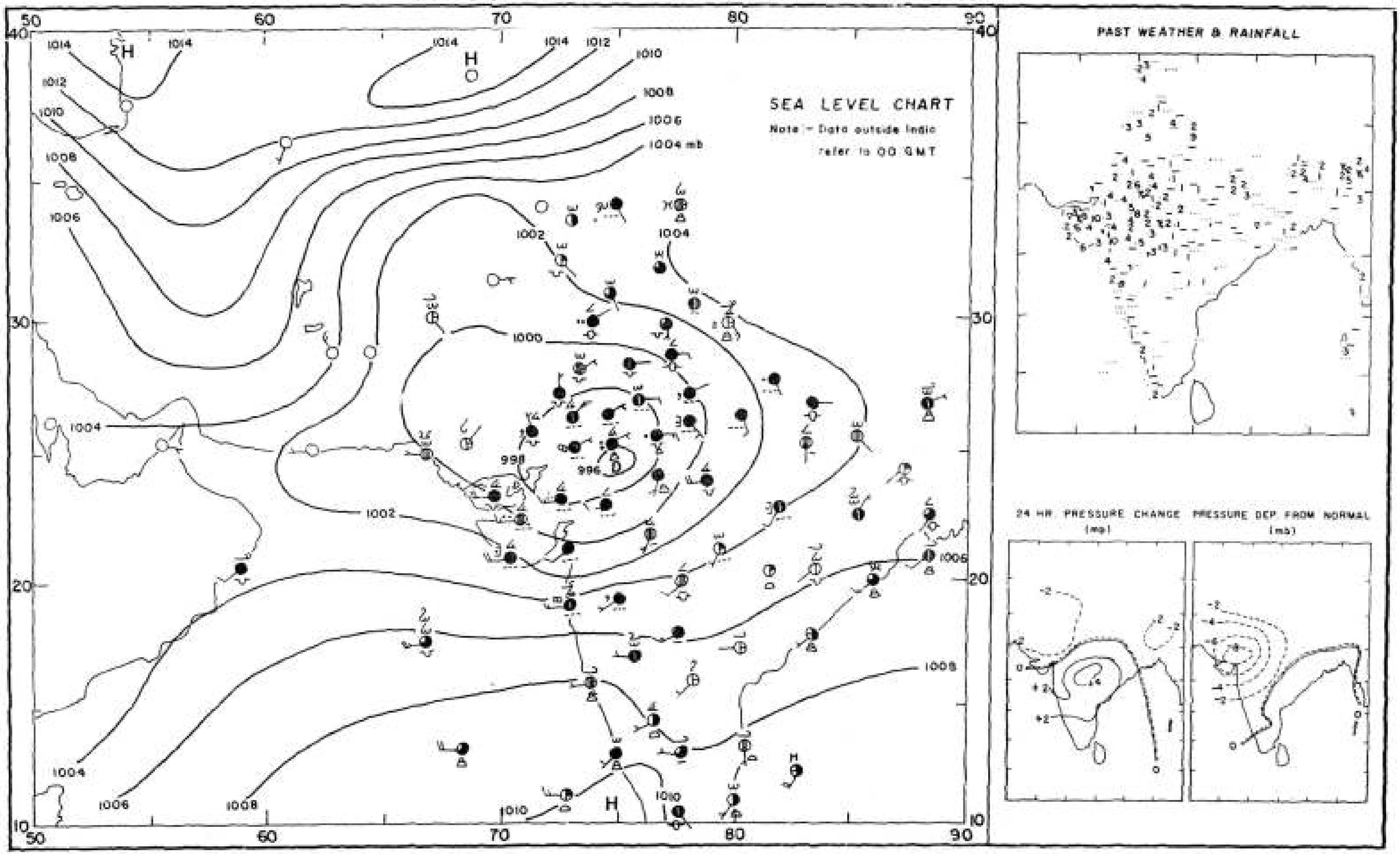
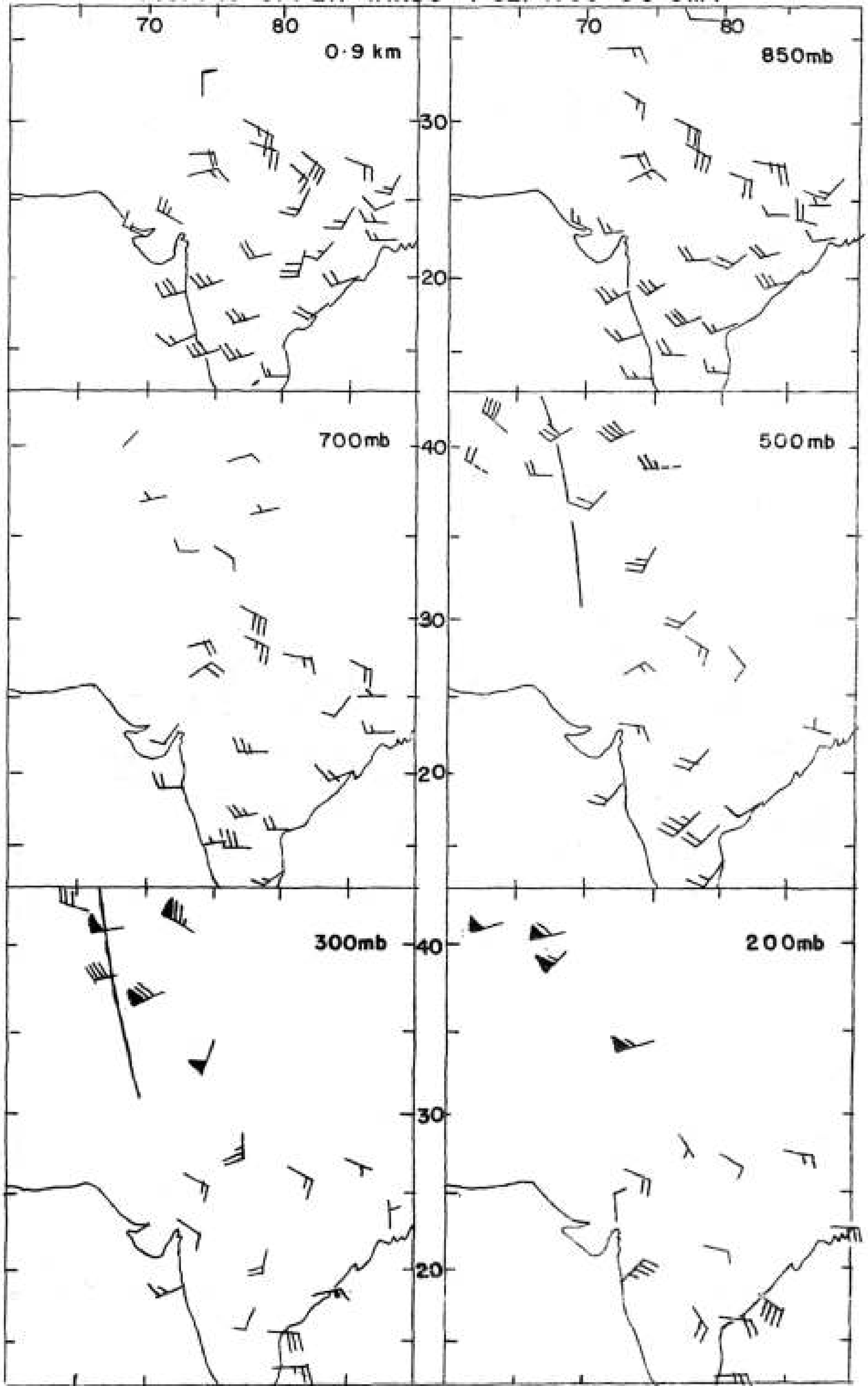


FIG. 6·10 UPPER WINDS 7 SEPT. 66 00 GMT



Note:- Broken shaft indicates 12 GMT data. —— Trough line

FIG. 6·11 SYNOPTIC CHARTS 0300 GMT 8 SEPT. 66

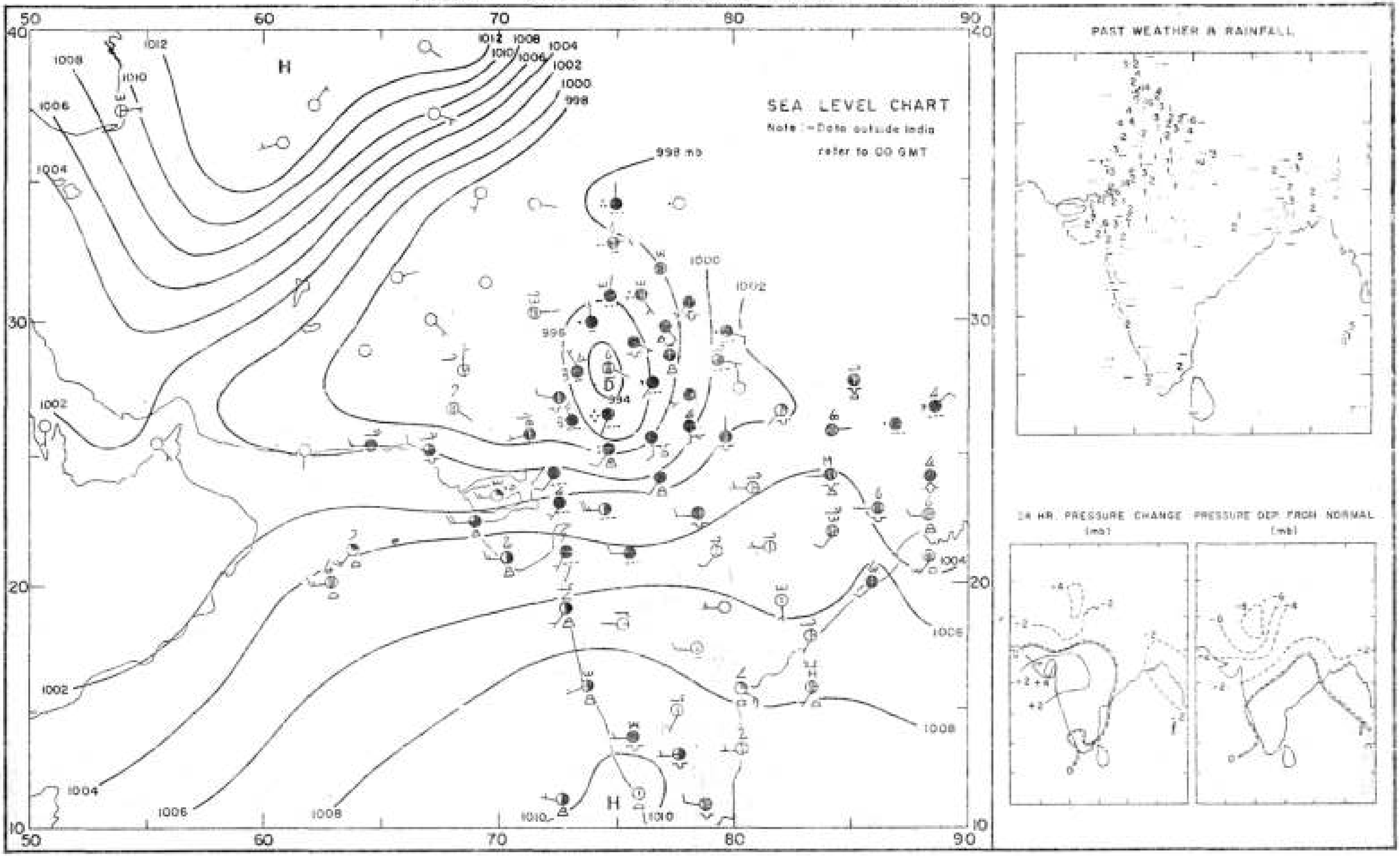
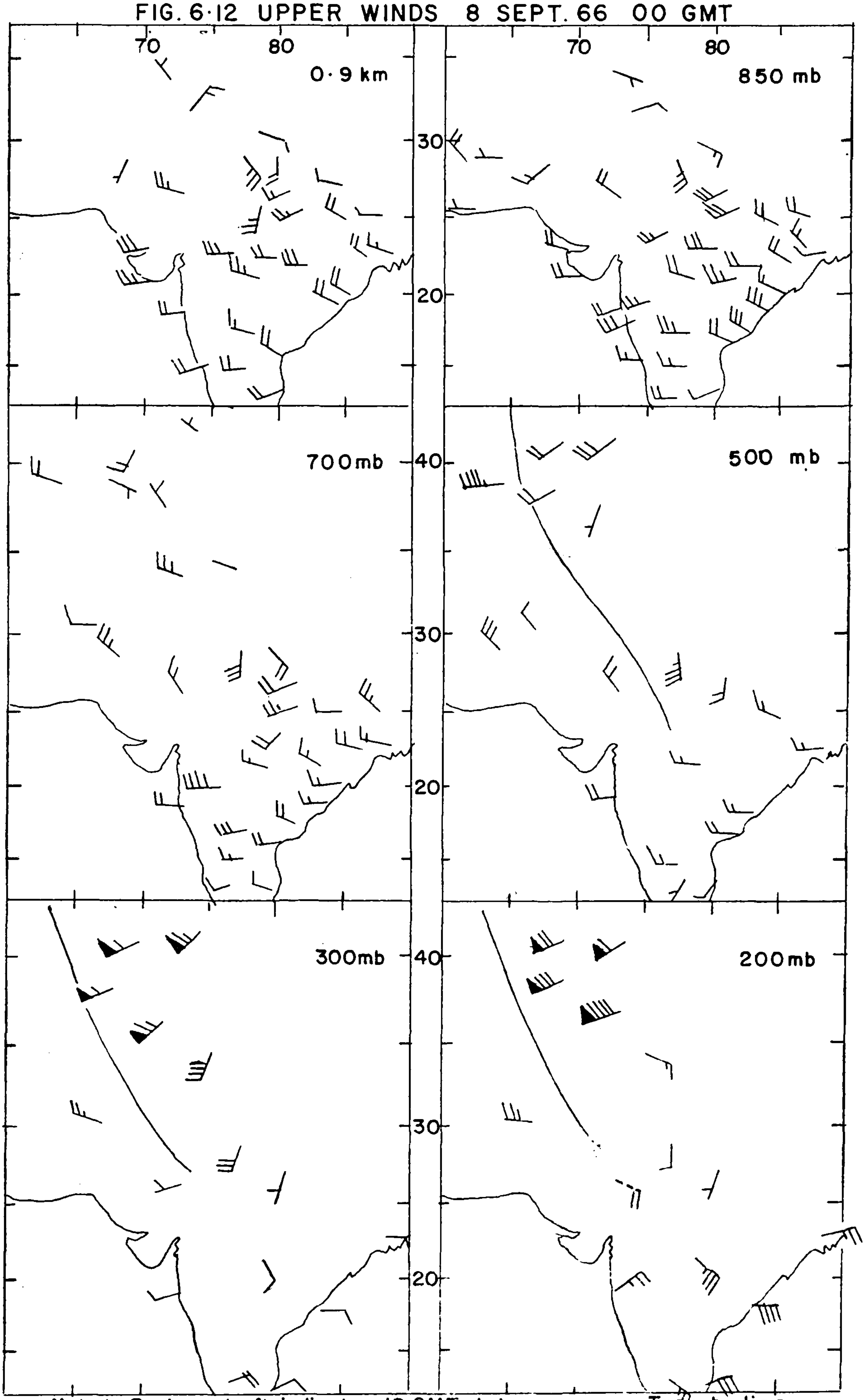


FIG. 6·12 UPPER WINDS 8 SEPT. 66 00 GMT



Note :- Broken shaft indicates 12 GMT data —— Trough line

FIG. 6·13 SYNOPTIC CHARTS 0300 GMT 9 SEPT. 66

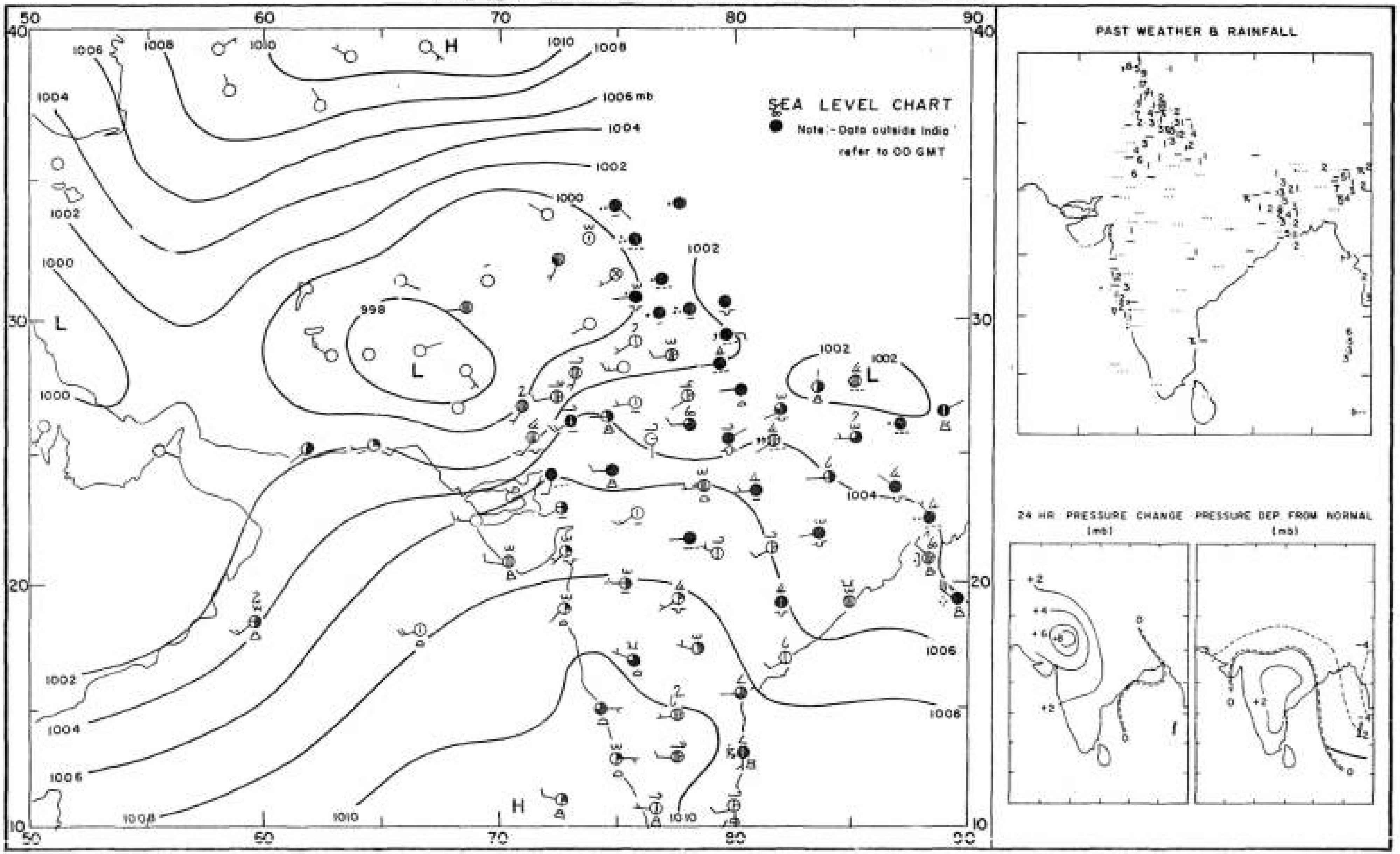
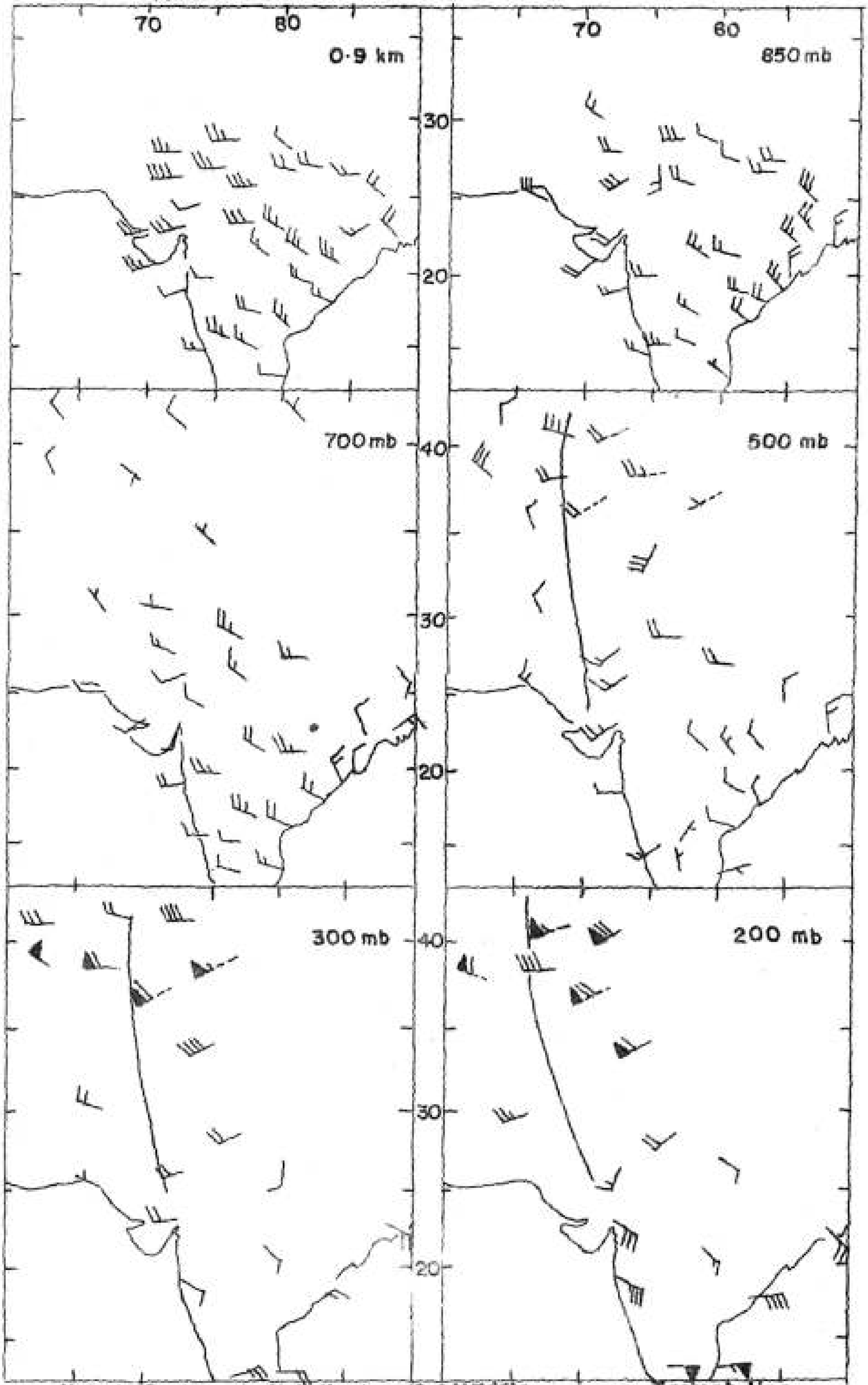


FIG. 6·14 UPPER WINDS 9 SEPT. 66 00 GMT



Note :- Broken shaft indicates 12 GMT data ——— Trough line

FIG. 7·1 SYNOPTIC CHARTS 0300 GMT 16 JUL 62

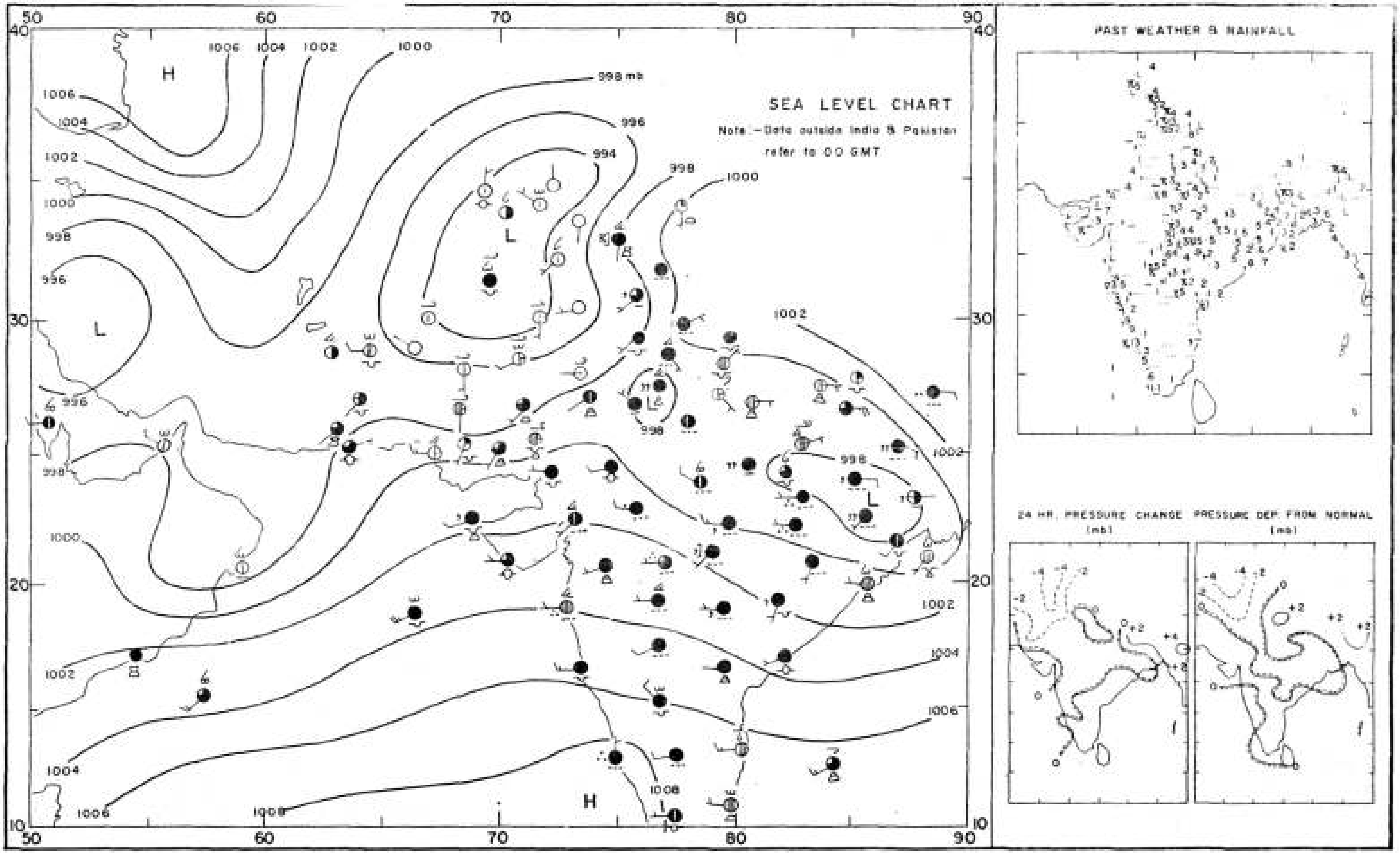
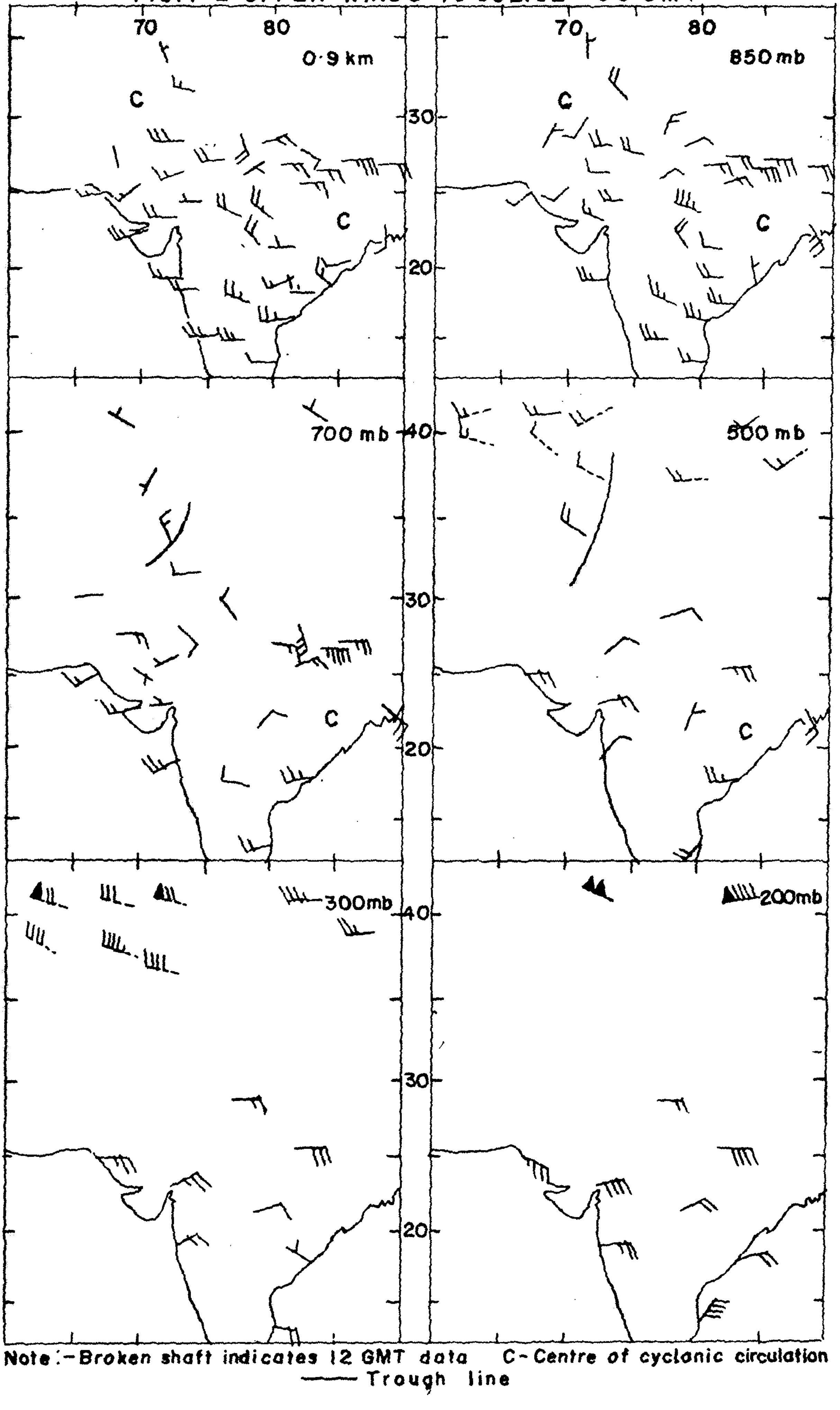


FIG. 7·2 UPPER WINDS 16 JUL. 62 00 GMT



Note:- Broken shaft indicates 12 GMT data C - Centre of cyclonic circulation
—— Trough line

FIG. 7·3 SYNOPTIC CHARTS 0300 GMT 17 JUL 62

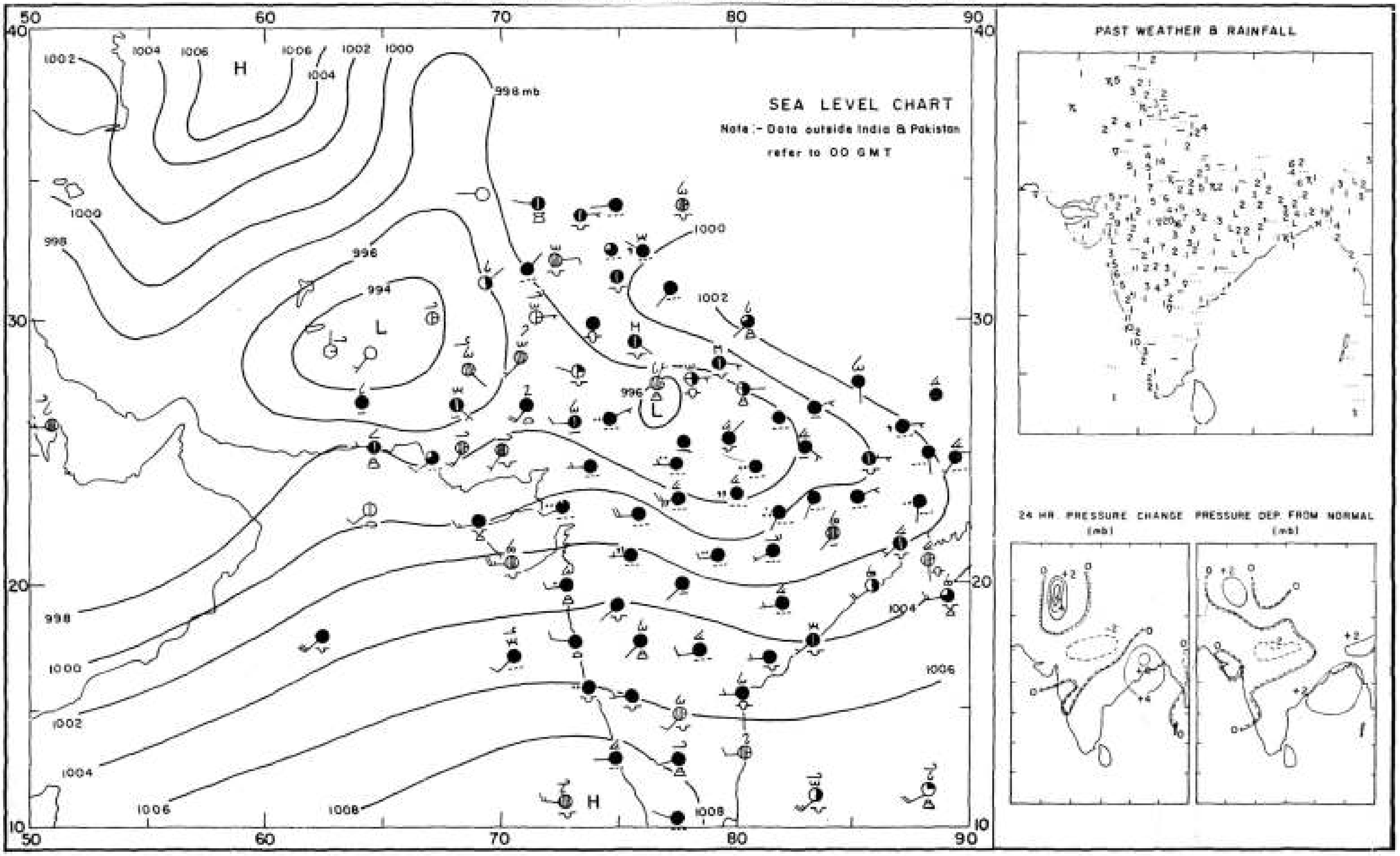
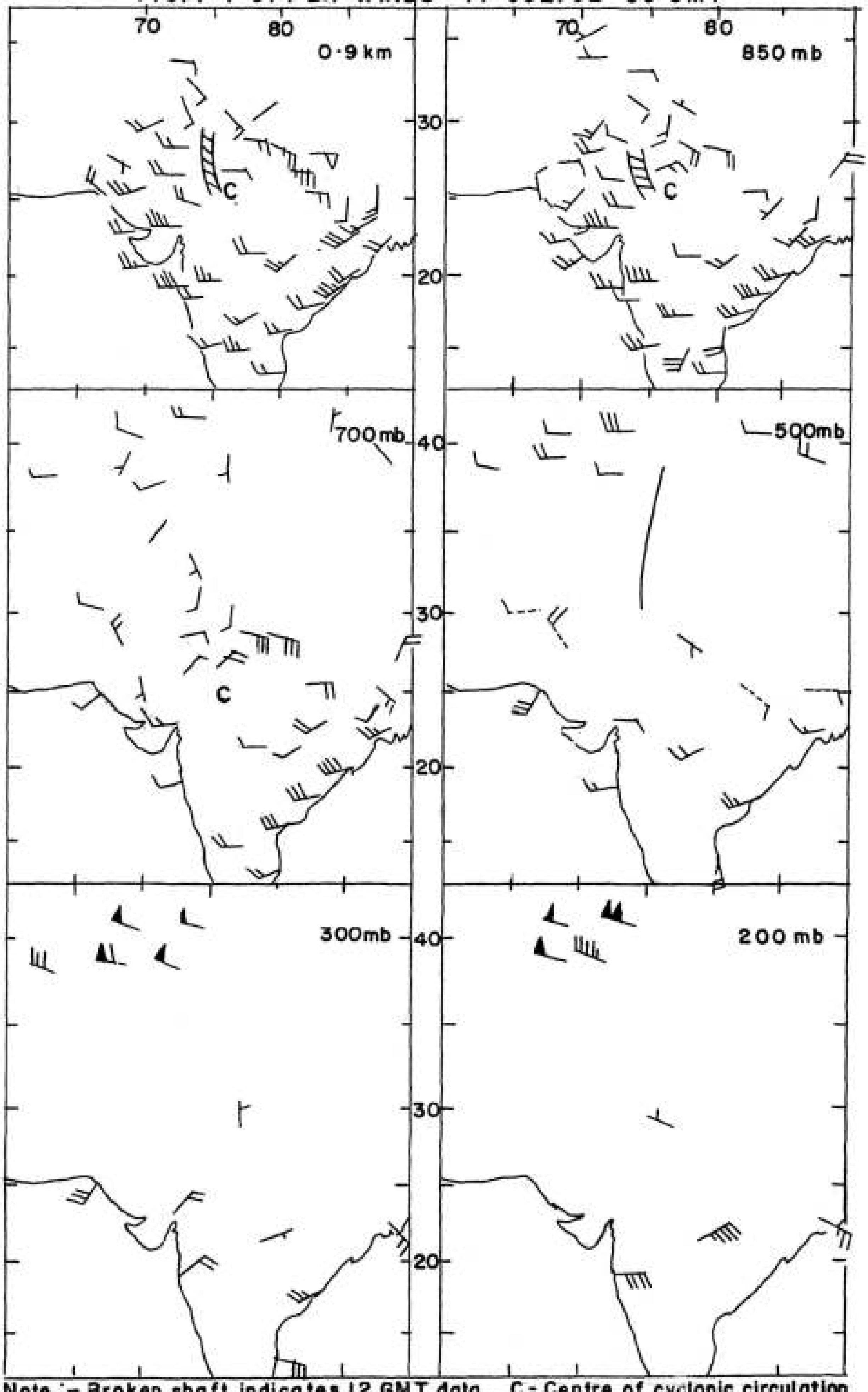


FIG. 7·4 UPPER WINDS 17 JUL. 62 00 GMT



Note :- Broken shaft indicates 12 GMT data C - Centre of cyclonic circulation
Zone of convergence —— Trough line

FIG. 7·5 SYNOPTIC CHARTS 0300 GMT 19 JUL 62

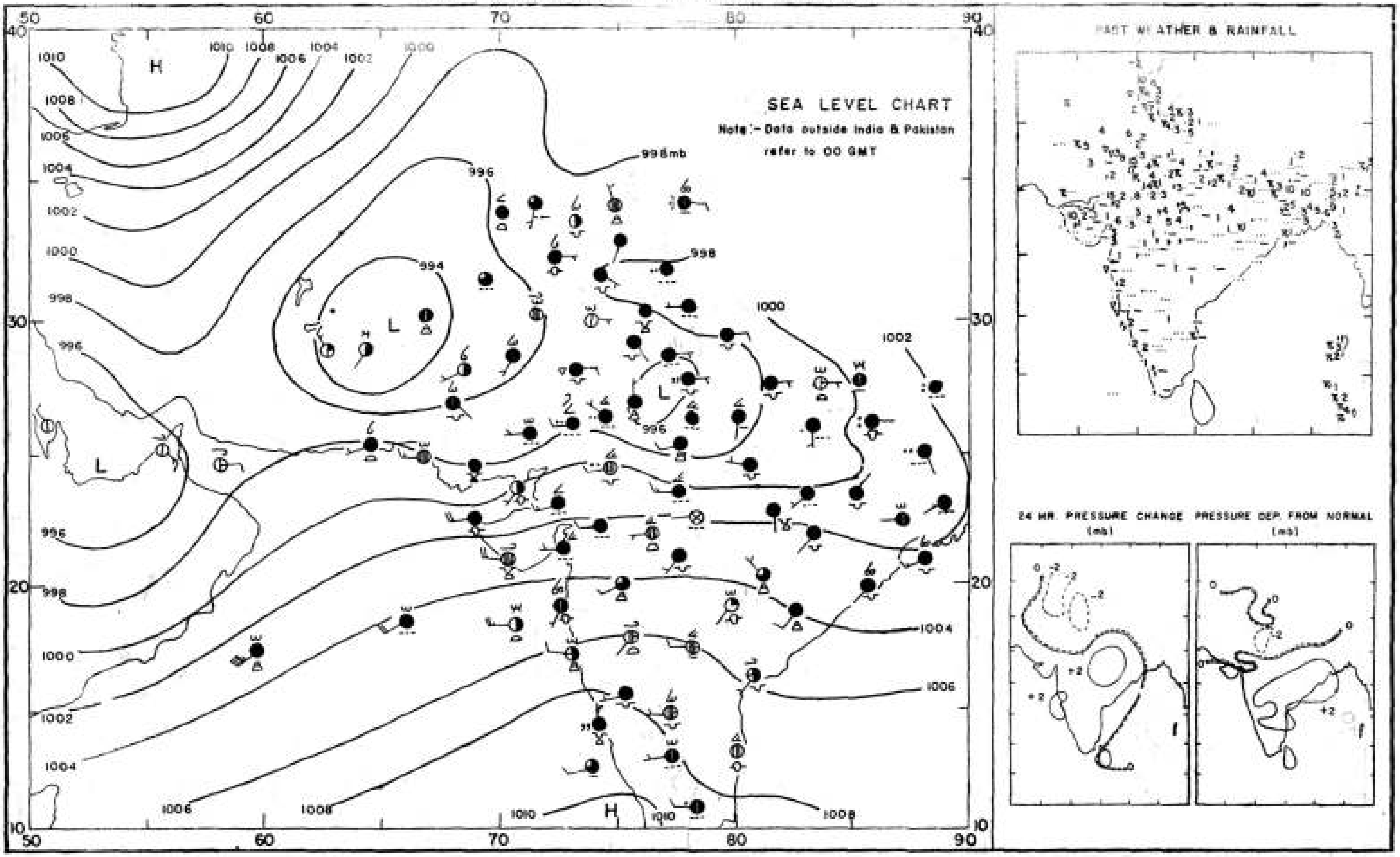
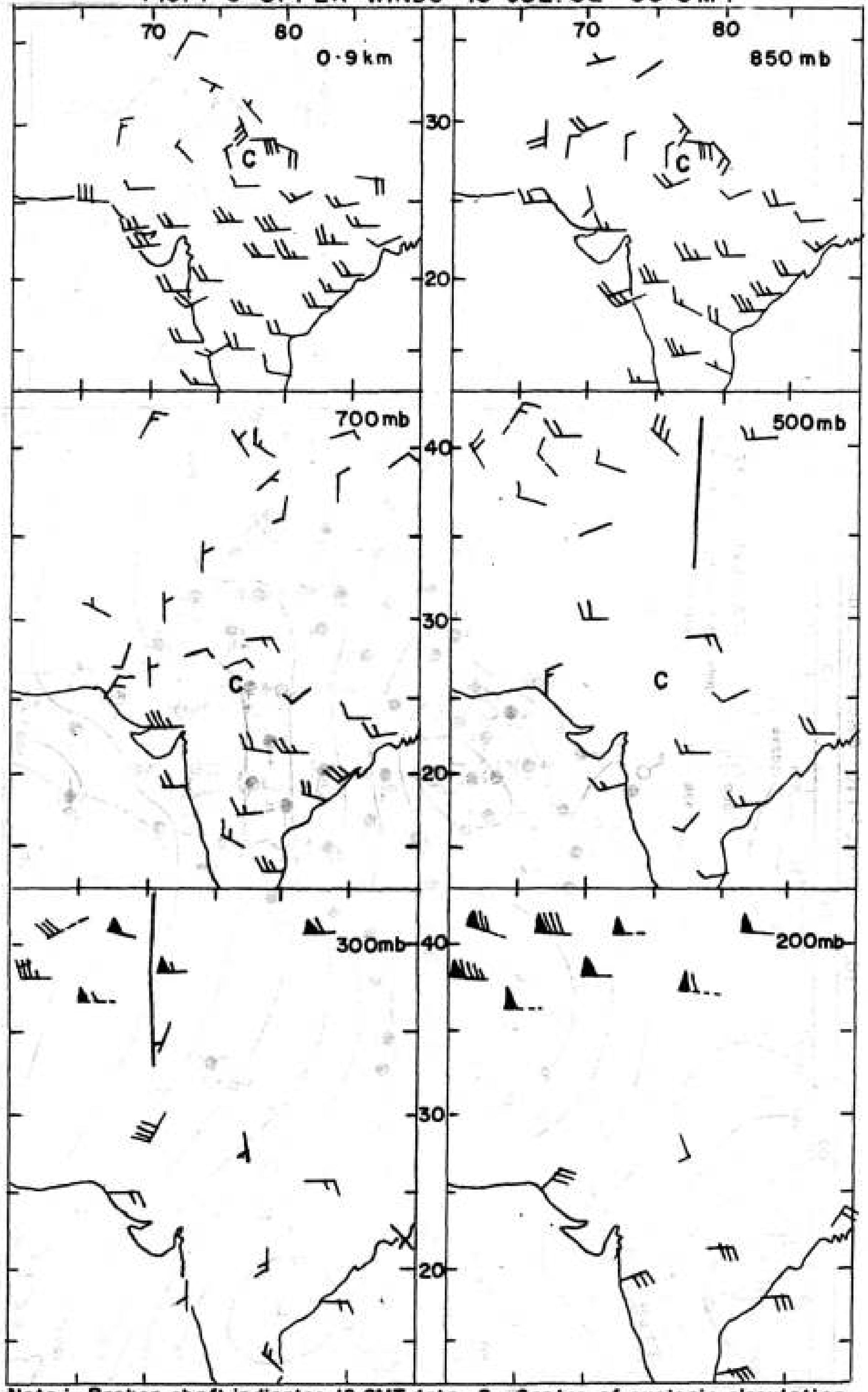


FIG. 7·6 UPPER WINDS 18 JUL. 62 00 GMT



Note :- Broken shaft indicates 12 GMT data C - Centre of cyclonic circulation
——— Trough line

FIG. 7·7 SYNOPTIC CHARTS 0300 GMT 19 JUL. 62

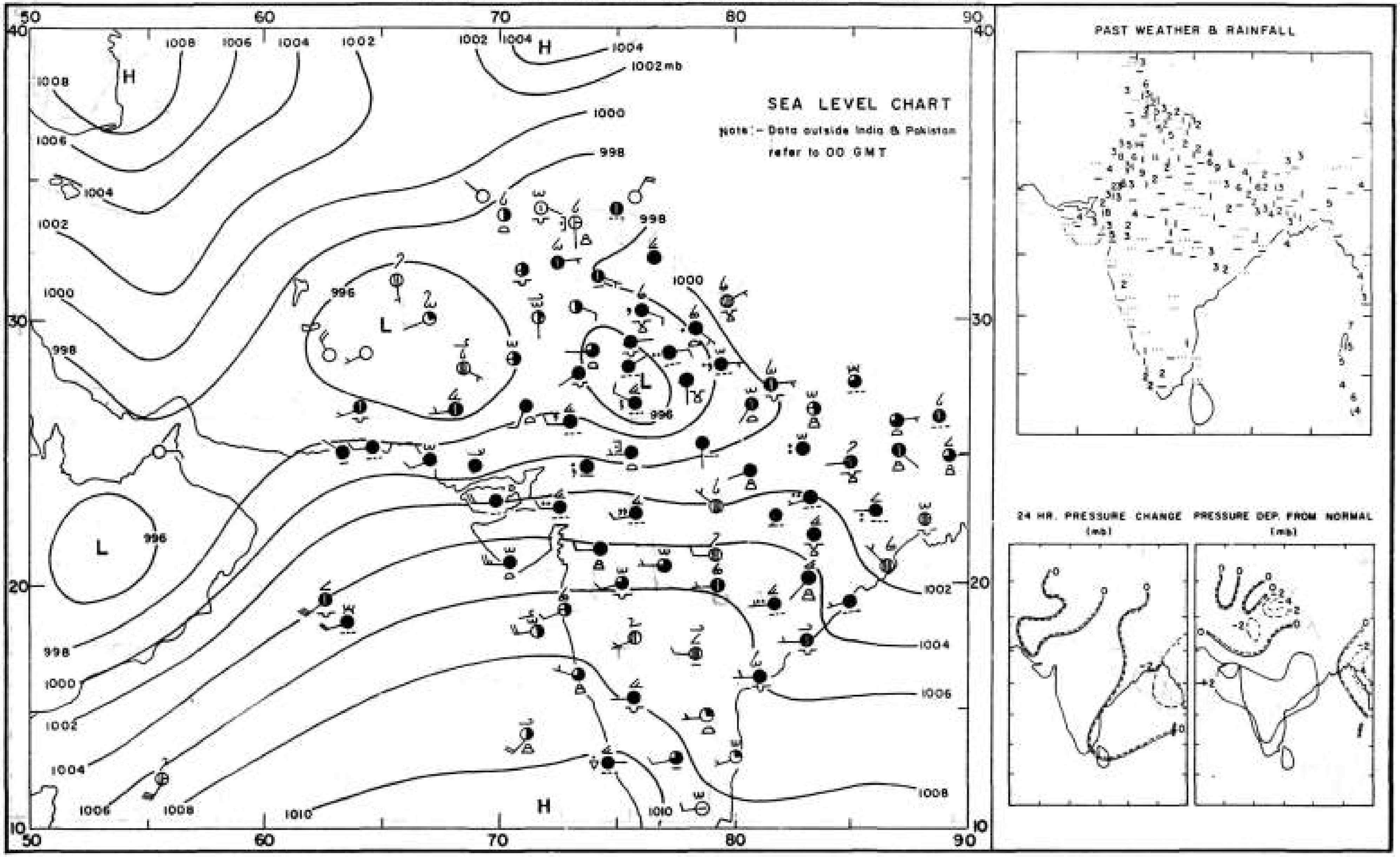
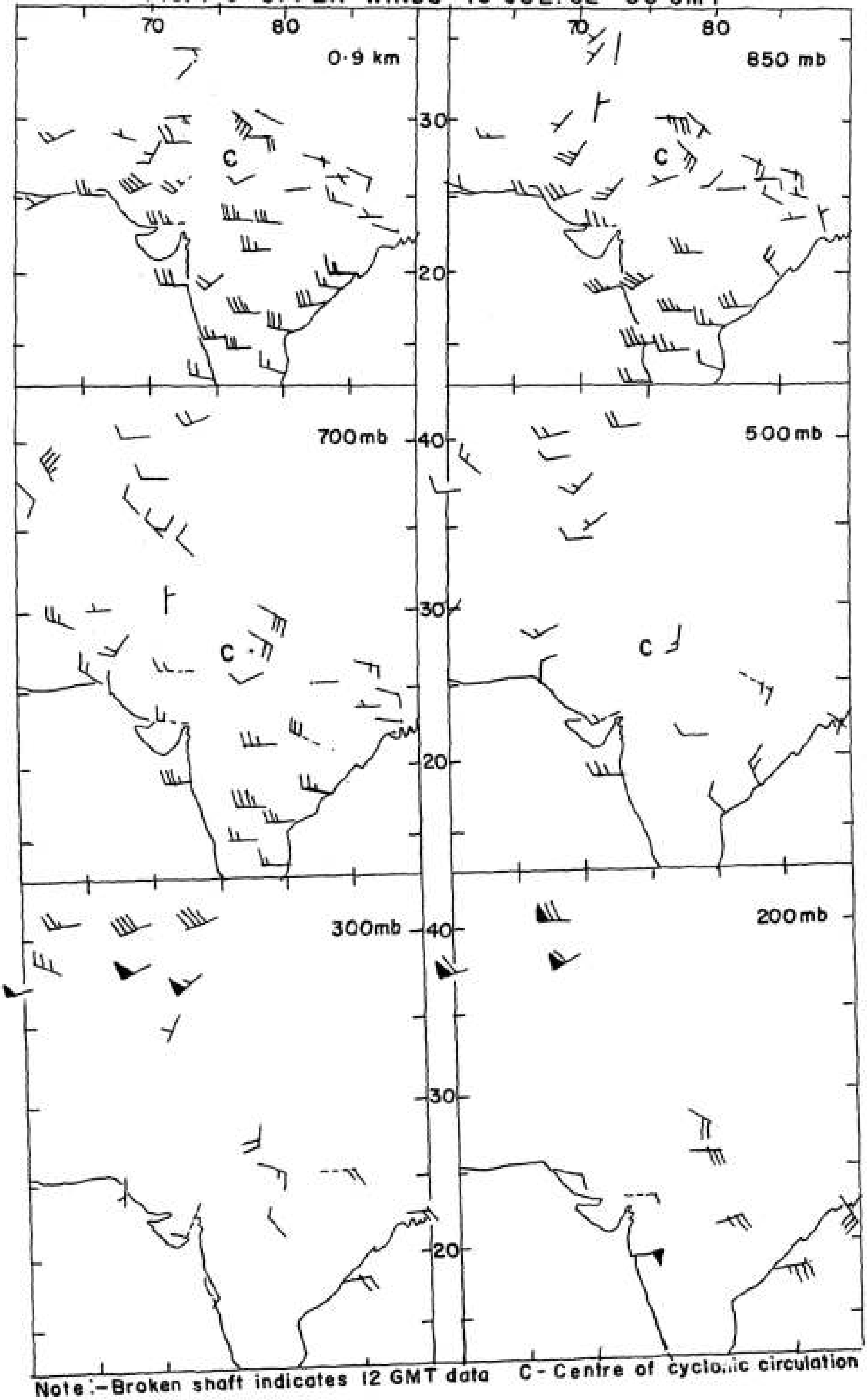


FIG. 7·8 UPPER WINDS 19 JUL. 62 00 GMT



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

FIG. 7·9 SYNOPTIC CHARTS 0300 GMT 20 JUL 62

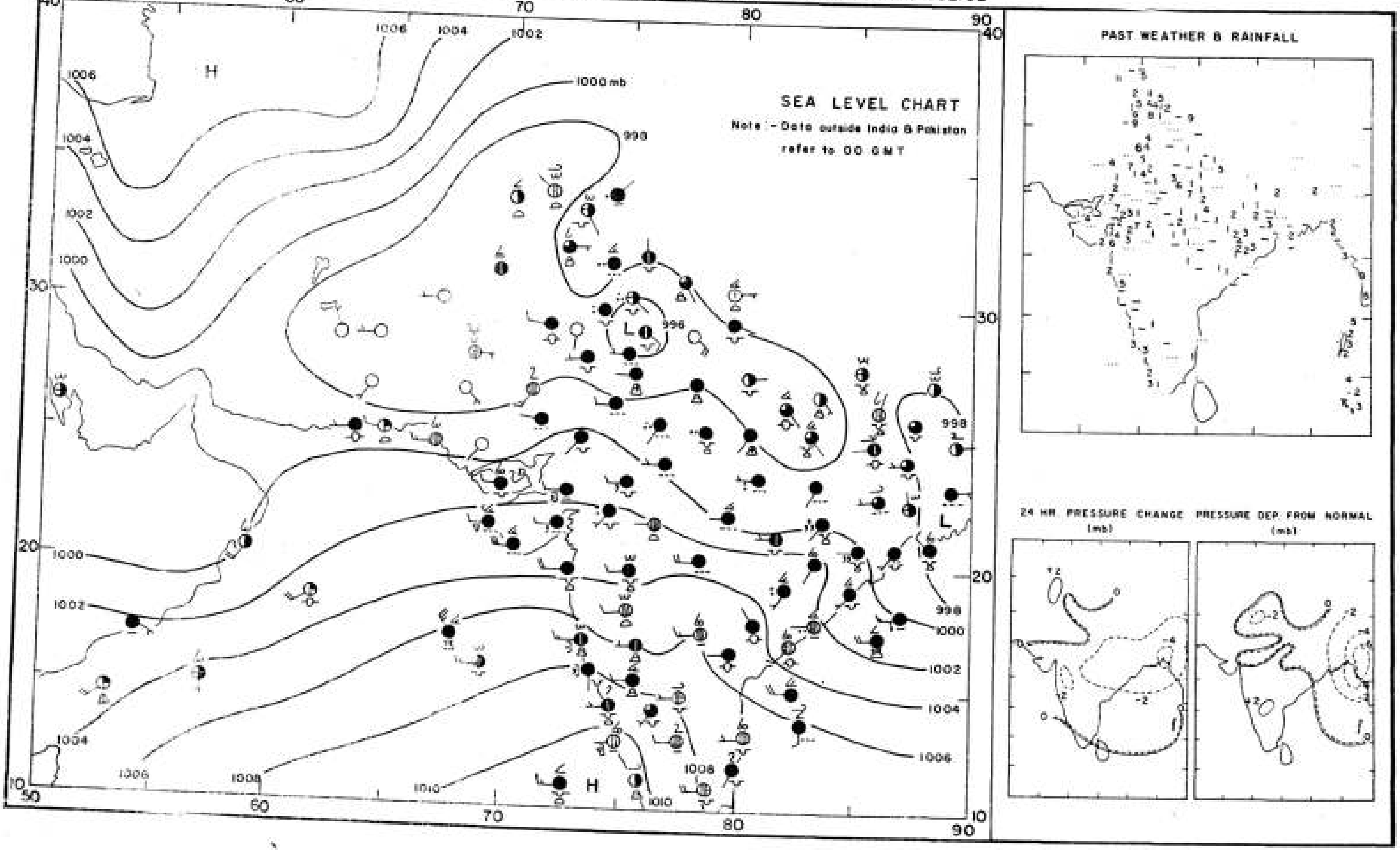
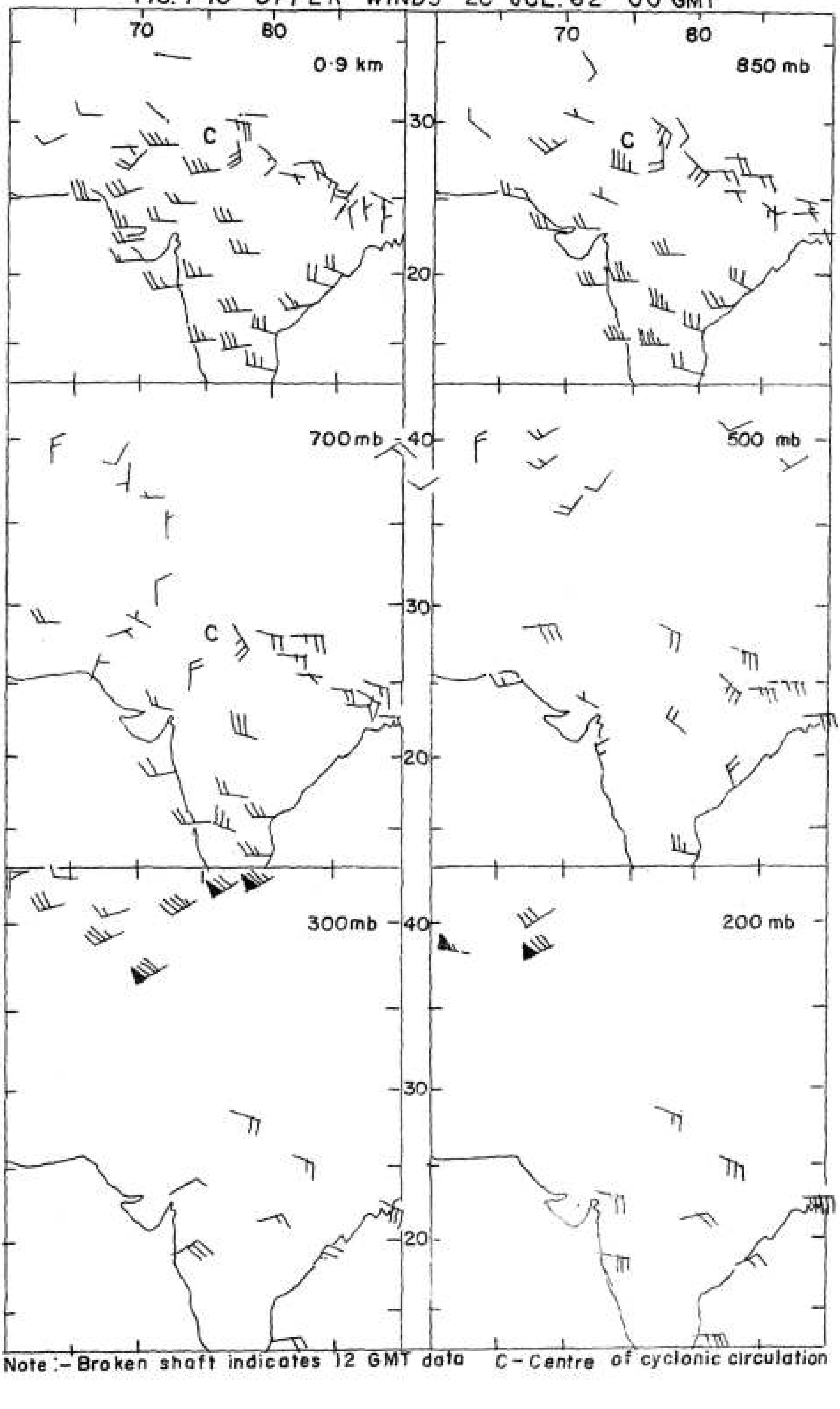


FIG. 7·10 UPPER WINDS 20 JUL. 62 00 GMT



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

FIG. 7·11 SYNOPTIC CHARTS 0300 GMT 21 JUL 62

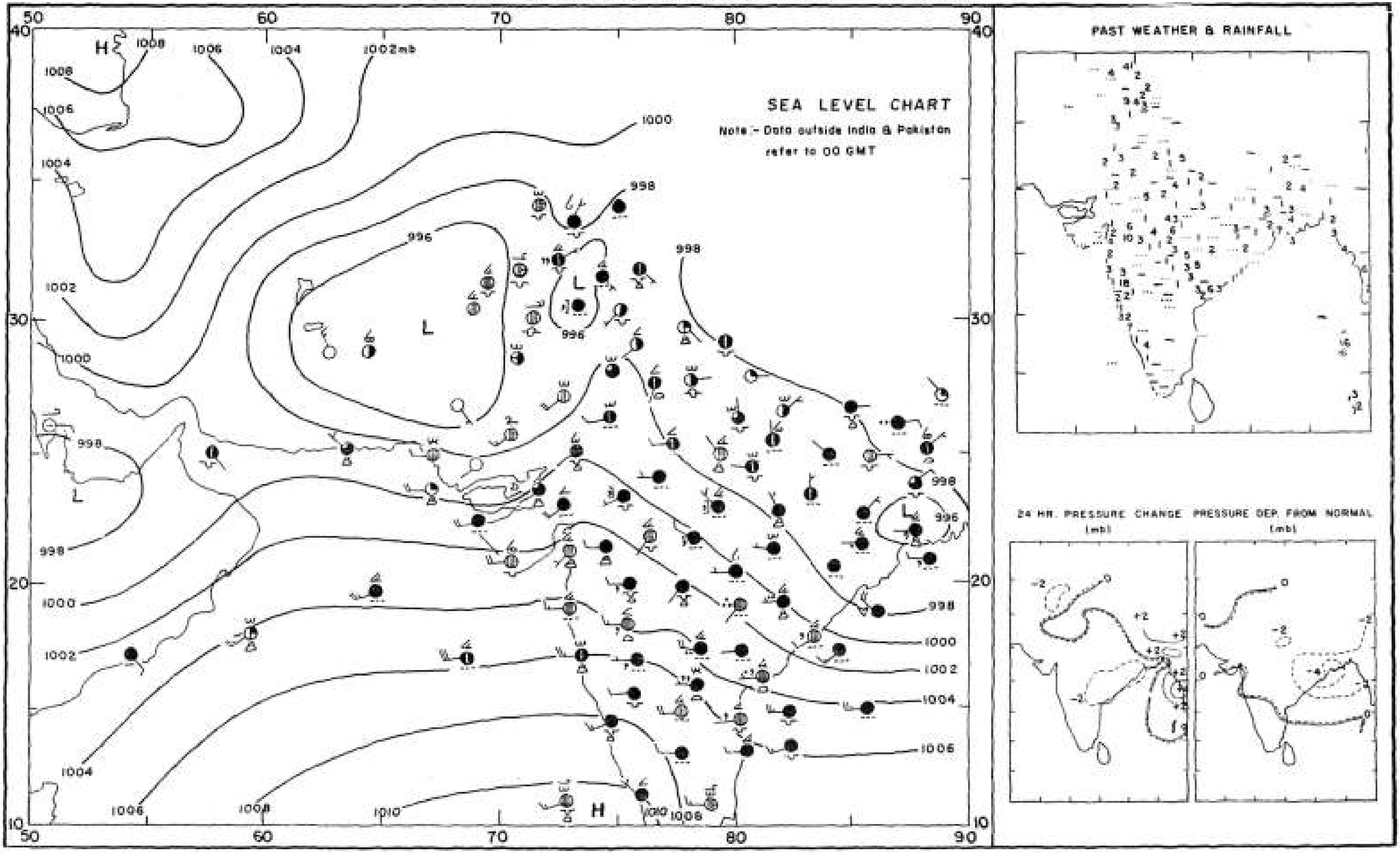
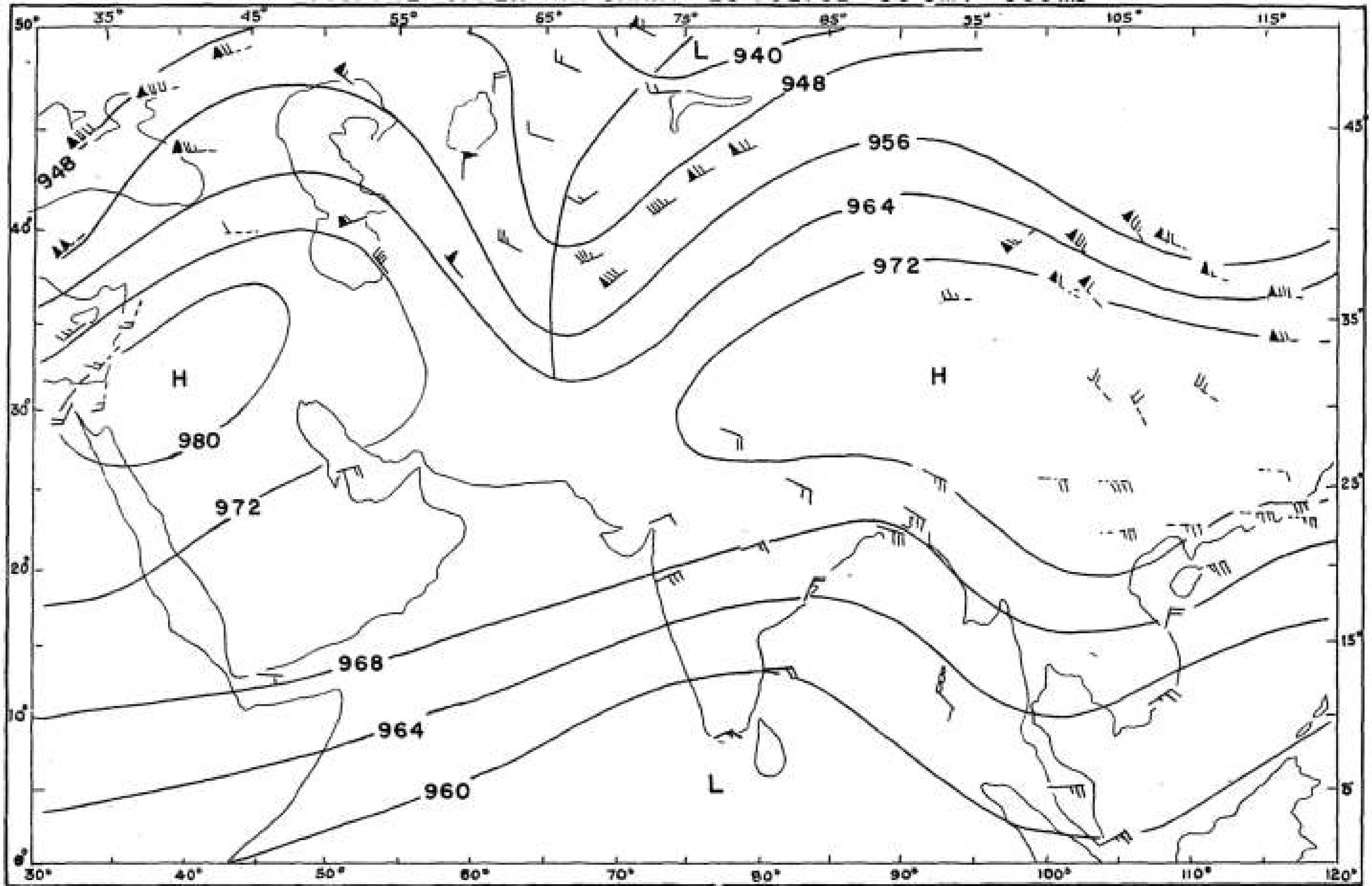


FIG. 7·12 UPPER AIR CHART 20 JUL. 62 00 GMT 300 mb



Note:- Broken shaft indicates 12 GMT data ——— Trough line

FIG. 8-1 SYNOPTIC CHARTS 0300 GMT 4 JUL. 67

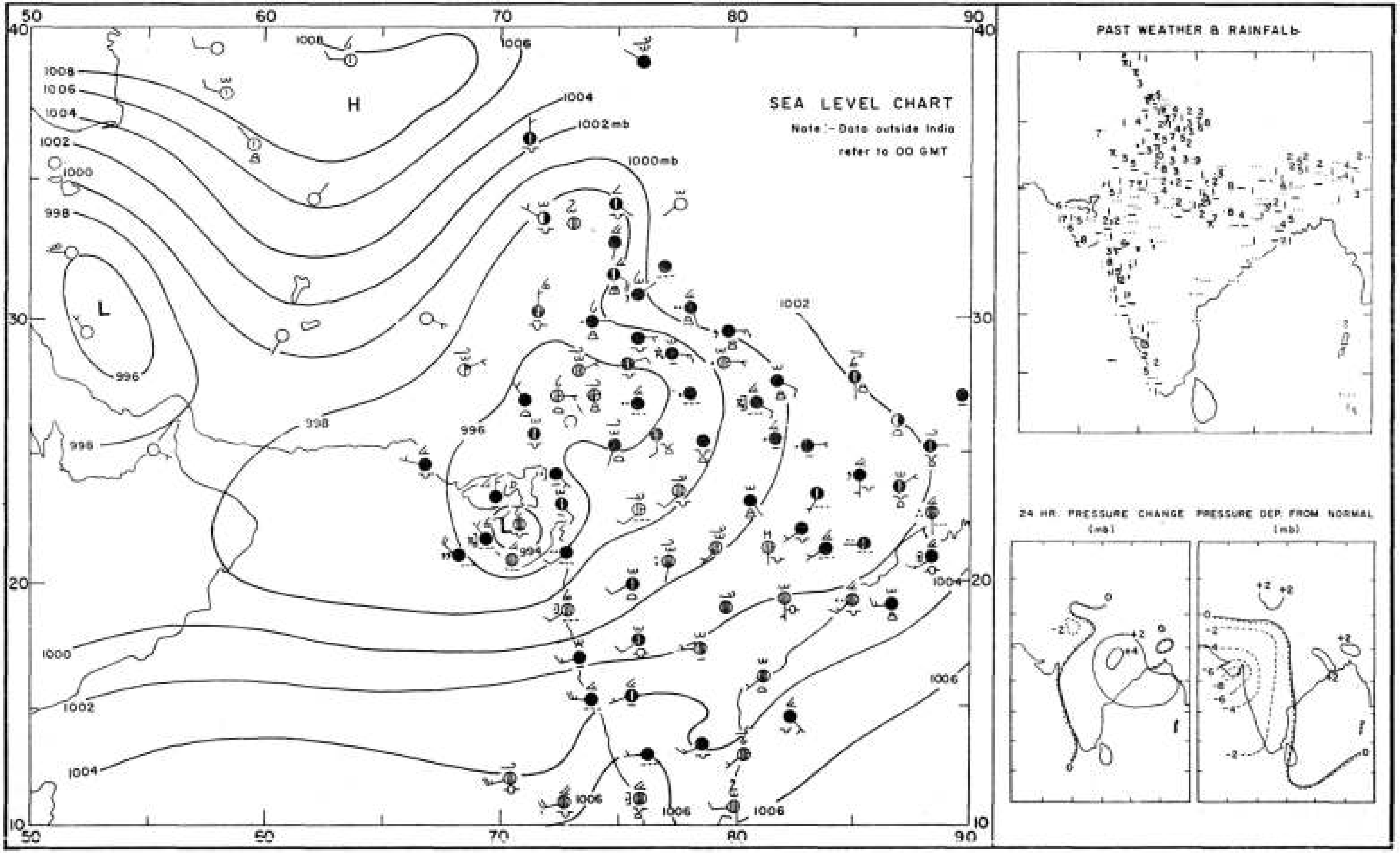
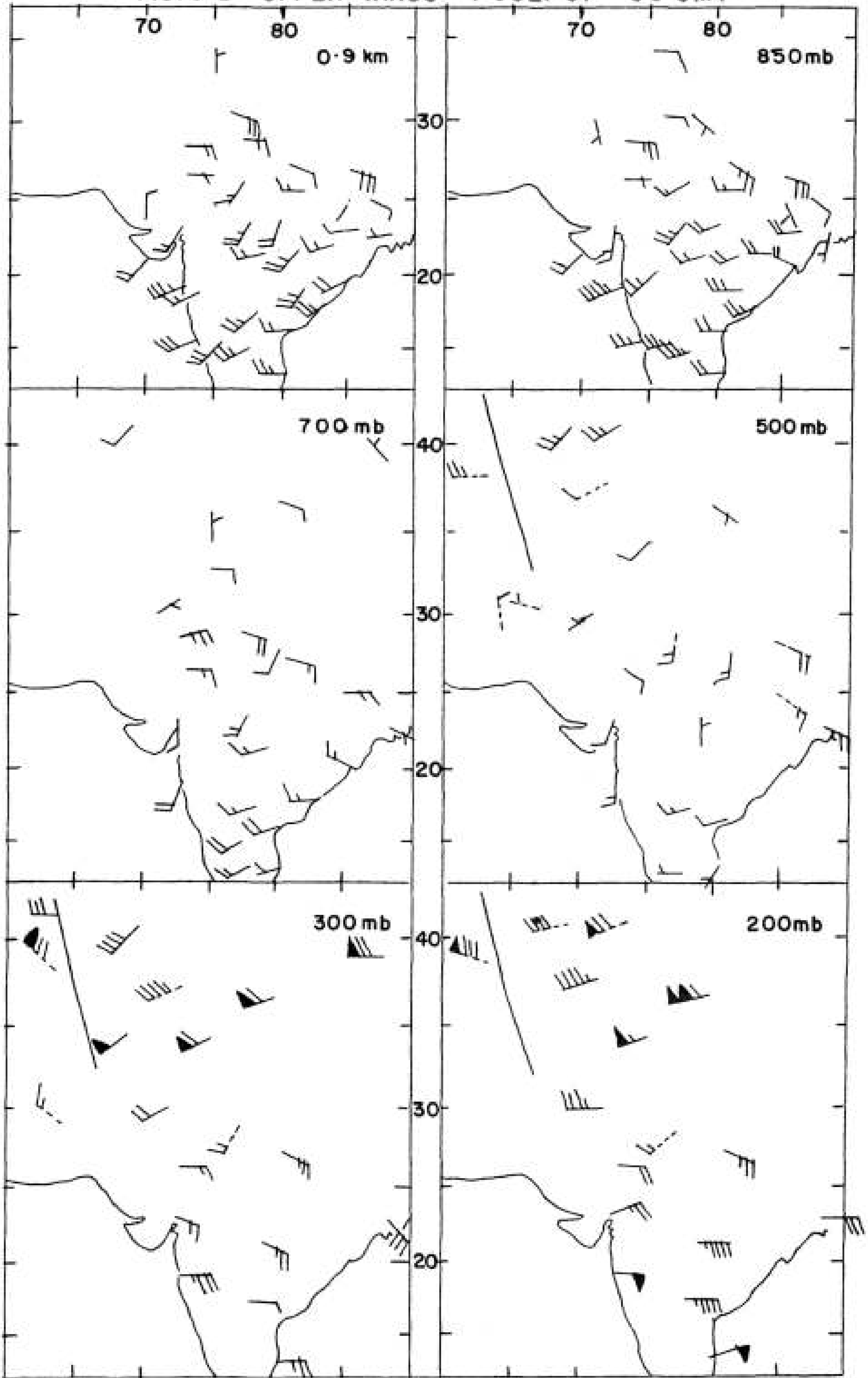
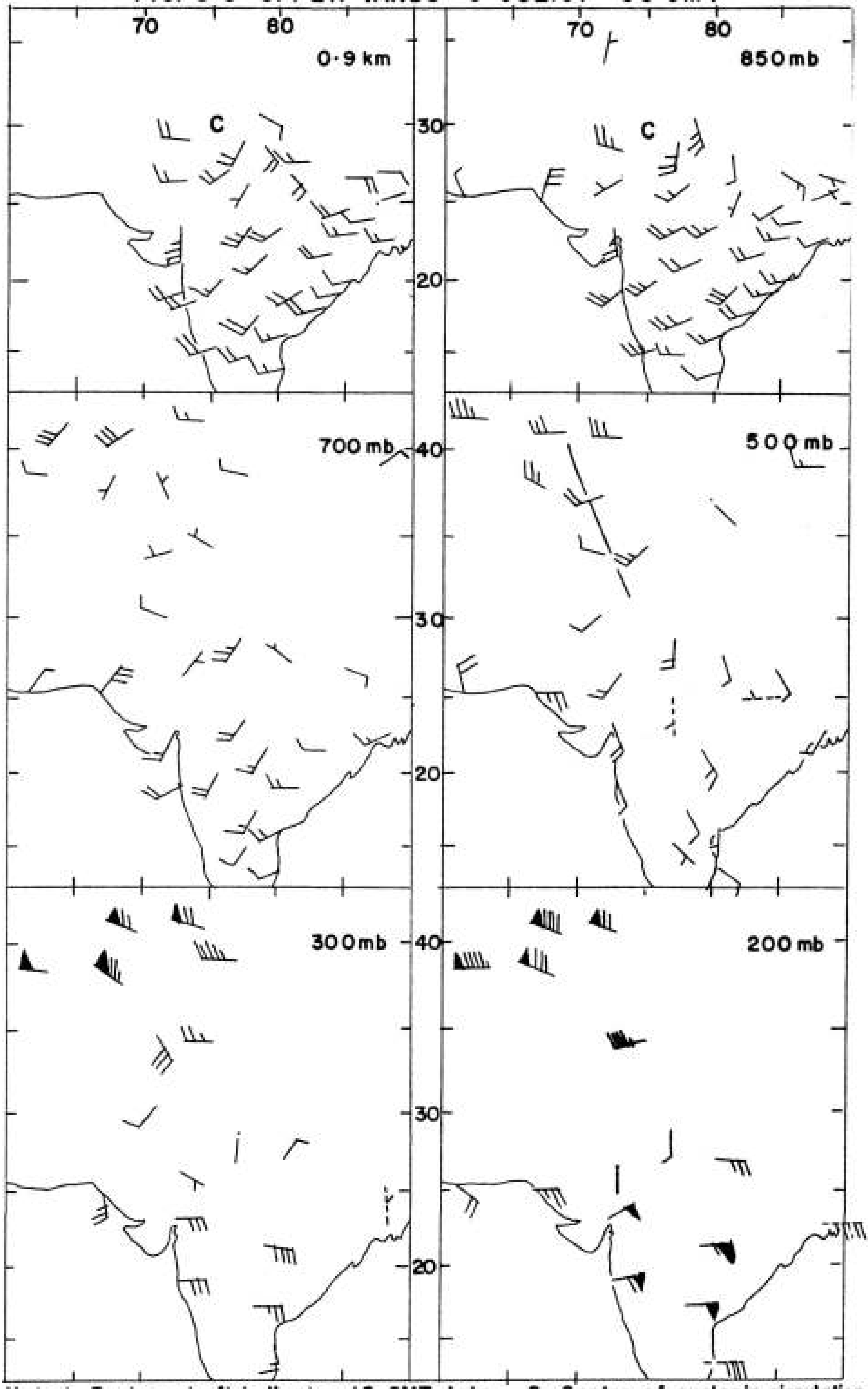


FIG. 8·2 UPPER WINDS 4 JUL. 67 00 GMT



Note:- Broken shaft indicates 12 GMT data —— Trough line

FIG. 8·3 UPPER WINDS 5 JUL.67 00 GMT



Note :- Broken shaft indicates 12 GMT data C - Centre of cyclonic circulation
——— Trough line

FIG. 8·4 ESSA 2 5 JUL. 67

ORBIT 6235

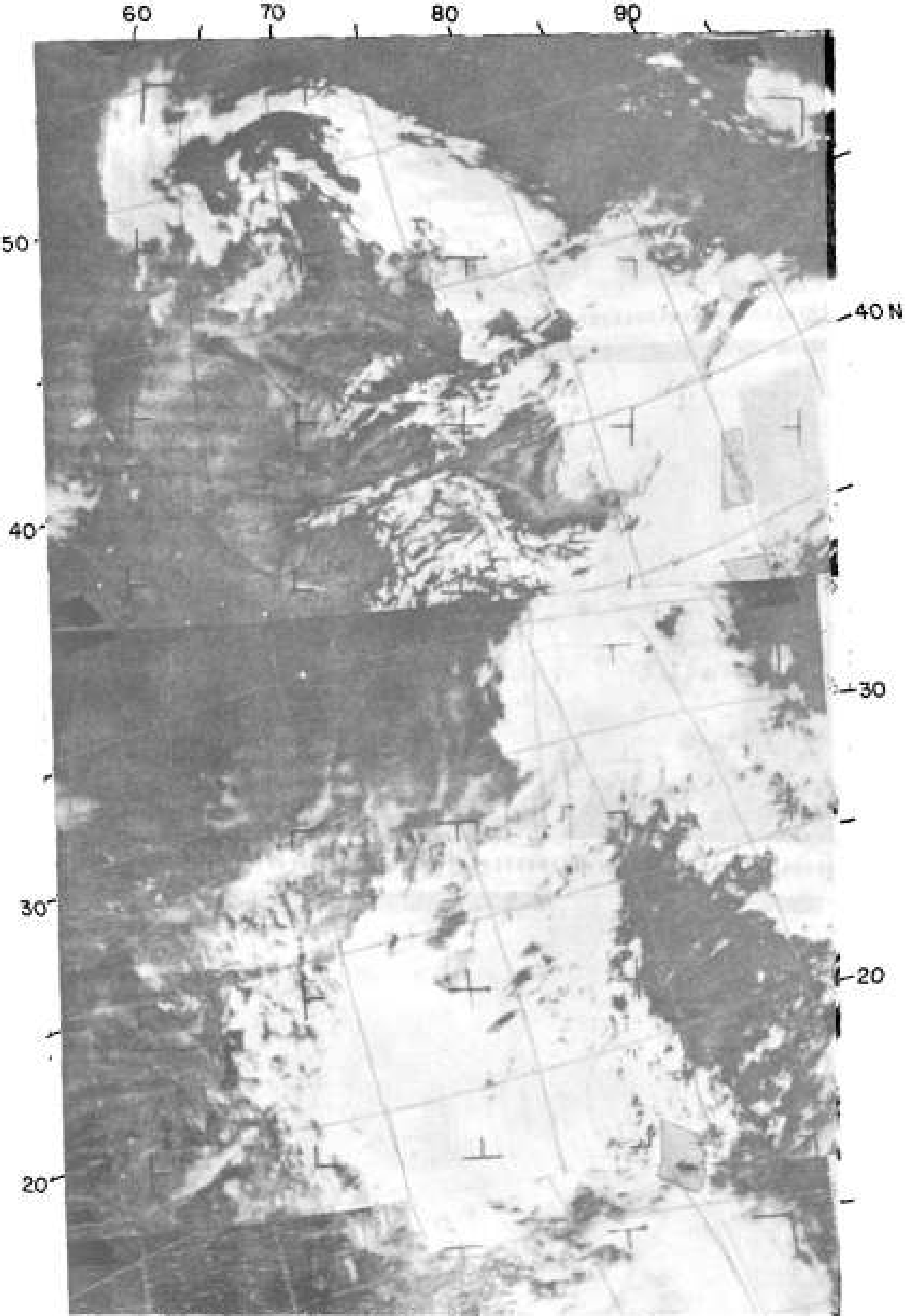


FIG. 8·5 SYNOPTIC CHARTS 0300 GMT 5 JUL. 67

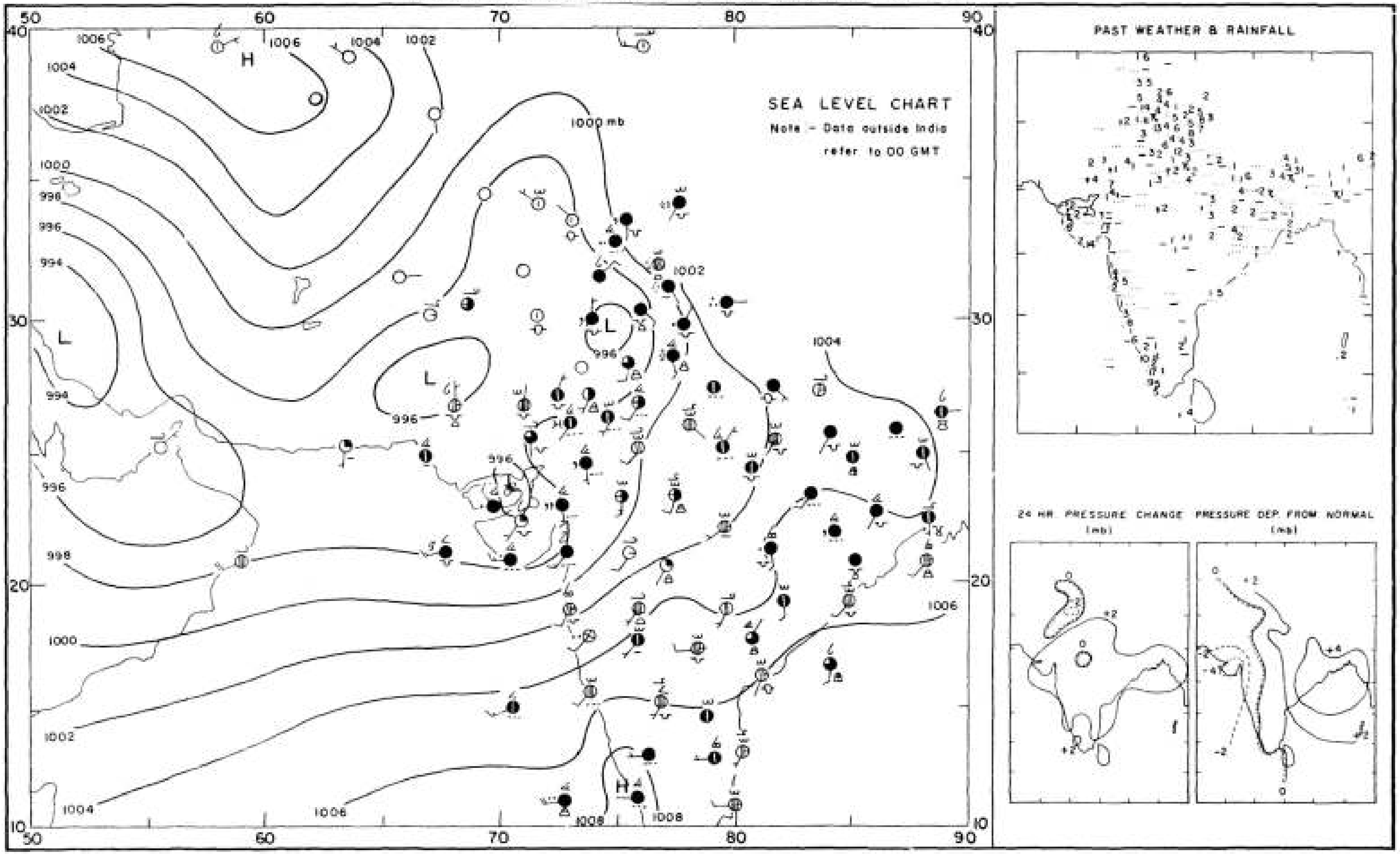
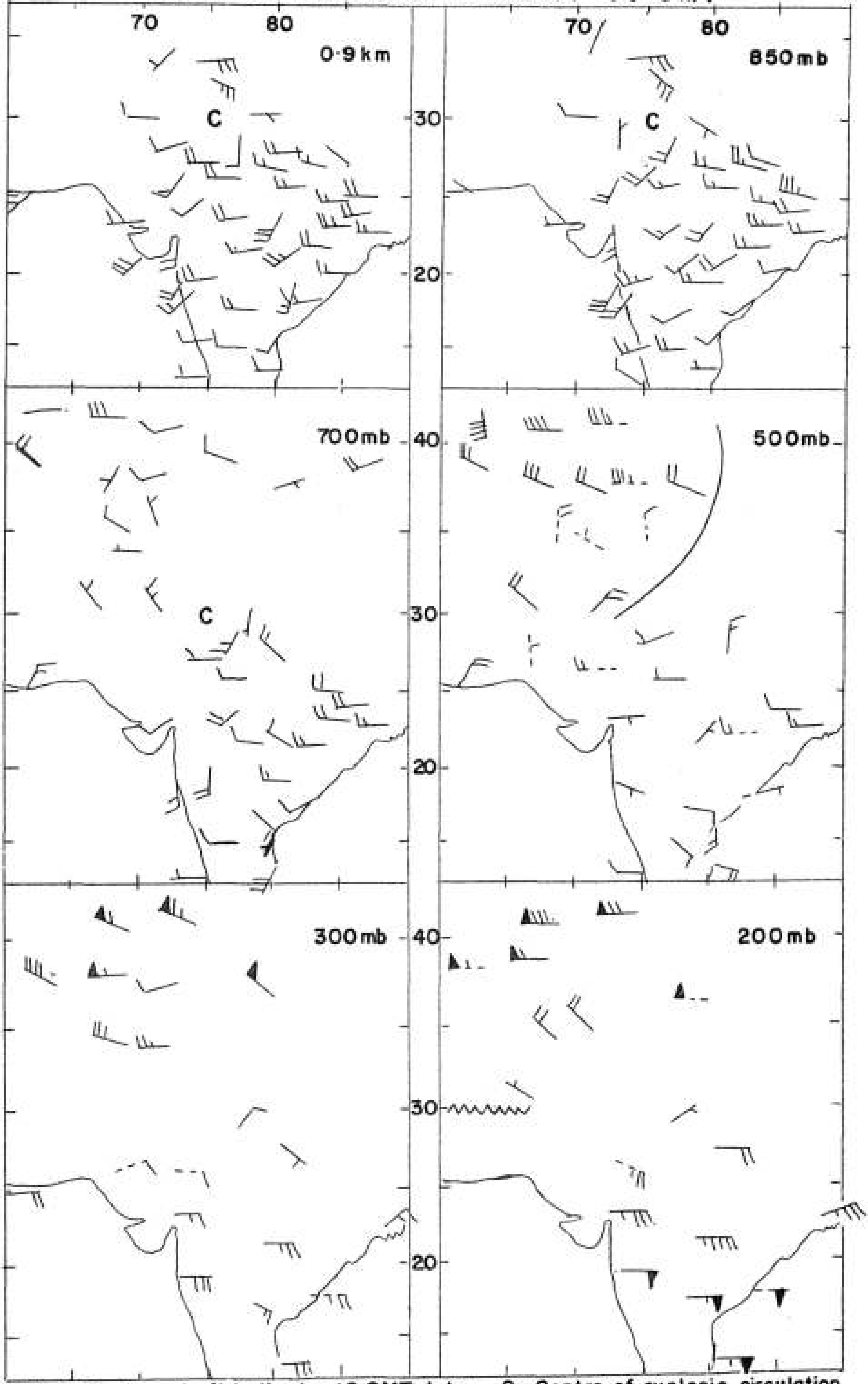


FIG. 8·6 UPPER WINDS 6 JUL.67 00 GMT



Note :- Broken shaft indicates 12 GMT data C- Centre of cyclonic circulation
——— Trough line ∿∿∿ Ridge line

FIG.8·7

NIMBUS – 2

ORBIT: 5551

DATE: 6 JULY 67

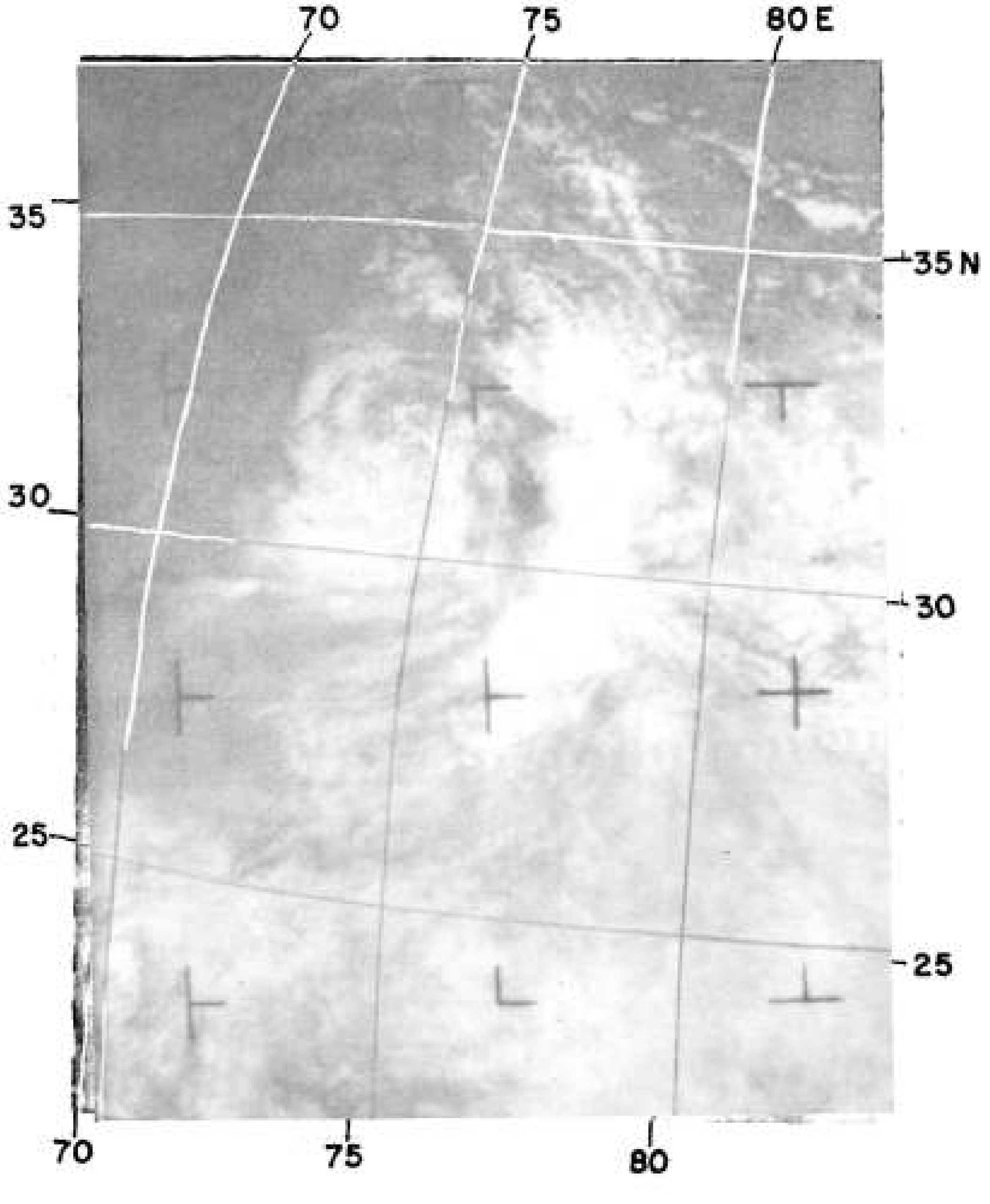


FIG. 8·8 SYNOPTIC CHARTS 0300 GMT 6 JUL. 67

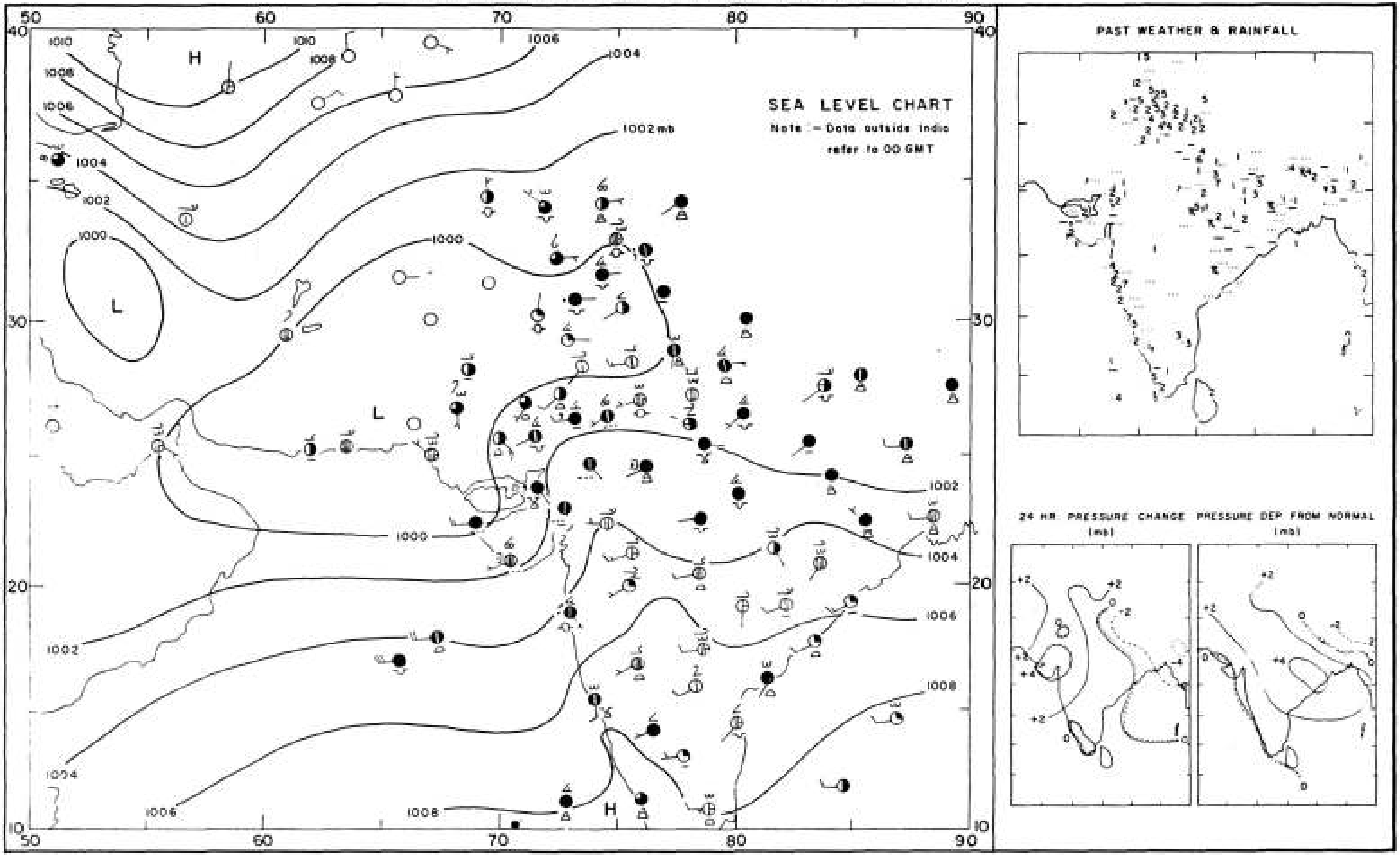
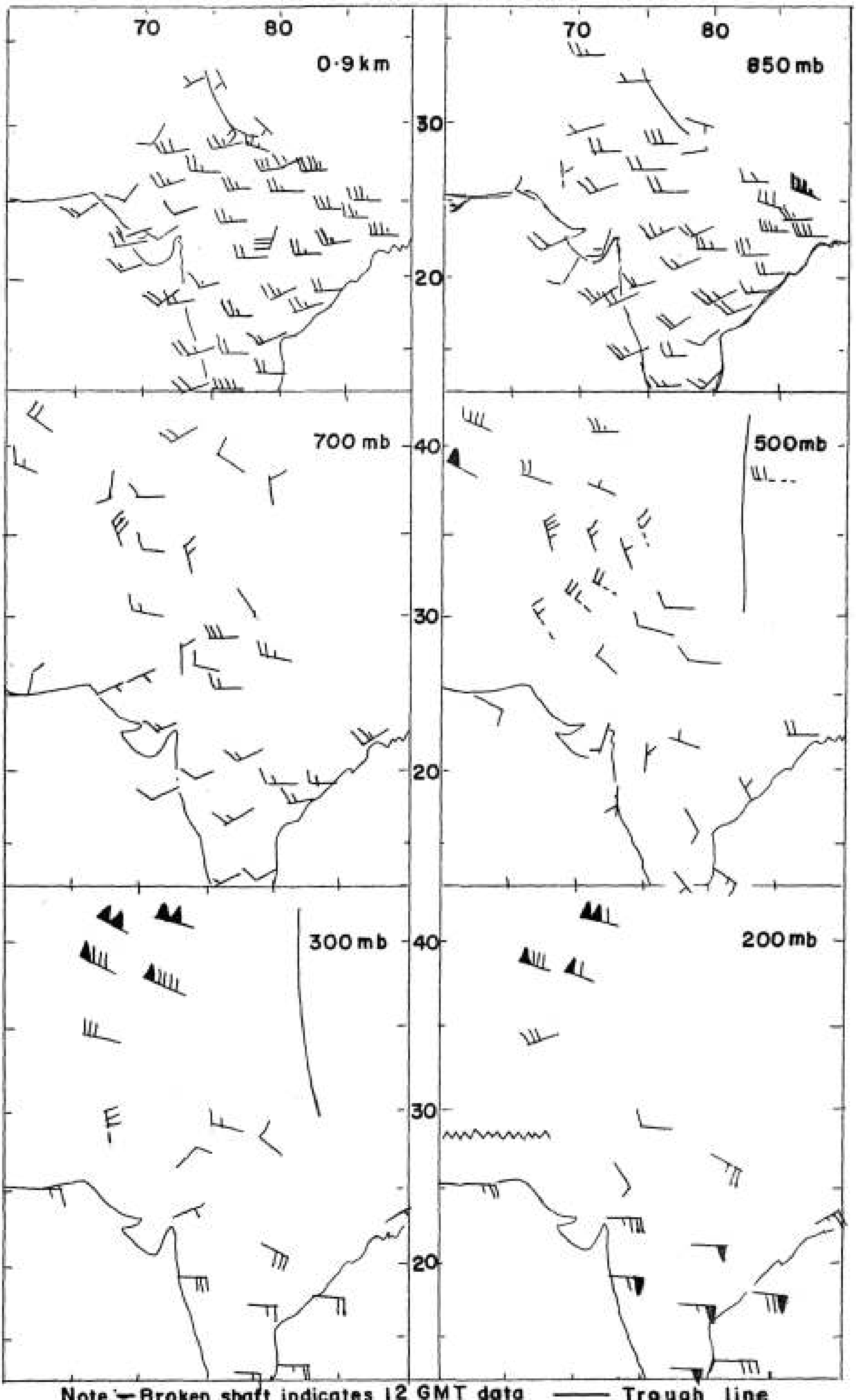


FIG. 8·9 UPPER WINDS 7 JUL. 67 00 GMT



Note :— Broken shaft indicates 12 GMT data —— Trough line
Ridge line

FIG. 8·10 SYNOPTIC CHARTS 0300 GMT 7 JUL 67

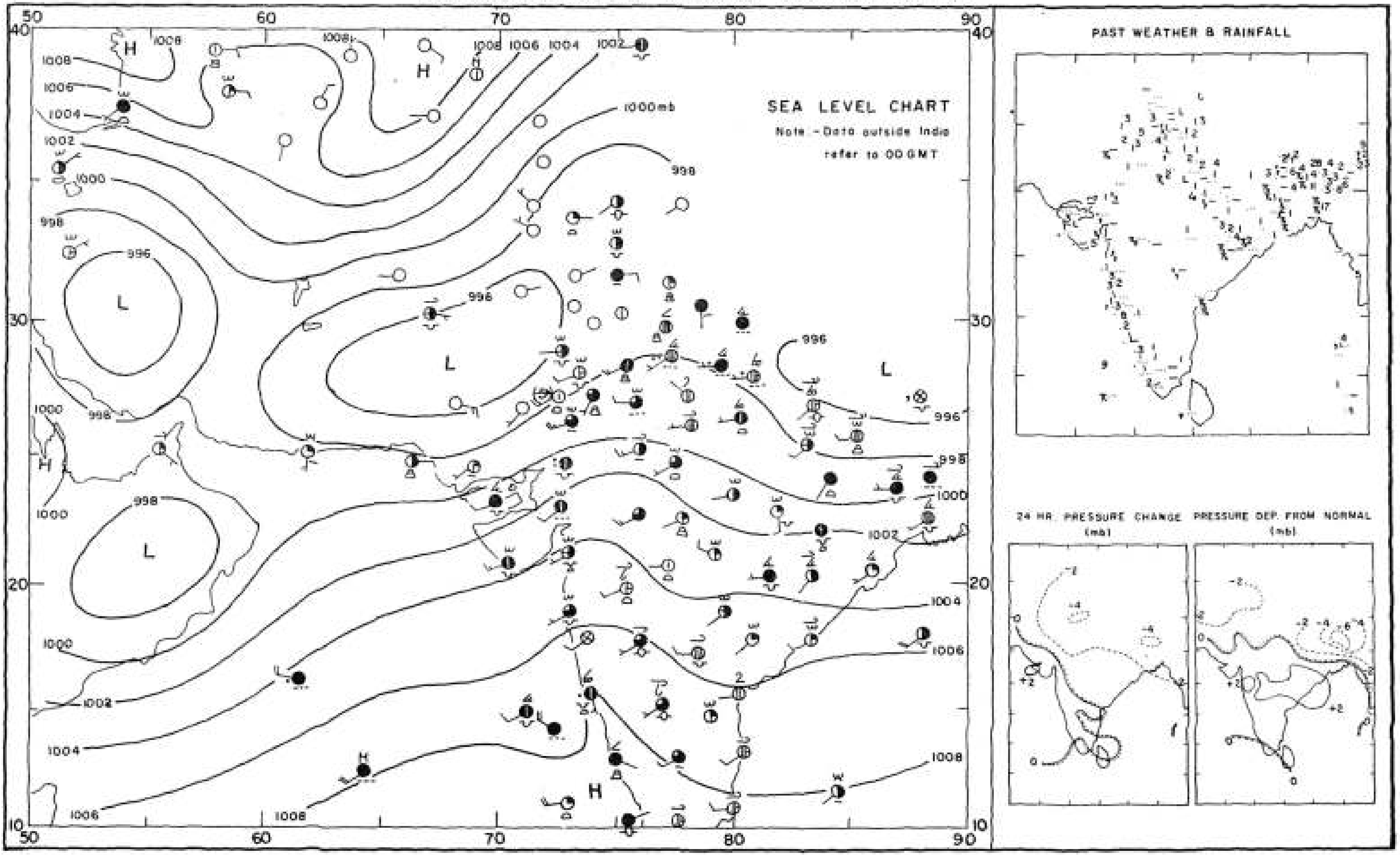


FIG. 8·11 SYNOPTIC CHARTS 0300 GMT 8 JUL. 67

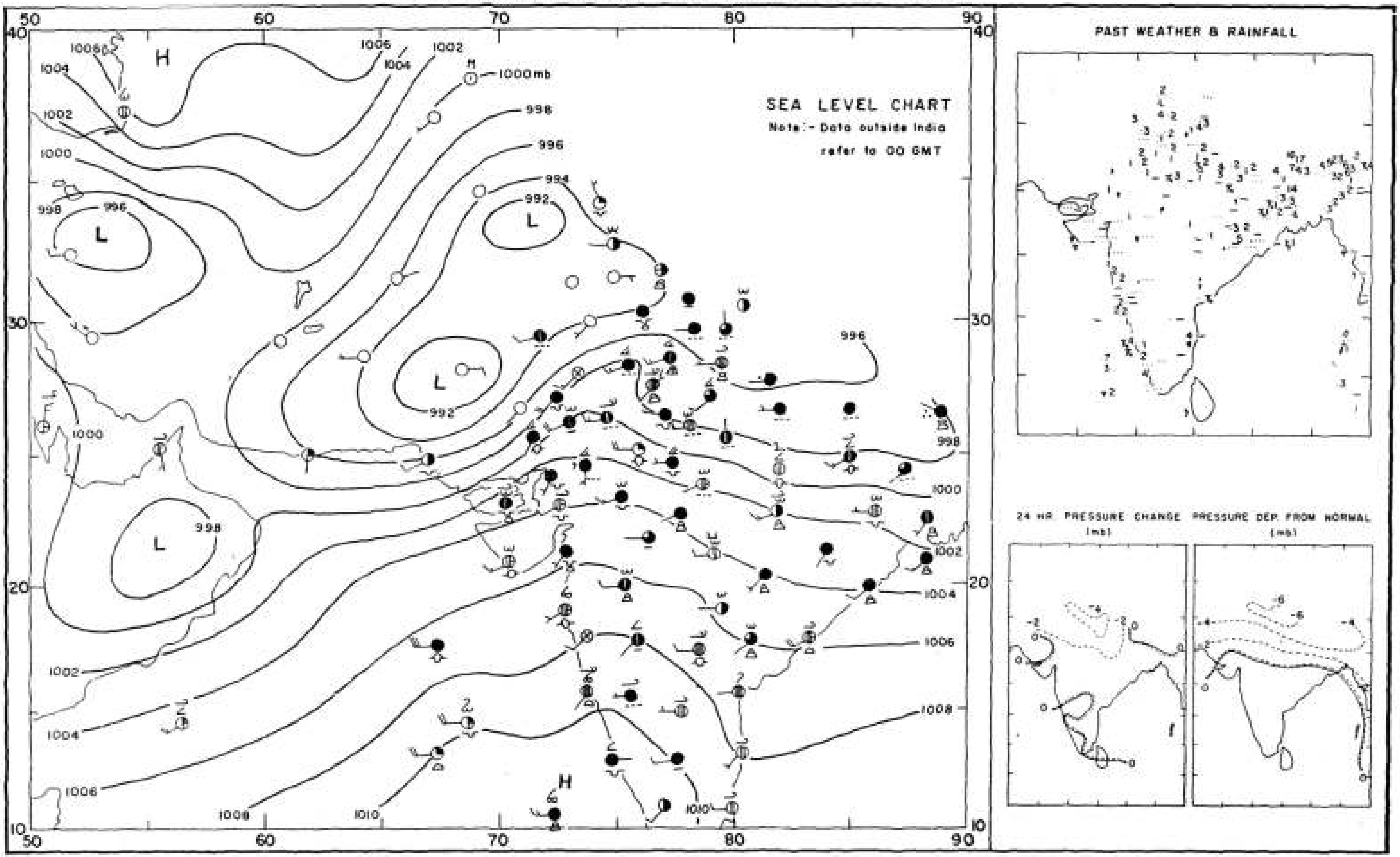
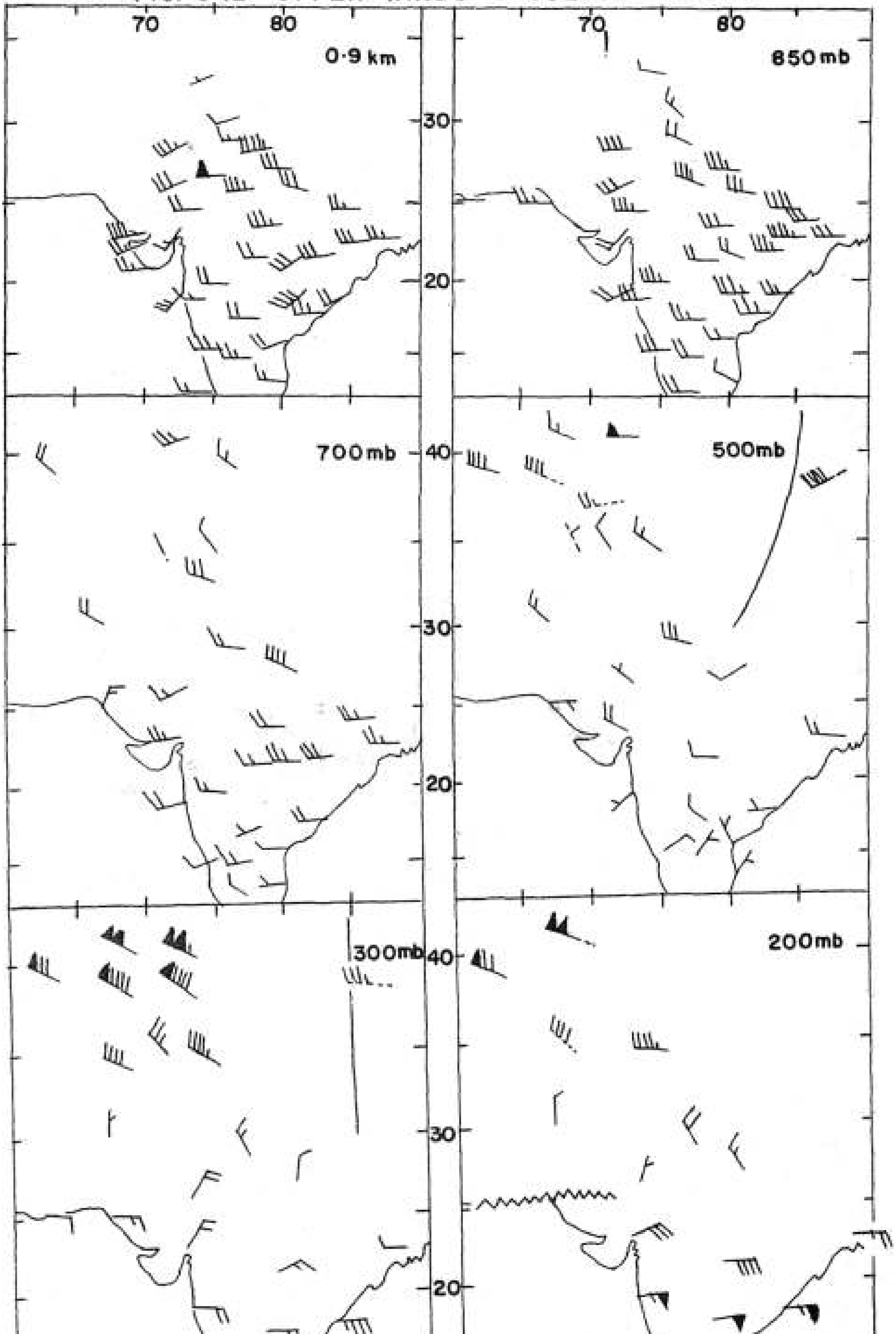


FIG. 8·12 UPPER WINDS 8 JUL. 67 00 GMT



Note :- Broken shaft indicates 12 GMT data —— Trough line
~~~~ Ridge line
~~~~

FIG. 8·13 SYNOPTIC CHARTS 0300 GMT 9 JUL. 67

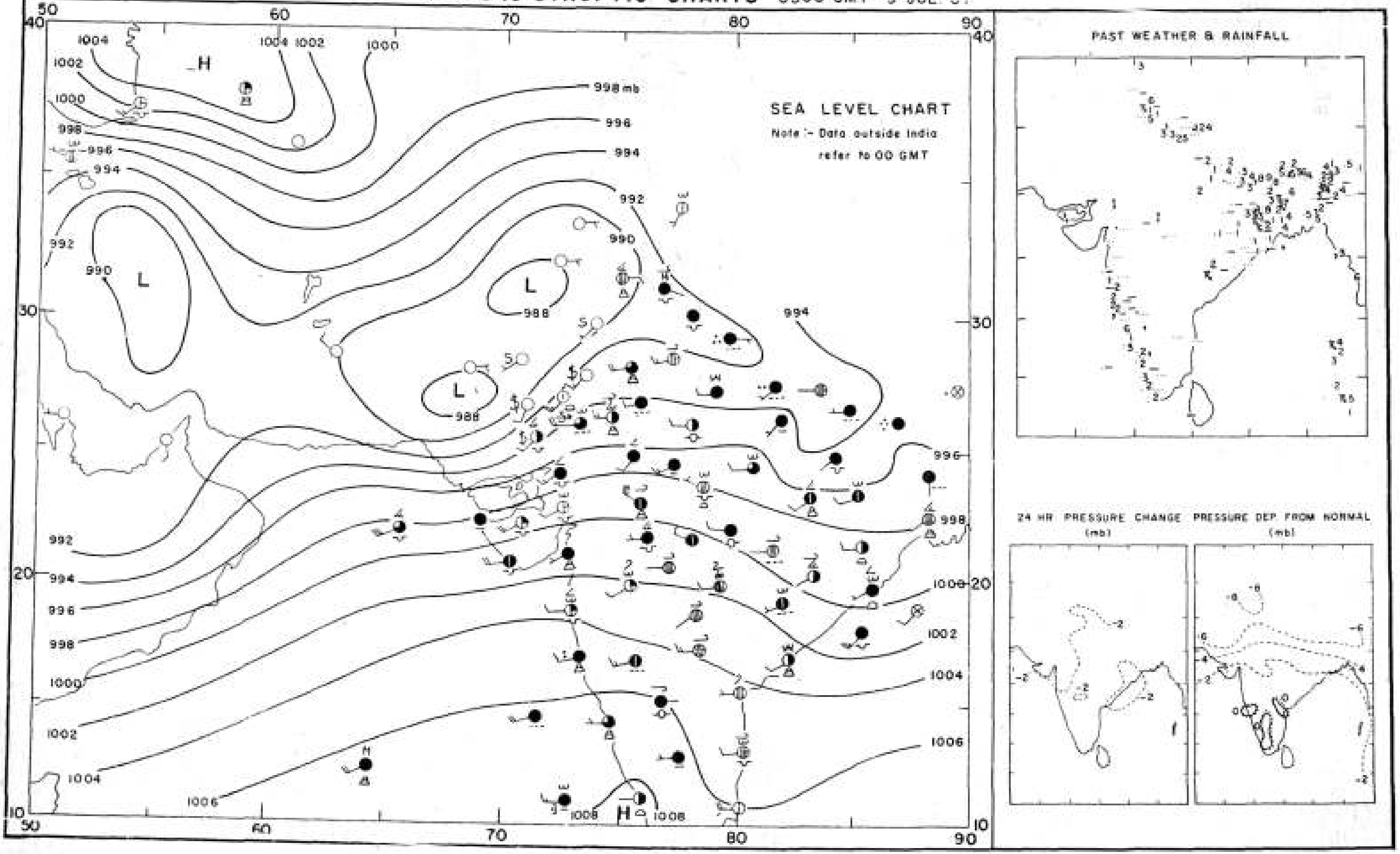
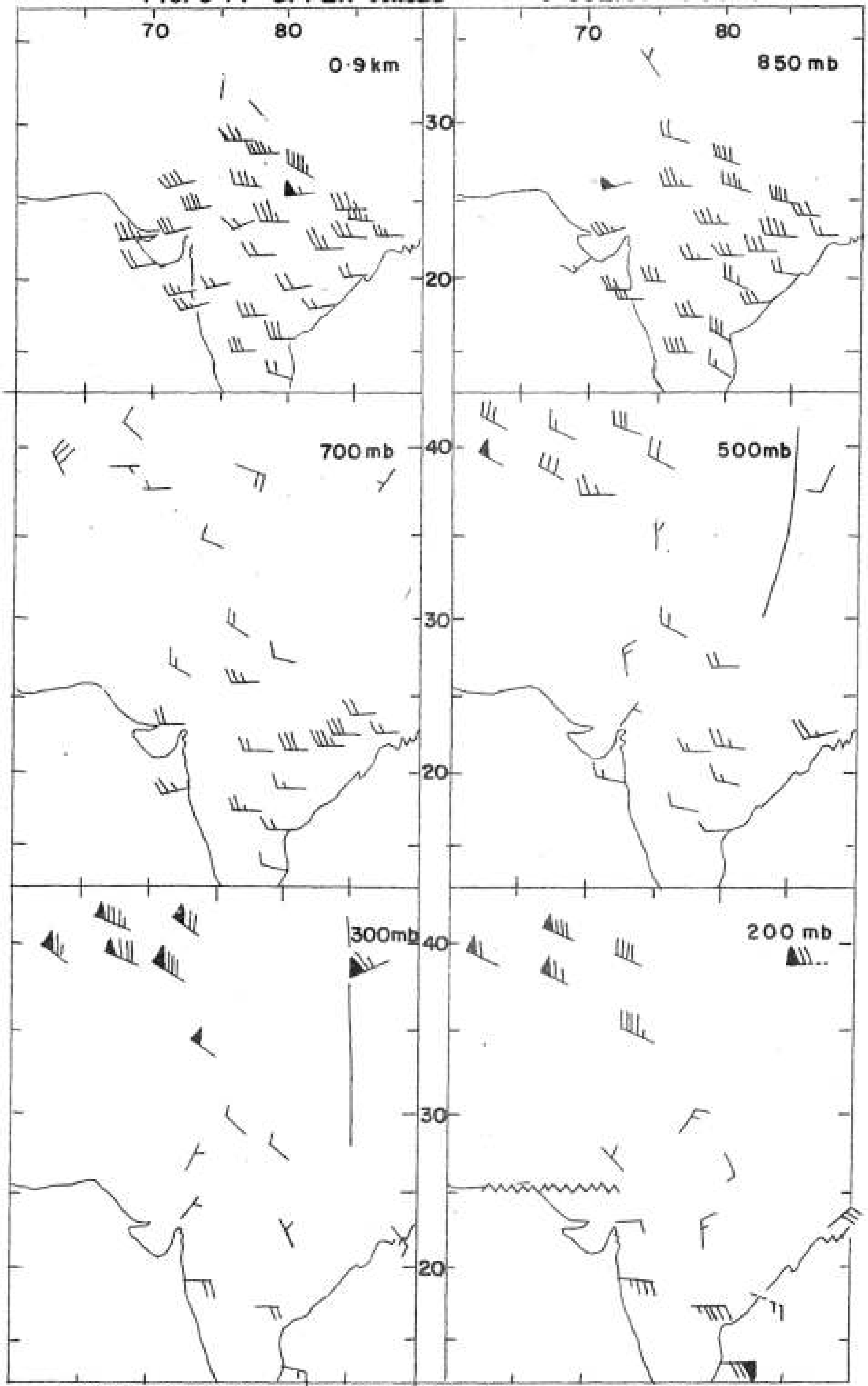
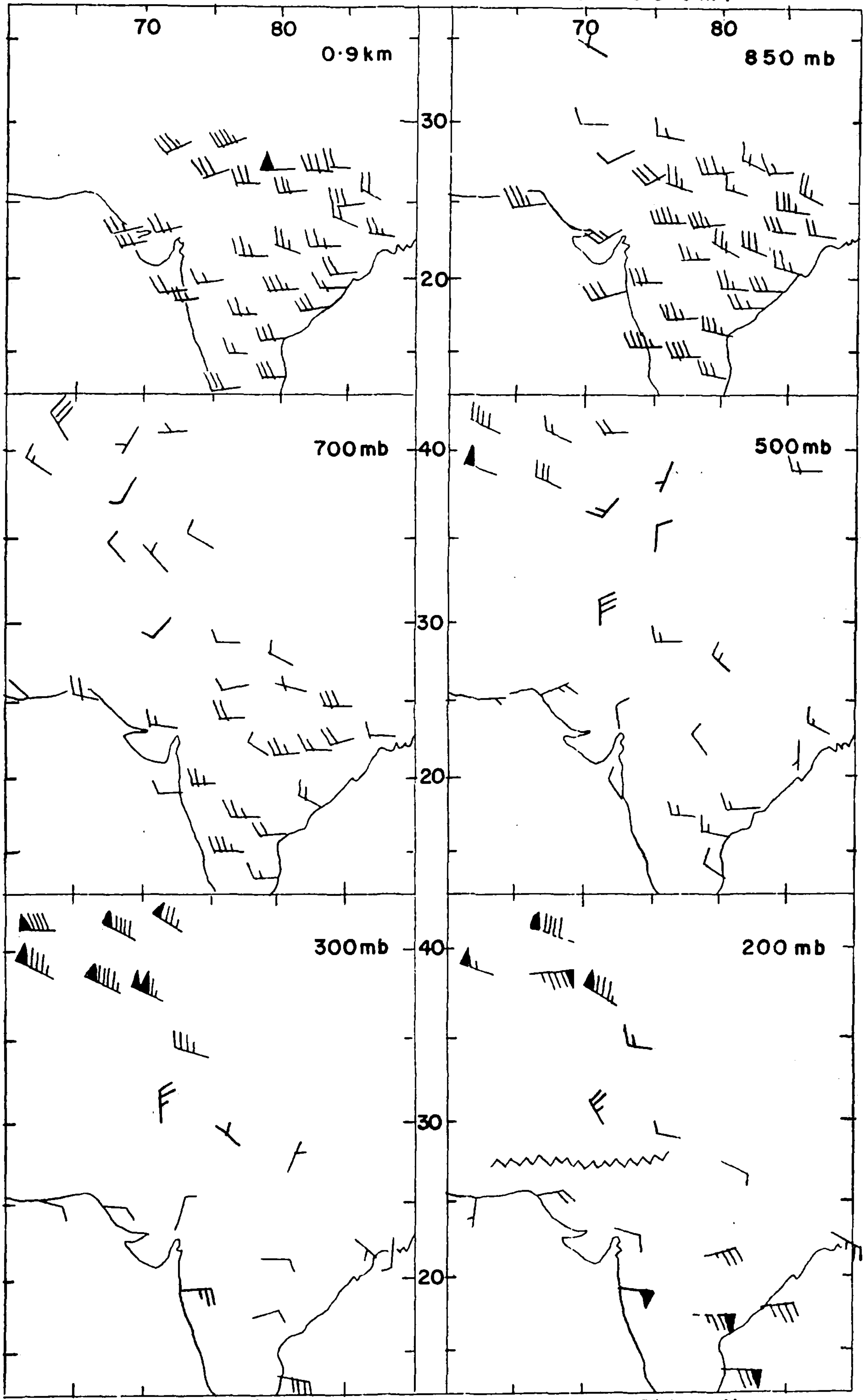


FIG. 8-14 UPPER WINDS 9 JUL. 67 00GMT



Note :- Broken shaft indicates 12 GMT data —— Trough line
~~~~ Ridge line
~~~~

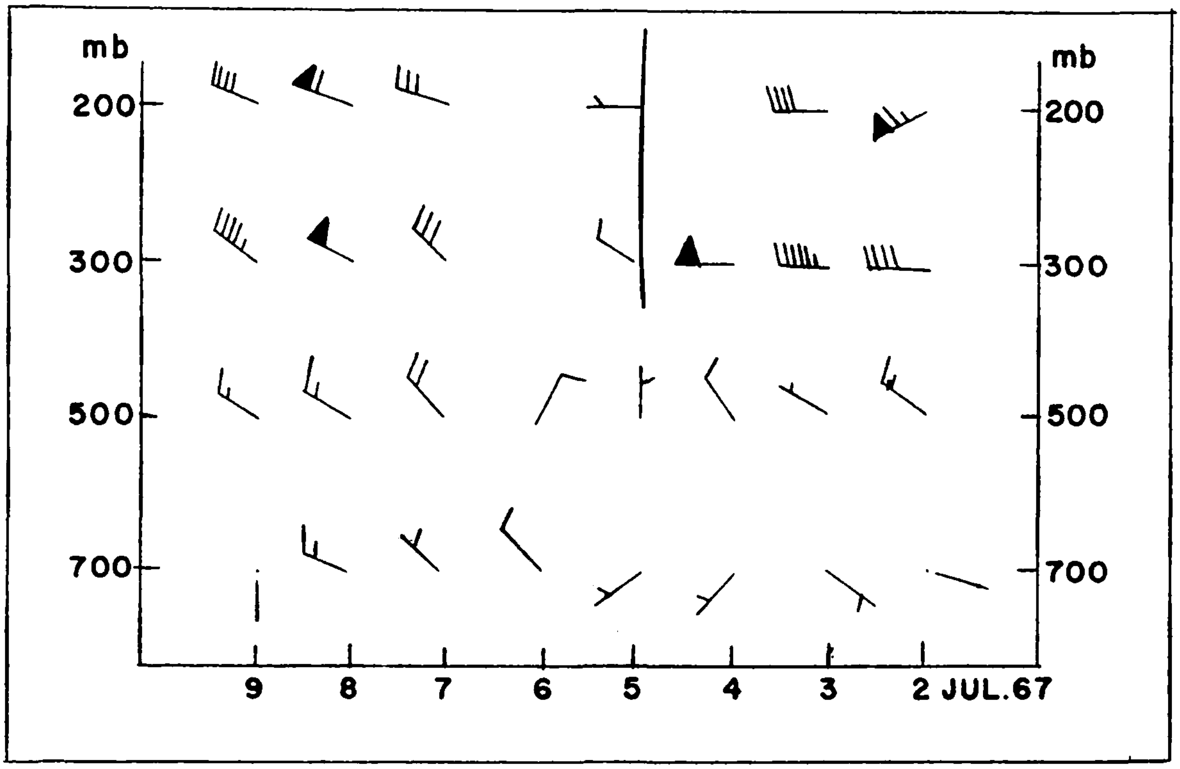
FIG. 8·15 UPPER WINDS 10 JUL. 67 00 GMT



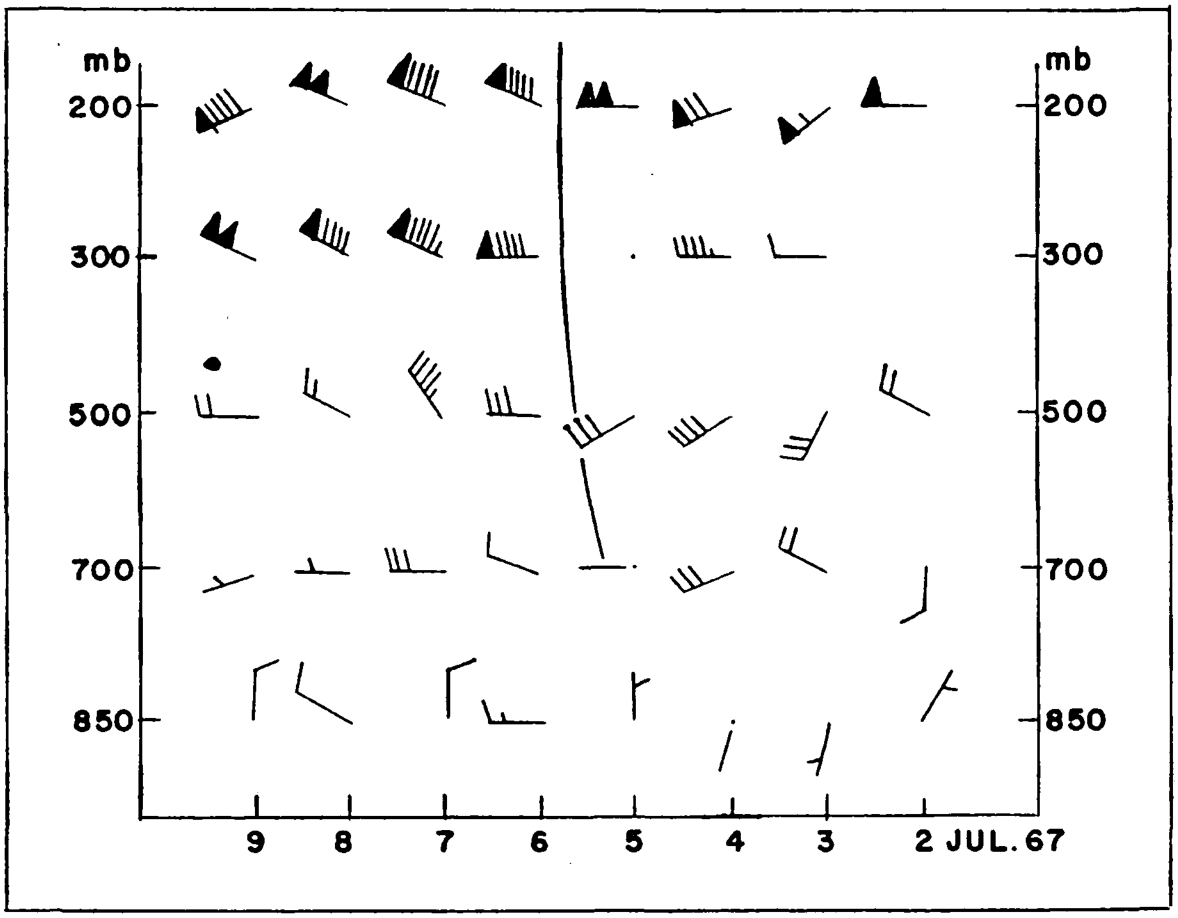
Note :- Broken shaft indicates 12 GMT data ﹏ Ridge line

FIG. 8·16 VERTICAL TIME SECTION 2–9 JUL.67 12 GMT

(a) SRINAGAR



(b) TASHKENT



——— Trough line

FIG. 8·17 SYNOPTIC CHARTS 0300 GMT 22 JUL. 67

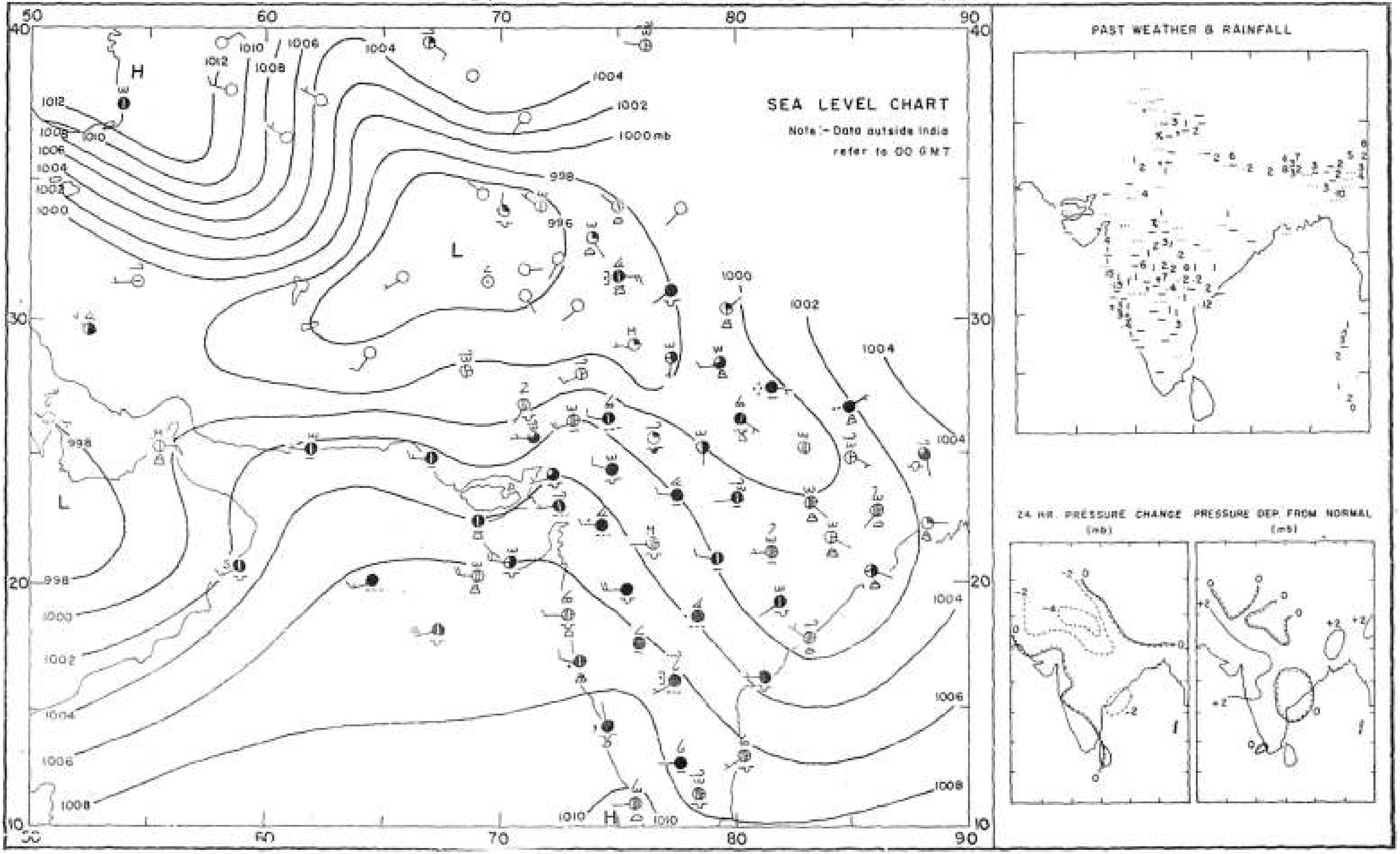


FIG. 8·18 UPPER WINDS 22 JUL 67 00 GMT

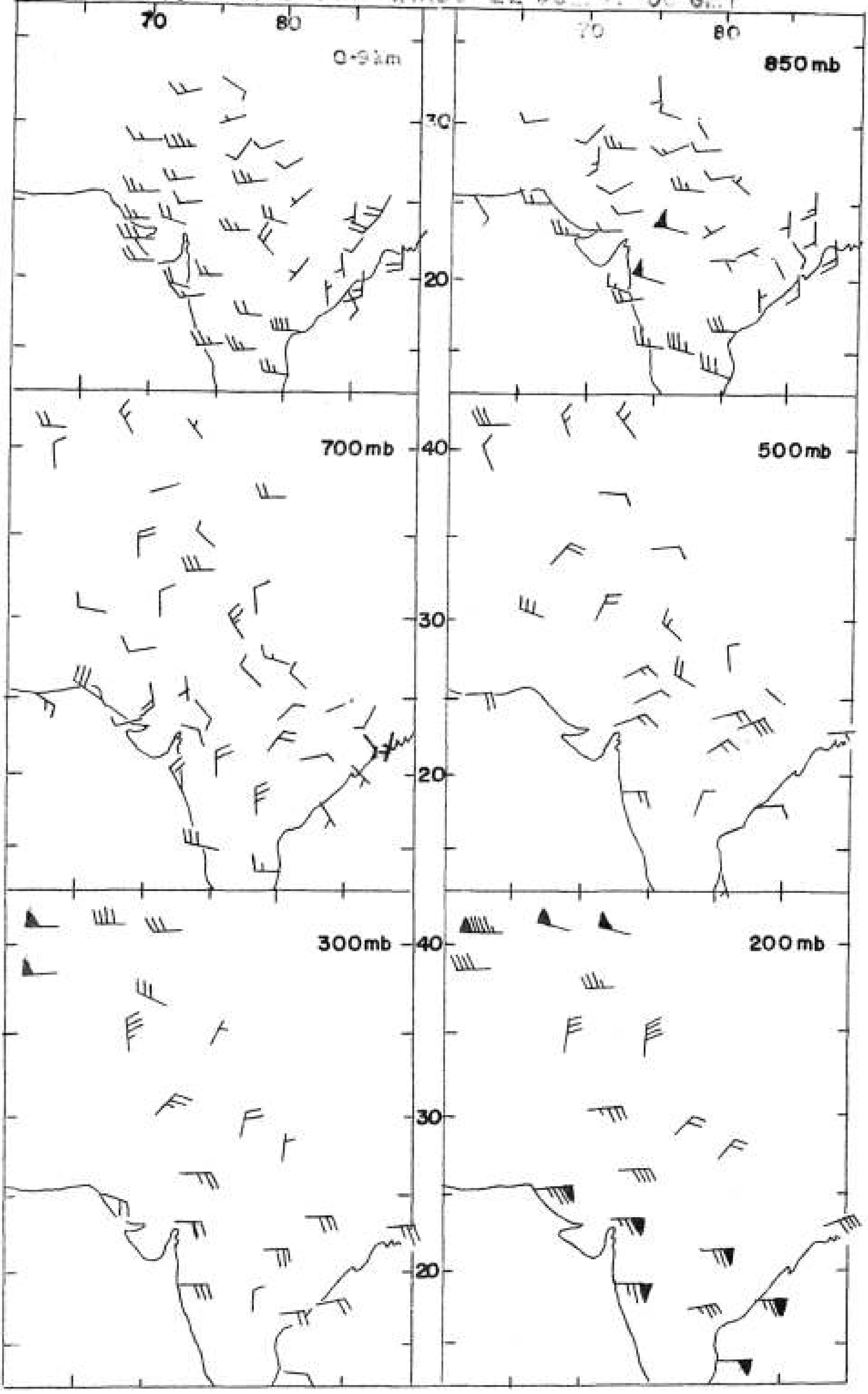


FIG. 9·1 SYNOPTIC CHARTS 0300 GMT 27 JUL. 87

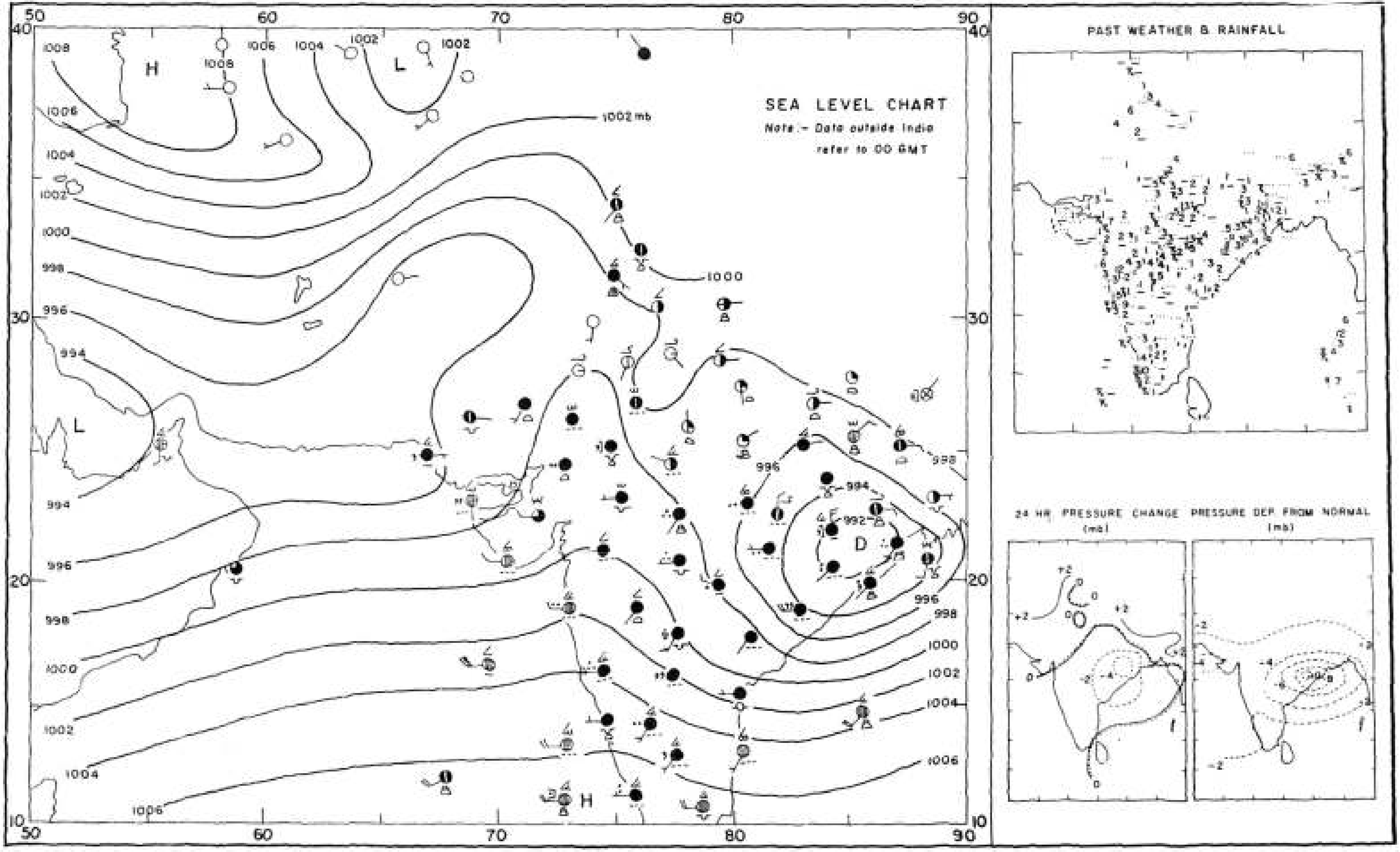
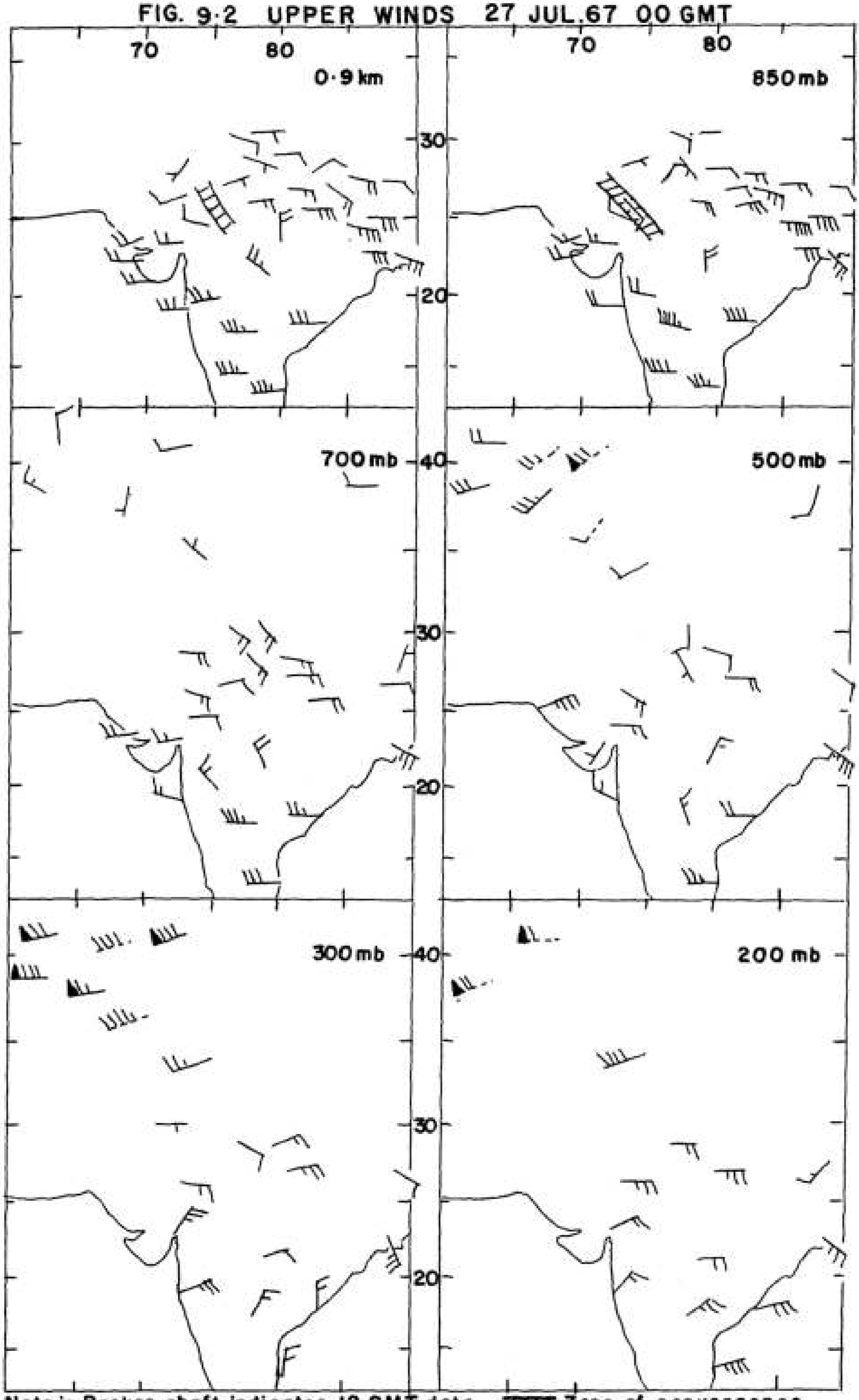


FIG. 9·2 UPPER WINDS 27 JUL.67 00 GMT



Note :- Broken shaft indicates 12 GMT data ZZZZ Zone of convergence

FIG. 9·3 SYNOPTIC CHARTS 0300 GMT 28 JUL 67

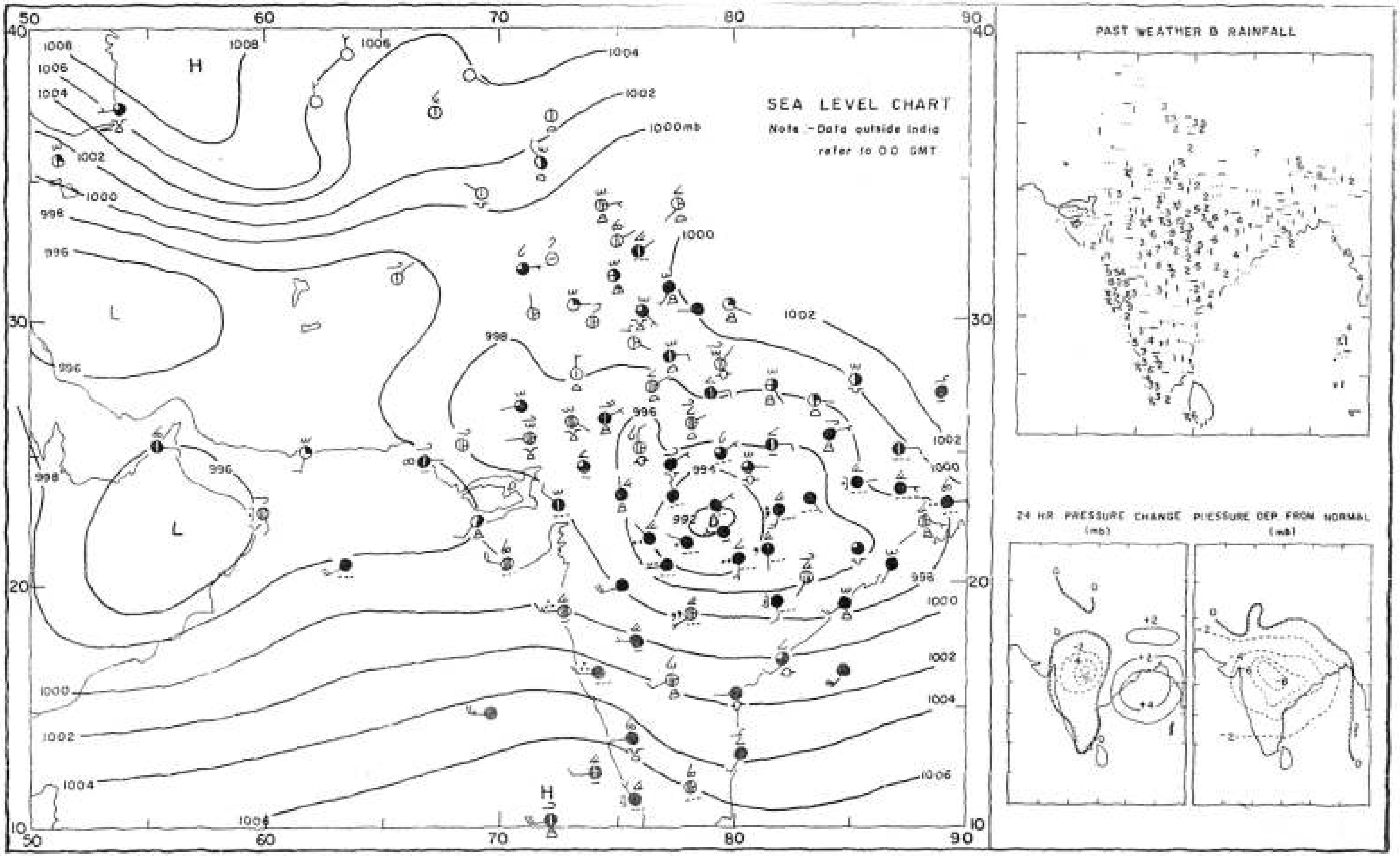


FIG. 9·4

NIMBUS - 2

28 JUL. 67

ORBIT 5844

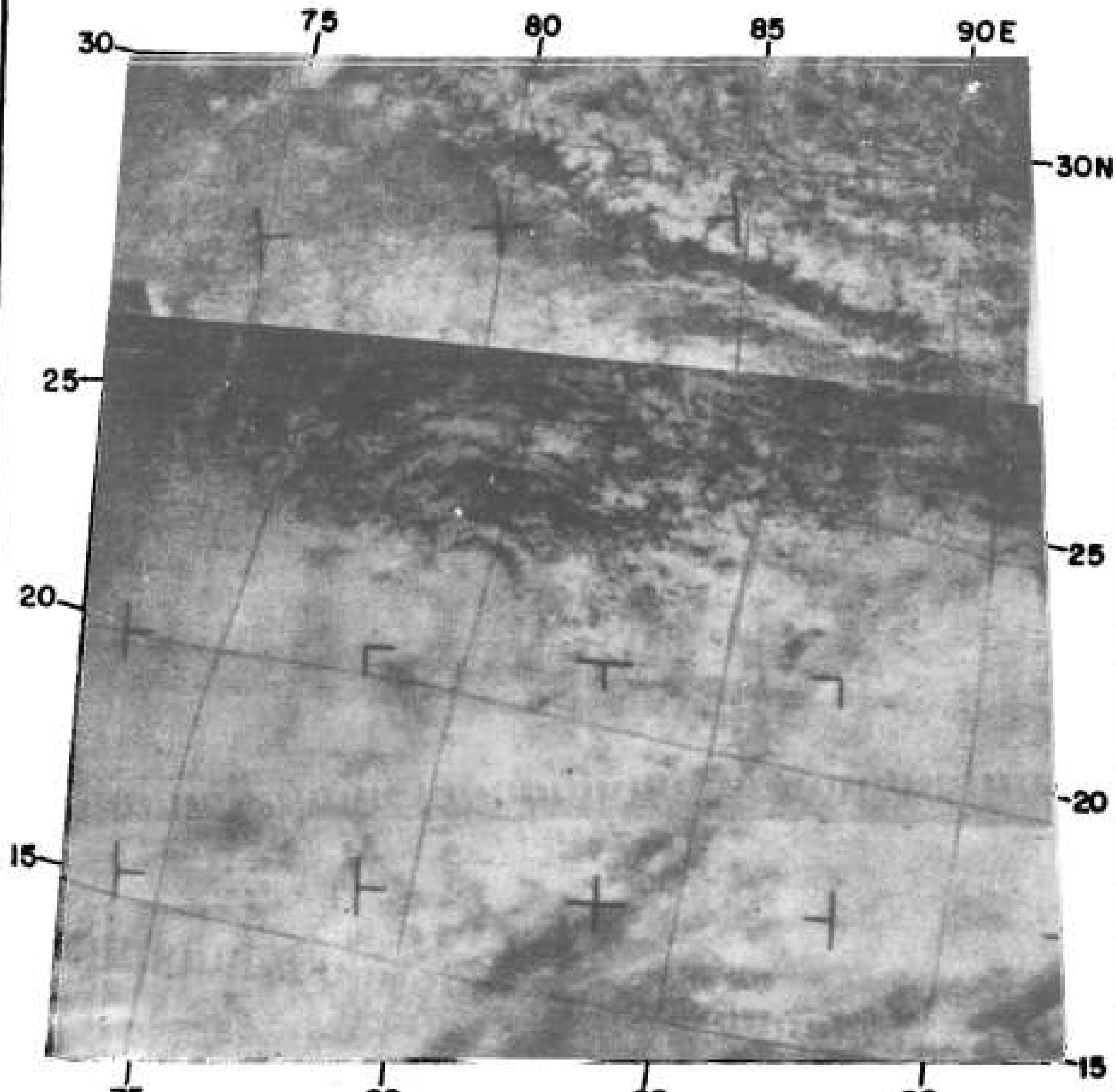


FIG. 9·5 SYNOPTIC CHARTS 0300 GMT

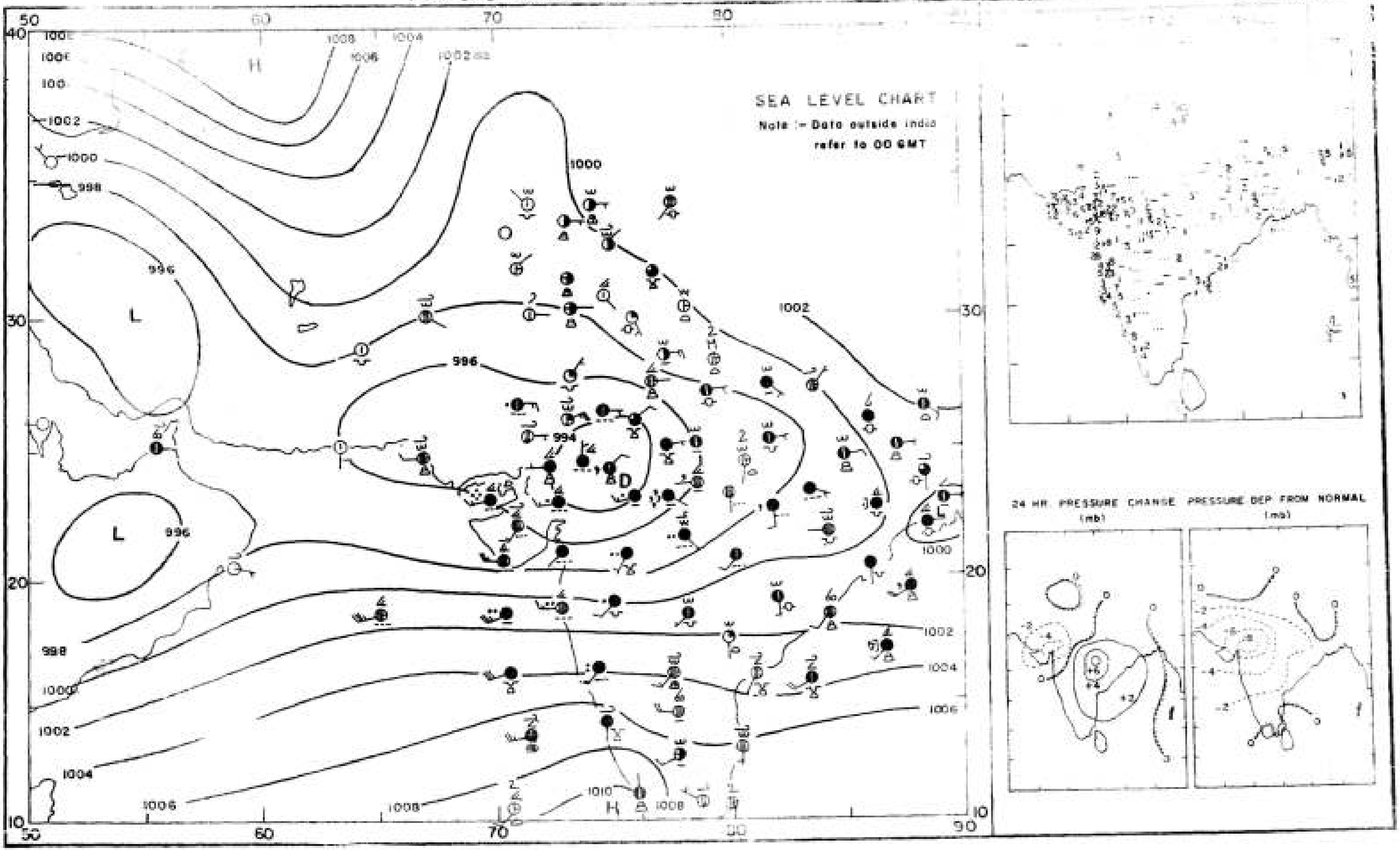
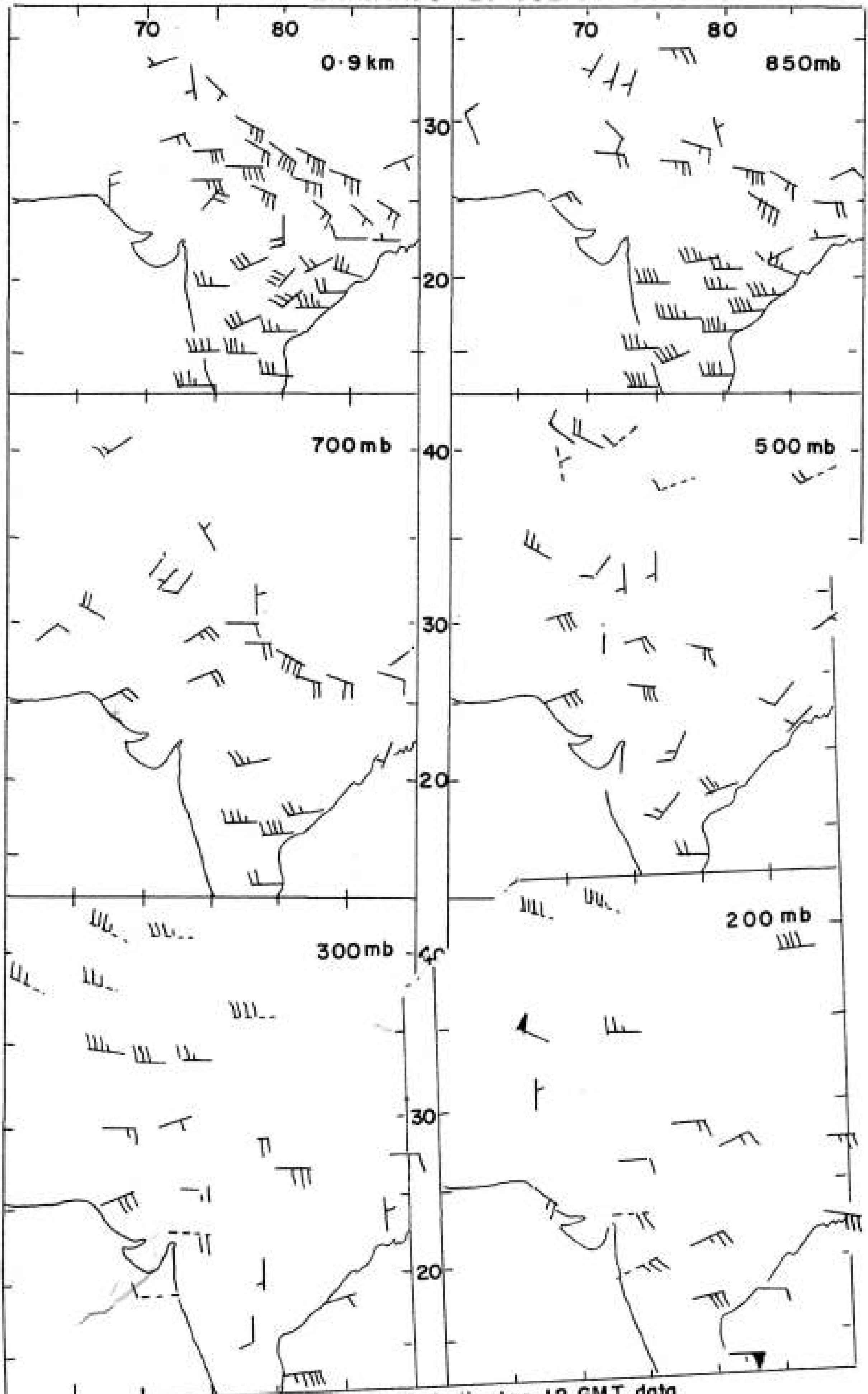


FIG. 9·6 UPPER WINDS 29 JUL. 67 00 GMT



Note :- Broken shaft indicates 12 GMT data

FIG. 9·7 UPPER AIR CHART 28 JUL. 67 00 GMT 300 mb

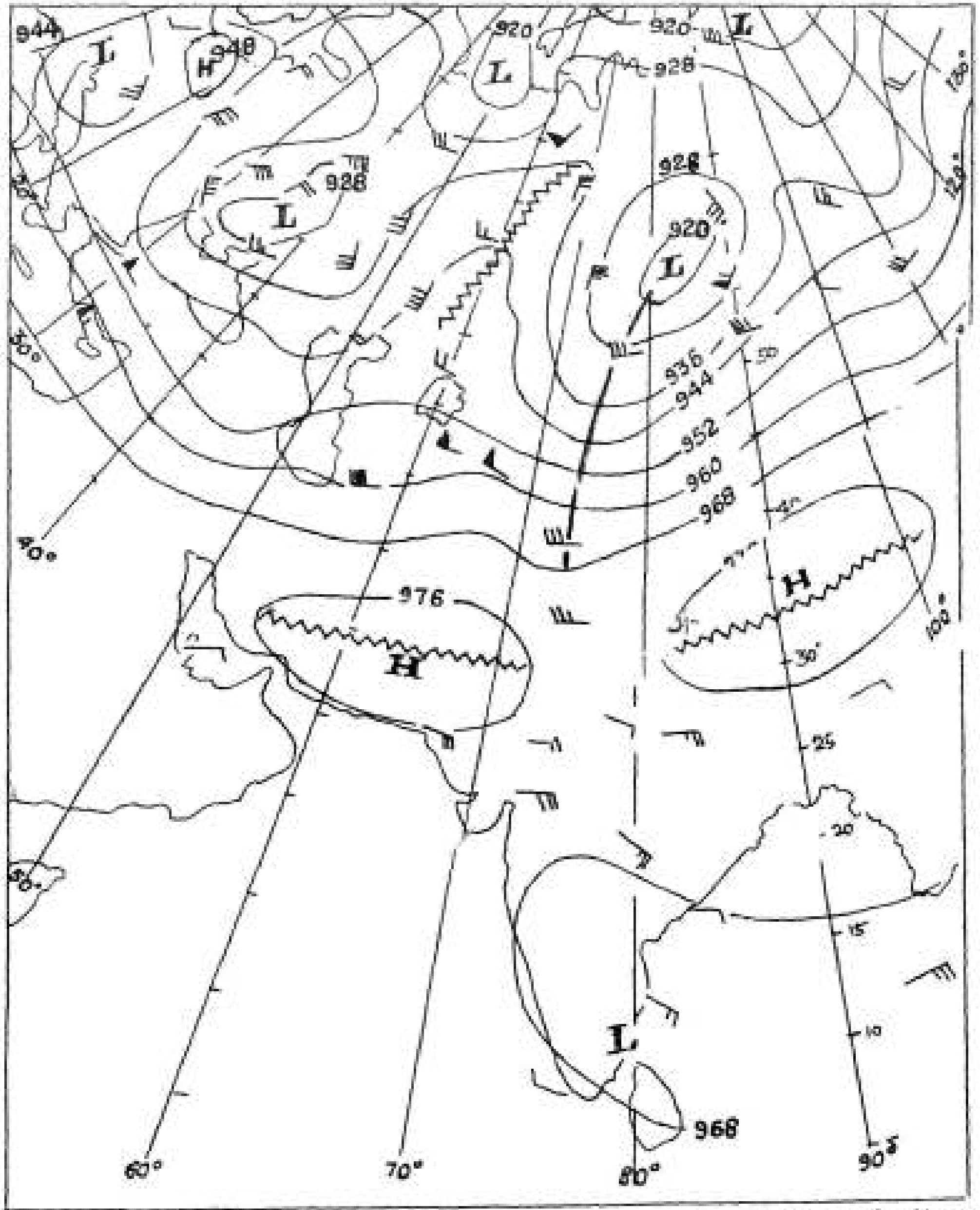
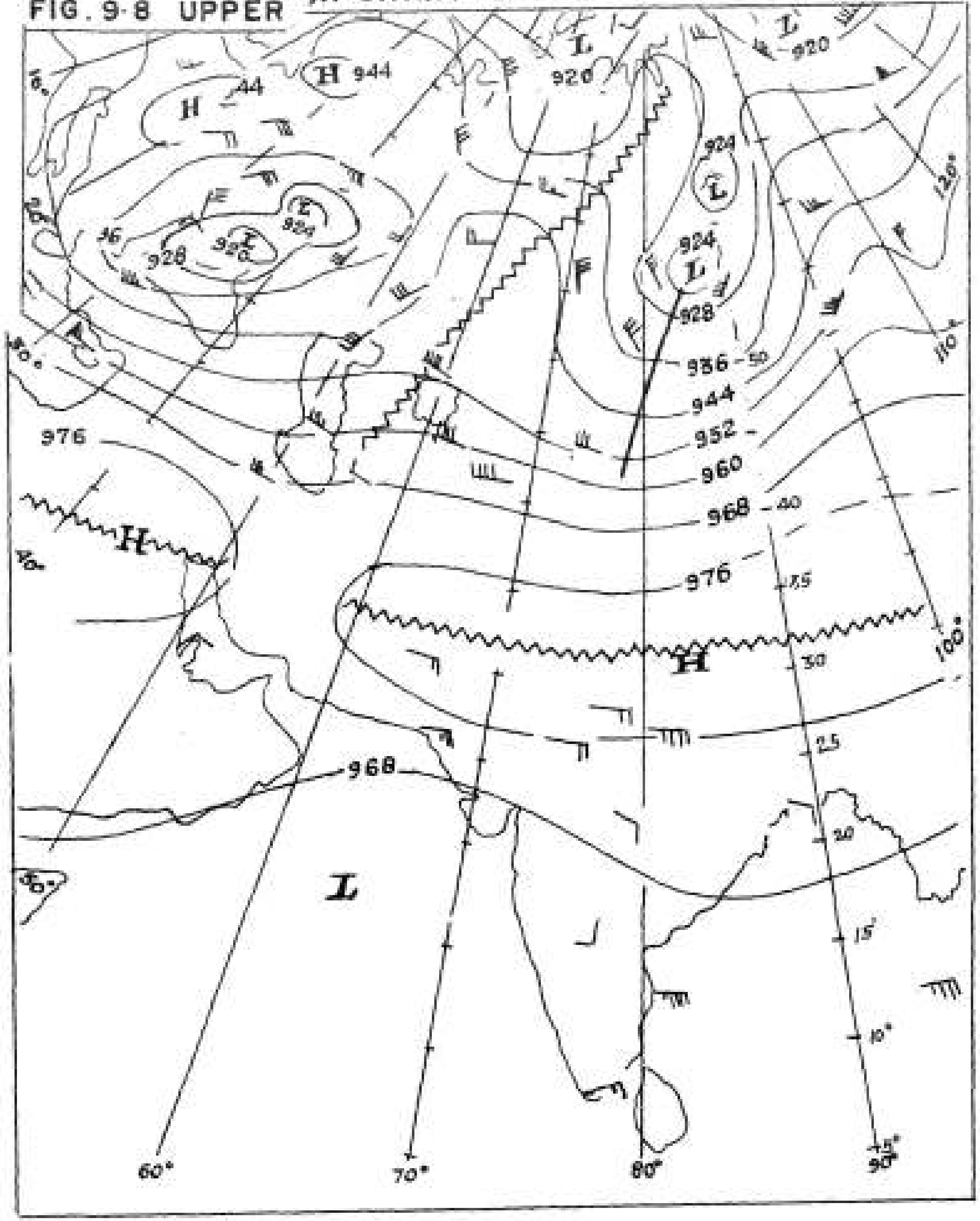


FIG. 9·8 UPPER AIR CHART 29 JUL. 67 00 GMT 300mb



—— Trough line   ∿∿∿ Ridge line

FIG.9·9

ESSA 2

29 JUL. 67

ORBIT 6540, 6539

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