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FORECASTING MANUAL

PART III

DISCUSSION OF TYPICAL SYNOPTIC WEATHER SITUATIONS

3·8 : SOUTHWEST MONSOON - TYPICAL SITUATIONS OVER KERALA AND ARABIAN SEA ISLANDS

BY

V. SRINIVASAN, S. MUKHERJI AND K. RAMAMURTHY

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FORECASTING MANUAL

Part III - Discussion of Typical Synoptic Situations

3.8 Southwest Monsoon - Typical Situations over Kerala and Arabian Sea Islands

by

V. Srinivasan, S. Mukherji and K. Ramamurthy

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1. Introduction

In this report we propose to discuss typical synoptic situations over Kerala and the Arabian Sea Islands during the southwest monsoon. The report begins with a review of the meteorological conditions over the area during the southwest monsoon, and then proceeds to survey the synoptic situations affecting these two meteorological sub-divisions. It is followed by a discussion of a few instances of active and weak monsoon conditions.

2. Southwest Monsoon in Kerala and Arabian Sea Islands

2.1 Advance and Withdrawal

2.1.1 The advance of southwest monsoon into Kerala and Arabian Sea Islands has been extensively dealt with in FMU Rep. No. IV-18.1; consequently, it will not be repeated here. The withdrawal of the southwest monsoon from Kerala is not usually mentioned in the departmental weather reports, as the rainfall continues over south Peninsula till the end of December. There is no clear cut demarcation between the withdrawal of the southwest monsoon, and the onset of the northeast monsoon; at least it is not so well defined as the onset of the southwest monsoon.

2.2 Rainfall

2.2.1 The mean monthly rainfall and number of rainy days in Kerala and Arabian Sea Islands are given in Table I. The rainfall distribution over Kerala, month by month during the monsoon season is shown in Fig. 2.1.

TABLE - I

Mean monthly rainfall (in cms) and number of rainy days*

	June	July	August	Sept.	Season's Total	Annual
Kerala						
Rainfall (in cm.)	67	68	42	24	201	300
Rainfall as percentage of season's total	33	34	21	12	67**	
No. of rainy days	23	24	19	13	79	126
Arabian Sea Islands						
a) Rainfall (in cms.)	35	27	21	15	98	157
b) Rainfall as percentage of season's total	36	27	21	16	62**	
c) No. of rainy days	17	15	12	10	54	87

*From Memoirs of the India Meteorological Department Vol.XXXI Part III
**Season's total as percentage of Annual Rainfall

2.2.2 Table I brings out the following features:-

i) The southwest monsoon season is the principal rainy period in Kerala and the Arabian Sea Islands. The rainfall during this season is about two-thirds of the total annual rainfall. However, unlike other meteorological sub-divisions further north along the west coast (i.e. coastal Mysore and Konkan), post-monsoon and pre-monsoon rainfall in Kerala and the Arabian Sea Islands forms a significant part of the annual total.

ii) The major part of the monsoon rainfall is in June and July. Rainfall of August and September put together accounts for only a third of the season's total.

iii) In Kerala, June and July are equally rainy, but in the Arabian Sea Islands the rainiest month is June.

iv) Within the sub-division of Kerala, the northern parts get considerably more rainfall than the southern parts; the north-south gradient of rainfall is a well-marked feature of the rainfall distribution in the months of June, July and August. In July, the southernmost parts get only about a quarter of the rainfall that occurs in the northernmost districts.

v) Arabian Sea Islands get considerably less rainfall than Kerala. Similar to Kerala, the northern Islands get more rainfall than the southern Islands in June and July.

2.2.3 The co-efficient of variation of rainfall in Kerala for the southwest monsoon season is small (20 to 30%), though in individual months the values are high. The variability of rainfall is considerably more in the second half of the monsoon than in the earlier half.

2.3 Heavy rainfall

2.3.1 Heavy rainfall occurs in Kerala and Arabian Sea Islands during the southwest monsoon season. But, these falls are more frequent in the northern parts than in the southern parts of Kerala. An analysis of heavy rainfall data have been made for Mangalore, Trivandrum and Minicoy by some workers. Considering Mangalore to be representative of northern parts of Kerala, and Trivandrum as representative of the southern Kerala, it is seen that

i) In the northern parts of Kerala, heavy rains occur mainly in June and July, the number of occasions decreasing rapidly in August; in September, it is negligible

ii) In the southern parts, the heavy rainfall is mainly in June, the frequency decreasing considerably in July and August. There is again an increase in September.

iii) In southern group of Arabian Sea Islands, the frequency is maximum in June, decreasing to about half the number of occasions in the subsequent months.

iv) The frequency of heavy rain is also considerably more in the northern parts of Kerala and Arabian Sea Islands compared to the southern parts.

v) Rainfall amounts are also heavier in the northern parts of Kerala than the southern parts. The heaviest falls during the monsoon season have been of the order of 20-25 cm in the northern parts, and 15-20 cm in the southern parts of Kerala and Arabian Sea Islands. Incidentally, when we consider the entire west coast, we find the magnitude of heavy falls is higher in the northern parts (i.e. Konkan and south Gujarat Region), the amount gradually decreasing as one proceeds south towards south Kerala.

2.3.2 Heavy rainfall is common in the first half of the monsoon season along the whole of the west coast. In respect of Kerala and Arabian Sea Islands, the season for heavy rains sometimes begins even in May, in association with the onset and advance of the monsoon, and pre-monsoon low pressure systems affecting the area. During May, these sub-divisions get even higher amounts of rainfall than in the main monsoon months of June to September. It may also be mentioned that the frequency of heavy falls in South Kerala in May is slightly greater than in June.

2.3.3 The difference between northern and southern parts of Kerala and Arabian Sea Islands in the amounts of rainfall and frequency of heavy rain is primarily due to

i) the anticyclonic wind flow in the lower tropospheric levels over the southern parts; and

ii) the presence of off-shore troughs on more number of occasions in the northern parts. As a matter of fact the troughs form generally along coastal Mysore, with their southern and extending to off north Kerala coast.

2.4 Monsoon activity

2.4.1 Rain spells usually last upto about 3 to 4 days in Kerala, although spells of 1 to 2 days are most common. Spells extending for a week to ten days also occur on about 30% of occasions, such long spells being more frequent in July than in the other three months. In the Arabian Sea Islands also, rain spells of 1–2 days are most frequent. Spells exceeding 4 days duration are much less frequent. Longer spells of duration of one week to ten days also occur, but their frequency is even less than in Kerala.

2.4.2 Weak monsoon conditions usually last in Kerala for one or two days or at most upto 3 days. Longer spells occur only occasionally. Weak monsoon in Arabian Sea Islands usually lasts upto 2 or 3 days. Occasionally, it may persist even upto a week or ten days in Kerala and the Arabian Sea Islands, such long spells being slightly more in Arabian Sea Islands than in Kerala.

2.4.3 The day-to-day monsoon activity* in Kerala and Arabian Sea Islands has been analysed for the monsoon months of the 5 years, 1966–1970. The results are given in Table II** in the form of % frequency of occurrence of different degrees of monsoon activity. These are also given in Fig. 2.2 in the form of histograms

TABLE – II

Percentage frequency of occurrence of Vigorous*/Strong, Normal and Weak monsoon days over Kerala and Arabian Sea Islands
(Based on data June to September of 1966–70)

Sub-division	June					July					August					September					June to Sept.				
	V	S	N	W	D	V	S	N	W	D	V	S	N	W	D	V	S	N	W	D	V	S	N	W	D
Kerala	0	13	48	35	4	2	17	52	28	1	0	3	57	23	17	3	2	47	23	25	1	9	51	27	12
Arabian Sea Islands	0	5	39	39	17	2	6	43	31	18	1	3	35	40	21	1	3	40	24	32	1	4	37	36	22

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

* See Appendix I for definition of the terms used.

* In order to bring out the day-to-day variations in rainfall in the Arabian Sea Islands, the monsoon activity in the Arabian Sea Islands has been included in Table II. However, it is not the departmental convention to describe the rainfall in Arabian Sea Islands in terms of the criteria for monsoon activity laid down for land areas.

2.4.4 The main features brought out by the Table are:-

i) Kerala

(a) Strong to vigorous monsoon conditions occur in Kerala on about 15% to 20% of the occasions in the first two months of the season. In the second half of the season, active to vigorous monsoon conditions rapidly decrease and they become rare (only about 5% of the occasions). Compared to Konkan and Coastal Mysore, the frequency of strong to vigorous monsoon conditions is less in Kerala.

(b) Weak monsoon is least frequent in July (about 30%).

(c) Normal monsoon is a common feature of weather in Kerala (occurring on about 50% to 60% of the occasions); weak monsoon conditions prevail on about 40% to 50% of the occasions except in July

ii) Arabian Sea Islands

(a) Strong to vigorous monsoon is a rare feature of the weather in the Arabian Sea Islands, occurring hardly on 5% of the occasions

(b) Weak monsoon is the common feature of weather, occurring on about 50% to 60% of the occasions

(c) Normal monsoon occurs on about 40% of the occasions.

(d) Whereas in Kerala there is a sharp decrease in monsoon activity (i.e. number of occasions of active to vigorous monsoon) in the second half of the season, over the Arabian Sea Islands there is only a slight decrease in the second half of the monsoon season.

2.5 Pressure

The pressure field over Kerala and Arabian Sea Islands during the monsoon season is characterised by a weak gradient, with higher pressure in the south and lower pressure in the north. The only synoptic feature noticed in the pressure field over Kerala and Arabian Sea Islands is the formation of weak troughs off the coast, which bring about an increase in the strength of the monsoon. During weak monsoon conditions, either the pressure gradient is very weak and diffuse or a ridge is present over the area.

2.6 Thunderstorms

Thunderstorms are most frequent in Kerala in the pre-monsoon months of April and May, the frequency being of the order of 15 days in a month. Thunderstorm activity progressively decreases after the monsoon establishes itself, and reaches a minimum in August. Subsequently, there is a slight increase in thunderstorm activity towards the end of the season. In the Arabian Sea Islands a similar trend is noticed, although the frequency of occurrence is considerably less than in Kerala.

2.7 Squalls

Squalls are characteristic of rainfall along the west coast. Along the Kerala coast they occur in June and July, the frequency being considerably less in the second half of the season. The squalls are mostly from a direction west to northnorthwest and generally do not reach more than 40 mph. On rare occasions they may go upto 60 mph.

2.8 Upper winds

2.8.1 The upper winds over Trivandrum are representative of the wind regime over Kerala and the Arabian Sea Islands. The mean upper winds in respect of this station for the months of May to October are given in Fig.2.3. The upper wind structure over Kerala and Arabian Sea Islands shows a deep belt of westerlies extending upto the mid-troposphere. Further aloft, there is an easterly flow extending into the stratosphere with a transition layer of about 2 km thickness between 5 and 7 km. Both the easterly and the westerly regimes are fairly steady, while in the transition layer, the winds are light and unsteady. The easterlies in the upper troposphere concentrate into a jet with its core near 150 mb. Similarly, the lower tropospheric westerlies also have a core of strong winds near 850 mb.

2.8.2 Extensive literature is available on the upper easterly jet stream, often referred to as the "Tropical Easterly Jet" (T.E.J.); consequently, we shall touch upon it only briefly here. In comparison with the sub-tropical jet, the easterly jet is more diffuse, because the zone of strong winds extends over a wide latitudinal belt. The jet level is near 14.5 km at the latitude of Trivandrum. The latitudinal position of the jet axis varies. In the mean, it is in the latitude belt 7-9°N, except in July when the area of strong winds shows more lateral extension. The mean speed at the core of the jet is of the order of 85 knots. On individual occasions, speeds reach well over 100 knots; on a few occasions it has been observed to reach 150 knots.

2.8.3 The westerly low level jet has a core at 1.5 km, with speeds of the order of 40-60 knots in July. Quite often the jet persists at the same location for a few days. Latitudinal oscillation of the core has also been noticed.

2.8.4 The lower tropospheric wind flow over Kerala and Arabian Sea Islands is often anticyclonic with winds along south Kerala coast showing considerable northerly components. This may be one of the reasons for the decrease of rainfall as one goes from north to south along the west coast. Stronger winds from southwest/west/westnorthwest direction in the lower troposphere are associated with strong monsoon activity, while northwesterlies/northerlies and weaker winds are associated with weak monsoon conditions in Kerala. This will again be discussed further in Sec. 3 dealing with synoptic situations. The lower tropospheric westerlies strengthen, and their depth increases in association with formation of depressions or lows in the Bay of Bengal or troughs or low pressure areas off the west coast. It has also been noticed on an examination of Minicoy upper winds (850 mb level) that an increase in the negative flux of angular momentum was closely associated with the formation of a depression in the Head Bay of Bengal. Sometimes when the seasonal monsoon trough is over a relatively more southerly position also, there is a strengthening and deepening of the westerlies.

2.9 Upper air temperatures and humidity

2.9.1 The mean monthly tephigrams of Trivandrum for the pre-monsoon and monsoon months show the following features (Fig. 2.4):-

i) there is a slight cooling of 1-2°C at all levels in June, with the setting in of the monsoon. A further cooling of 2°C takes place in the upper troposphere from June to July;

ii) in the lower troposphere (below 850 mb) there is hardly any increase in moisture content as we proceed from the pre-monsoon to monsoon months; and

iii) considerable increase in moisture takes place between 850 mb and 600 mb even in May. Subsequently, the moisture content remains practically constant throughout the monsoon.

2.9.2 Comparing the mean tephigrams of Bombay and Trivandrum for July (a typical mid-monsoon month) (Fig. 2.5), it is found that there is a certain amount of similarity in the two curves. But,

i) Bombay is warmer than Trivandrum at all levels, the warming being considerable in the upper troposphere (about 6°C at 200 mb);

ii) The moisture content is much higher at Bombay than Trivandrum at all levels

2.9.3 The mean tephigrams of Trivandrum for days of strong to vigorous, normal and weak monsoon conditions are given in Fig. 2.6. It is seen that:

i) on strong to vigorous monsoon days, the air has a lapse rate very nearly equal to saturated adiabatic (5.5°C per km) with a high degree of saturation extending to the mid-troposphere (no wet bulb temperature data are available above 550 mb);

ii) on weak monsoon days, the air is moist upto 850 mb. Above this level, there is rapid decrease of moisture and a slight increase in stability;

iii) normal monsoon conditions show characteristic features in between strong and weak days; and

iv) on dry days, the air becomes somewhat dry, even below 850 mb.

2.9.4 Studies on convection have shown that high relative humidity through a deep layer is "at least as important as a steep lapse rate" in the development of clouds. The higher humidity in lower and mid-tropospheric levels during the active to vigorous monsoon days favours the build up of tall clouds as well as thick middle clouds while the convergence produced by the synoptic system provides the necessary vertical velocity to maintain the growth of the clouds. On the other hand, the drying up of the air above 850 mb level during the weak monsoon and the absence of synoptic scale disturbance, both contribute to lack of weather.

2.9.5 The tephigrams of Trivandrum for typical individual days of strong, normal and weak monsoon activity in Kerala are given in Figs. 2.7(a) to 2.7(c).

3. Survey of Synoptic Systems Affecting Kerala and Arabian Sea Islands

3.1 The features noticed on the synoptic and upper air charts during days of increased monsoon activity in Kerala and Arabian Sea Islands are:

i) A trough of low pressure in the surface and in the upper air, below 0.9 km;

ii) Strong lower tropospheric westerlies, with slight backing to westerly to westsouthwesterly direction;

iii) A trough, or a cyclonic circulation in the mid-troposphere; and

iv) Low pressure systems moving westwards across south Peninsula. These systems may be seen both at the surface and in the upper air, through a fairly deep layer.

3.2 It is usually noticed that a combination of two or more of the features (i) , (ii) and (iii), is present on days of active monsoon. The following Table (Table III) gives the percentage frequency of occurrence of the above three types of synoptic situations on active to vigorous monsoon days in Kerala either alone or in combination.

TABLE - III

Synoptic systems associated with active monsoon days in Kerala
(Based on data of June to August of years 1966-70)

S.No.		Synoptic Situation	No. of occasions	Percentage
(a)	1.	Surface or lower tropospheric trough alone present	4	8
	2.	Strong winds in lower troposphere alone present	3	6
	3.	Mid-tropospheric trough/low alone present	2	4
	4.	Surface trough and strong winds	22	42
	*5.	Surface trough and mid-tropospheric trough/low	13	25
	6.	Trough, strong winds and mid-tropospheric trough/ low - all present	8	15
		Total ...	52	
(b)		Total No. of occasions in which the above were present either alone or associated with other systems		
	1.	Trough at surface	47	90
	2.	Strong winds	33	63
	3.	Middle tropospheric trough/low	23	44

* Low pressure systems moving westwards across the Peninsula are very few in number in July and August. In this Table, such systems have been included under item No. 5.

1. Kerala:

The table shows that it is predominently the presence of a trough off the coast, (at sea level and in the lower levels) in combination with strong winds in the lower troposphere that causes active monsoon conditions. The next significant feature is the presence of a trough on the surface chart along with a trough or a cyclonic circulation in the mid-troposphere.

2. Arabian Sea Islands:

The monsoon activity in Arabian Sea Islands is, in general, less than in Kerala. The number of occasions of heavy rain is also small. Hence, a frequency distribution similar to Table III, is not presented. However, an examination of working charts shows that:

i) The presence of a surface trough with a cyclonic circulation/trough in the mid-troposphere is the most frequent synoptic situation leading to active monsoon.

ii) Unlike Kerala, strong winds do not appear to be associated with active monsoon in any significant manner. However, backing of winds to westerly or westsouthwesterly direction is associated with increased rainfall.

iii) Low pressure areas moving across the south Peninsula also cause active monsoon in Arabian Sea Islands. Some features of the various synoptic situations that cause monsoon activity will be discussed in the following paragraphs.

3.3 Trough of low pressure

3.3.1 The presence of a trough of low pressure off Kerala-Mysore coasts is a very favourable and common situation for active monsoon conditions in Kerala. The trough is mainly off coastal Mysore, with its southern portion extending to North Kerala. Usually it does not extend further south. Occasionally, a small cyclonic vortex may be embedded in the trough, when very heavy rain usually occurs in the immediate neighbourhood of the vortex. The trough may extend in the upper air also - at best upto about 0.9 km. On some occasions, instead of a trough, there may be only weak west winds present in the upper air over the region corresponding to the location of surface trough with stronger west winds just south of it, resulting in a strong cyclonic shear. More often, the upper winds are quite strong over the area. A light southerly wind or a light wind with an easterly component along the coast on the surface chart and in the lower levels is a very significant observation in locating the trough on the charts.

3.3.2 In view of the small pressure gradient over this area and the shallowness of the trough, it may be useful to draw the isobars at one mb interval. Another helpful guide will be to give sufficient weightage even to small pressure falls over the area. Negative pressure departures are another useful indication. These troughs are often seen better in the morning or mid-night charts than in the afternoon or evening charts.

3.4 Strong winds

3.4.1 Strong lower tropospheric winds, with or without a trough at the surface, is another feature associated with active monsoon in Kerala. The number of occasions of strong winds in the lower troposphere with a trough, is very much more than the number of occasions of a trough without strong winds. On occasions of strong monsoon activity in Kerala, the wind speeds are 30 kts or more in the lower troposphere, particularly above 0.9 km. The strong winds extend upto 2.1 km and sometimes even upto 3.1 km. Wind speeds of 45-50 kts have also been noticed in these levels on some occasions of strong monsoon.

3.4.2 Such strengthening of winds over the south Peninsula may occur in association with the formation of a low or a depression in the Bay, or the shi of the monsoon trough to more southerly position over the country.

3.4.3 An analysis of the wind direction and speed at 850 mb over Trivandrum and the monsoon activity in Kerala was made with the data for 5 years (1966-70). The results are given in Table IV.

TABLE – IV

(a) Percentage frequency of wind speeds of Trivandrum at 1.5 km (850 mb) (00Z) associated with monsoon activity in Kerala

Wind speed	No. of cases	Percentage of occasions of monsoon activity			
		Active	Normal	Weak	Dry
9 m.p.s.	53	4	36	47	13
9–12 m.p.s.	148	5	46	39	10
12–15 m.p.s.	143	12	55	25	8
> 15 m.p.s.	105	22	63	14	1

(b) Percentage frequency of wind directions at Trivandrum (1.5 km asl 850 mb) (00Z) associated with monsoon activity in Kerala

Wind Direction	No. of cases	% frequency of occasions			
		Active	Normal	Weak	Dry
240–270	32	25	55	20	0
271/290	147	20	54	22	4
291/310	215	4	56	33	7
311 330	44	4	28	43	25

Table brings out the following features:-

i) The monsoon activity increases as the westwind component increases. On 75% of the occasions of wind with westerly component of 25 knots or more, the monsoon was strong to normal. Westerly component of less than 18 knots is predominently (60%) associated with a weak monsoon.

i) On 75% to 80% of days with wind direction between 240° and 290°, monsoon was active to normal in Kerala. With winds from a direction to the north of 290°, activity decreased; when the wind direction was 310–330°, monsoon was predominently weak. Thus, in general, a backing of the winds from the seasonal mean direction (300°) is favourable for rainfall while a veering reduces monsoon activity.

iii) In the case of Arabian Sea Islands, strong lower tropospheric winds are not significantly associated with an active monsoon.

iv) Localised convergence or divergence may also occur due to speed variations in the general westerly wind field leading to variations in the rainfall distribution but such speed variations are short-lived and may not be usually traceable from chart to chart.

3.5 Middle tropospheric cyclonic circulations or troughs

3.5.1 These are found in the layer between 600 mb and 400 mb (4.5 and 7.6 km). No doubt this layer is one of transition from lower tropospheric westerlies to upper tropospheric easterlies, and consequently a region of weak and variable winds in which it is difficult to trace a circulation or trough. However, when a definite mid-tropospheric circulation is present, we find it in more than one or two levels over the same area. They also persist for 2 to 3 days. Their movement, formation and dissipation are difficult to prognosticate In view of weak contour gradients in low latitudes, and instrumental errors, these lows may not be always discernible in the contour field. One has to lean heavily on wind analysis for locating the mid-tropospheric disturbance.

3.5.2 The system may either be seen as a complete closed circulation or only as a trough.

3.5.3 On occasions of mid-tropospheric circulation a trough is also usually noticed on the sea level chart.

3.5.4 Mid-tropospheric circulations are more common in June at the time of onset and advance of the monsoon along the west coast. They are much less frequent later in the season, while they are likely on occasions of "break" monsoon or "weak" monsoon over the country.

3.5.5 In the Arabian Sea Islands, the mid-tropospheric circulation with a trough in the surface is the predominent synoptic feature on days of active monsoon

3.6 Low pressure systems moving westwards across the south Peninsula.

3.6.1 This type of synoptic system is noticed either during a 'break' period, or at the end of the monsoon season. They usually extend through a fairly deep layer in the troposphere, sometimes from sea level upwards to the mid-tropospheric level. They generally travel from the Bay of Bengal to the Arabian Sea across the south Peninsula. The revival of the monsoon takes place, if after emerging into the Arabian Sea, these systems move northwestwards or northwards along the west coast, taking up the monsoon current with them. These systems have been discussed and illustrated in detail in FMU Rep. No. IV-18.3 on 'break' monsoon. The onset of the monsoon in Kerala as well as revival of monsoon after a recession* of the monsoon rains are also associated with low pressure systems (surface and or upper air) moving across the south Peninsula or developing locally in southeast Arabian Sea. These systems have been discussed in detail in FMU Rep. No. IV-18.2 "Synoptic Features associated with Onset of SW monsoon over Kerala". In June, when these systems are associated with the onset of the monsoon, some of them may intensify into storms/depressions in the Arabian Sea. However, in the other monsoon months, they do not intensify, but continue to travel as a low pressure area or an upper air cyclonic circulation till they dissipate.

4. Weak Monsoon

4.1 Weak monsoon conditions prevail in Kerala and Arabian Sea Islands when none of the synoptic features discussed in para 3 are present. The typical features noticed on weak monsoon days are:

i) A North-South oriented ridge in the surface and in the lower troposphere over Laccadives-Maldives, with pronounced north-westerly/northerly winds along Kerala coast.

ii) Strong anticyclonic shear in the lower tropospheric levels with strong

* For a definition of "recession of monsoon rain", see FMU Rep.No. IV-18.1 para 11.2 (v).

winds to the north of Kerala and weaker winds to the south.

iii)A weak to moderate lower tropospheric windfield over Kerala and Arabian Sea Islands without any low pressure system in the neighbourhood. The winds along Kerala coast may be northwesterlies/northerlies on such occasions also.

4.2 Over the Arabian Sea, except for surface observations from ships, synoptic data are difficult to come by. On many occasions, even ships' data are lacking. At other times, pibal data from Arabian Sea Islands and the Kerala coast may not be available due to rain and low clouds. In such cases, the satellite pictures are of great use for judging the extent and intensity of the system affecting Kerala and Arabian Sea Islands. Similarly, the information regarding moisture content and stability of the atmospheric layers provided by the radiosonde ascents at Trivandrum and Minicoy help the forecaster in predicting the weather over the area.

5. Strong Monsoon – Typical Situations

5.1 Strong monsoon over Kerala with off-shore trough and strong lower tropospheric winds – 3 to 5 July 1968

5.1.1 As pointed out in para 3.3.1, off-shore troughs off Kerala are mostly associated with strong lower tropospheric winds, particularly above 0.9 km. In this section we consider a typical case of the more common type, i.e. those associated with strong lower tropospheric winds.

5.1.2 During the first week of July 1968, there was a spell of monsoon activity in Kerala, associated with a trough of low pressure off the coast and strong lower tropospheric westerlies. The trough was seen only on the surface charts. Due to paucity of upper air data from Mangalore and Cochin during this period, it was not possible to say whether the trough extended into the upper air or not. The synoptic situation from 3 to 5 July, when the monsoon was active in Kerala is discussed in this section.

5.1.3 On the morning of 3 July 1968, a trough of low pressure lay over Laccadives area (Fig. 5.1.1), The lower tropospheric winds over Arabian Sea Islands and the south Peninsula were strong, with speeds reaching upto 50 knots, (the strengthening of winds commenced on 2nd) (Fig. 5.1.2). The westnorthwesterly flow over Arabian Sea Islands and Kerala at very low level (below 1 km) which was present on 2nd, was replaced by southwest/westerlies. As a result of these developments, there was an increase in rainfall in Kerala and the monsoon became active.

5.1.4 By the 4th morning, the trough moved slightly eastwards, and lay off Coastal Mysore and Kerala on the surface chart (Fig. 5.1.3). The lower tropospheric wind field over the Arabian Sea Islands and Kerala continued to be strong (Fig. 5.1.4). The winds over Arabian Sea Islands were consistently westsouthwesterlies below 1.0 km. Moderate to strong westsouthwesterly to westerly flow in the lower troposphere is often an indicator of active monsoon in these areas. The rainfall increased still further in Kerala and a few heavy falls upto 10 cm were recorded. Rainfall also increased in Arabian Sea Islands.

5.1.5 The surface trough off the Kerala-Mysore coast, as well as the strong lower tropospheric westerlies over Arabian Sea Islands and south Peninsula persisted on the 5th. The monsoon continued to be strong in Kerala with all the coastal stations Calicut, Cochin and Alleppey recording heavy rains (9 to 11 cm).

5.1.6 By 6th morning, the surface trough was confined to coastal Mysore and a well-marked ridge established itself off Kerala coast (Fig. 5.1.5). The lower tropospheric upper winds also decreased in speed over south Peninsula (Fig. 5.1.6). As a result, the rainfall activity considerably decreased in Kerala.

5.1.7 The following interesting features may be noted in this case:-

i) The trough of low pressure was seen only on the surface chart and could be delineated by the surface wind and pressure observations. Due to paucity of data, it could not be stated definitely whether the trough extended into the lower troposphere. Forecasters are handicapped by the fact that pilot balloon observations along the coast are not available on such occasions due to rain. Such troughs do not extend so far to the south as to affect the winds over Trivandrum.

ii) The trough along the Kerala coast was replaced by a ridge on the 6th and the rainfall subsequently decreased in Kerala.

iii) In this case, the 24 hr. pressure changes and pressure departures did not indicate any significant feature.

iv) The lower tropospheric winds over Arabian Sea Islands and south Peninsula were strong reaching upto 50 knots. They were also westsouthwesterlies over Arabian Sea Islands below 1.0 km. The backing of the winds in Kerala and Arabian Sea to westerly or westsouthwesterly is generally associated with increased monsoon activity (in this connection refer to Table IV on the analysis of upper winds of Trivandrum).

v) Over Minicoy and extreme south Kerala, there was anticyclonic vorticity generally due to speed variation and to a lesser degree due to anticyclonic curvature of streamlines. Consequently, the rainfall was more in north Kerala than in the south.

vi) During this spell, the strongest winds were generally to the south of Lat. 15°N; towards the end period (6th) winds weakened south of Lat.10°N and the strongest winds were noticed to the north of 15°N. Thus in addition to the ridge off Kerala, the anticyclonic vorticity due to stronger winds to the north of Kerala also contributed to the decrease of rainfall after the 5th.

vii) The upper easterlies over south Peninsula were quite strong during this period, the maximum reaching 100–120 knots.

viii) The APT pictures showed extensive nearly-overcast areas in the east Arabian Sea from the equator to 17°N extending westwards upto 70°E. Ships observations in this area also showed strong westsouthwesterlies (reaching 45 knots) with Cb development, showers and squalls. Although the presence of the trough off the coast could be responsible for the heavy clouding and rain along the west coast and Arabian Sea Islands, it is difficult to account for the extensive cloudiness upto the equator, because of lack of observations.

5.2 A feeble surface trough, strong lower tropospheric winds and a mid-tropospheric circulation present simultaneously and causing active monsoon conditions in Kerala and Arabian Sea Islands – –24 to 27 July 1971

5.2.1 A combination of two or more synoptic features is often noticed on occasions of active monsoon in Kerala. In this section we will discuss a case where a feeble off-shore trough, strong lower tropospheric winds and a mid-tropospheric cyclonic circulation were simultaneously present. This caused active monsoon conditions in Kerala and Arabian Sea Islands.

5.2.2 For about a week, between 20 and 26th July 1971, there was a spell of good rainfall in Kerala and Arabian Sea Islands, with strong monsoon conditions on many days. During this period, the lower tropospheric winds over Arabian Sea Islands and Kerala were strong (sometimes reaching 50 knots). A trough of low pressure was also present off Kerala coast or over the Laccadives Islands on some days. Particularly between 24 and 26th, the activity was quite marked and extended over the Arabian Sea Islands. Moreover, a mid-tropospheric low also moved across the area. Thus, there was the combined influence of the three synoptic features

i) surface trough

ii) strong lower tropospheric winds and

iii) a mid-tropospheric low during the period 24 to 26th

5.2.3 On the morning of 24th, a feeble trough (of small areal extent) lay along and off the north Kerala coast (the trough could be located only with the surface wind and pressure observations of Mangalore and Calicut) Fig. 5.2.1. Pressures were falling over the area, and the negative departures were a maximum there (–3 to –4 mb). The pressure gradient to the south of trough was slightly more than normal. The lower tropospheric winds were strong and there was also weakening of wind strength downstream over Kerala (Fig. 5.2.2). The monsoon was strong to vigorous in Kerala. Rainfall was also widespread in the Arabian Sea Islands, with generally moderate falls.

5.2.4 By 25th morning the feeble trough moved westwards to Laccadives (as may be inferred ~~as may be inferred~~ from the winds and their changes at Agathi and Amini Divi–Amini Divi backing to southsouthwest/light (on 25th) from west/30 kts (on 24th) and Agathi becoming southwest 25 kt on the 25th morning from westnorthwest/15 kts (on 24th) (Fig. 5.2.3). The lower tropospheric winds continued to be strong over the area (Fig. 5.2.4). In the meanwhile, a mid-tropospheric 'low' also came over Laccadives and was seen between 3.6 and 6.0 km asl. Due to lack of upper air data it was not possible to trace the earlier history of the low. The backing of winds at 500 mb over Trivandrum and Minicoy (from north~~northeasterlies~~ to north westerlies) on 24th to westerlies on 25th would suggest that perhaps the low moved across Ceylon from the east. The monsoon continued to be active in Kerala and heavy falls extended to Arabian Sea Islands.

5.2.5 On the 26th, the trough of low pressure persisted over the Laccadives on the sea level chart, although it was slightly less defined. The lower tropospheric winds continued to be strong. The mid-tropospheric cyclonic circulation travelled northnorthwestwards along the coast and was off Coastal Mysore and Konkan.(Fig. 5.2.5). Presumably due to the mid-tropospheric low moving to Coastal Mysore, the rainfall decreased in Kerala and the Arabian Sea Islands; the heavy falls on this day were in south Coastal Mysore.

5.2.6 By the 27th, the feeble surface trough moved to a position off Coastal Mysore (Fig. 5.2.6), while the mid-tropospheric cyclonic circulation became less marked (Fig. 5.2.7). However, strong lower tropospheric westerlies continued. The rainfall further decreased in Kerala and Arabian Sea Islands, although it continued to be fairly widespread.

5.2.7 To sum up, the following significant features of the situation may be noted:-

i) A feeble trough of low pressure of small extent formed off north Kerala coast on 24th; it moved westwards to Laccadives on 25th and subsequently towards Coastal Mysore. The trough could be seen only on the surface chart. The pressure changes and departures on 24th morning when the trough developed off north Kerala coast were significant. Normally such troughs generally develop off Coastal Mysore and south Konkan, and only the southern end of the trough extends to north Kerala. In this ease, however, the main trough was off Kerala and over Laccadives. Consequently, the rainfall was also more in Kerala than in Coastal Mysore and Konkan. Rainfall increased in Coastal Mysore, when the trough (and the mid-tropospheric low) moved northwards.

ii) The lower tropospheric winds were strong (generally 30-35 knots), reaching 40-50 knots on some days. The wind flow was a straight westerly flow over the Laccadives and Kerala. The normal anticyclonic curvature of the flow over south Kerala was not present on these days. Convergence due to weakening of the westerlies downstream was also present on some charts.

iii) The mid-tropospheric low was seen clearly when it moved over to Laccadives and off Kerala on 25th and extended from 3.6 to 6.0 km. It gradually travelled northwards to Konkan and Gujarat during the next two days, weakened and apparently merged into the seasonal circulation over these areas.

iv) The mid-tropospheric low was cold-cored. The tongue of cold air along and off the west coast in the lower troposphere, which is a seasonal feature, became pronounced during this spell.

v) The mid-tropospheric lows form usually in the latitudes of Konkan and Gujarat during such periods. However, when the axis of the monsoon trough moved north, and a 'break' or 'weak' monsoon conditions set in over most of the country, these mid-tropospheric lows travel across the extreme south Peninsula and Laccadives. The present case, however, is a unique one in this respect, ~~respect~~ because the mid-tropospheric system was noticed over Laccadives even though there was no 'break' monsoon.

vi) The combined influence of the surface trough, strong lower tropospheric westerlies and the mid-tropospheric cyclonic circulation led to a spell of heavy to very heavy rains over Laccadives and Kerala. During the week ending on 28 July 1971, the mean rainfall in these two sub-division was nearly double the normal.

vii) The upper easterlies during the period were quite strong and steady over south Peninsula. The maximum winds were of the order of 90–100 knots all the way from Gan (equator) to Goa (15°N). The maximum wind speeds were nearly of the same order, with perhaps slightly stronger winds in the latitudinal belt 8 to 10°N (Trivandrum-Minicoy) (Fig. 5.2.8).

viii) The APT picture (ESSA 8) for 25.7.71 (Fig. 5.2.3) shows a heavy mass of clouding over Laccadives-Maldives area, with the tops sheared towards the west by strong upper easterlies. Such masses of clouds are characteristic of the mid-tropospheric circulation. On this day also the cloudiness was present over the area of the mid-tropospheric circulation. The APT (ESSA) picture for 27th (Fig. 5.2.6) shows the clearing over southeast Arabian Sea as the low level and mid-level systems weakened. The cumulus lines in east Arabian Sea are oriented west to east along the strong lower tropospheric westerly flow. Such cumulus lines are usually noted when the monsoon is weak or moderate, and the low level westerlies are strong. Both open and closed type cellular patterns can be noticed in the ~~Cuf~~ Cumuliform field. As there is no evidence of the tops of these clouds being sheared to the west, they have not apparently reached the level of the strong upper tropospheric easterlies.

5.3 Low pressure system moving westwards across south Peninsula into southeast Arabian Sea and then northwestwards along the west coast, causing active monsoon in Kerala and Arabian Sea Islands – 18 to 23 August, 1971.

5.3.1 During 'break monsoon' periods, low pressure areas may form over south Bay of Bengal and move westwards across south Peninsula causing increased rainfall in this area. The low pressure system is more often noticed in the upper air; on some rare occasions, it may be deep extending from the surface upto 500 mb or 300 mb. In association with these low pressure systems, there is an increase in rainfall in Coastal Mysore, Kerala and Arabian Sea Islands and on some occasions monsoon may become "active" to "vigorous" over these areas. Thus, a 'break' monsoon need not necessarily be a period of scanty rain in Coastal Mysore, Kerala and the Arabian Sea Islands. This type of a synoptic situation is also noticed when "weak" monsoon conditions prevail over the country, though it may not be a typical 'break' situation.

5.3.2 The feeble troughs of low pressure which form along and off Kerala and Coastal Mysore during the monsoon, do not extend beyond 0.9 km (sometimes they could not be located even at 0.9 km). In contrast, the low pressure systems which emerge into the east Arabian Sea across the south Peninsula usually extend through a fairly deep layer of the atmosphere, sometimes from the surface upto 500 mb or 300 mb. The rainfall and cloudiness associated with these westward moving low pressure areas are also found to extend to a large distance westwards into the Arabian Sea. After the movement of the low northwestwards along the west coast to a northerly latitude, the monsoon westerlies re-establish along Kerala and Mysore coast and the upper air pattern reverts to the seasonal monsoon type over these sub-divisions. Consequently, the rainfall may sometimes continue in these sub-divisions even after the low had moved north.

5.3.3 In this section, we will discuss a case where the low was seen on the surface chart, and in the upper air.

5.3.4 With the movement of a low pressure area across Uttar Pradesh and its breaking up over the hills of west Uttar Pradesh, the monsoon trough moved northwards and was close to the foot hills of the Himalayas on 18th August 1971 (Fig. 5.3.1). As is common in weak monsoon situations, the presure gradient along the west coast and over the Peninsula was weak, and the isobars were oriented northsouth along the west coast with a weak trough along the east coast. An upper air cyclonic circulation (which formed over southeast Bay of Bengal on the 16th) moved westwards and lay over the southwest Bay off Srilanka and Tamil Nadu coast on the 18th morning (Fig. 5.3.2). This circulation extended from 1.5 to 3.1 km asl; at 3.6 km it was seen only as a trough. The rainfall in Tamil Nadu on this day was due to a pronounced low level trough over interior Tamil Nadu, while the upper air low was still out at sea. The monsoon was weak in Kerala. Arabian Sea Islands had widespread rainfall, but it was not associated with the westward moving low. The 24 hour pressure changes over the south Peninsula were slightly negative. The pressure departure chart was characteristic of a "break" monsoon, with large negative values along the foot hills of the Himalayas as well as over Srilanka and south Peninsula, and large positive values over the central parts of the country.

5.3.5 On the morning of the 19th, the upper air cyclonic circulation moved to south Tamil Nadu and the Gulf of Mannar (Fig. 5.3.3); it induced a feeble low over the Gulf of Mannar where 24 hour pressure falls were maximum, of the order of -2 to -3 mb (Fig. 5.3.4). The maximum negative pressure changes over the Comorin area and the extreme south Peninsula on the morning and evening charts, suggested the likelihood of an intensification of the system. The pressure departure pattern was similar to the 18th, and the maximum departures (about -3 mb) were over Srilanka and the Comorin area. With the approach of the low, rainfall extended to Kerala and also increased over the Arabian Sea Islands.

Isolated heavy falls of 8 to 10 cm were recorded. Lower tropospheric north-westerly/northerly flow along Kerala-Mysore coasts is usually associated with a weak monsoon in these areas; but, in the present case, as these northerlies were part of the circulation of the low pressure system, there was good rainfall in Kerala and Arabian Sea Islands. On the evening of the 19th, the low pressure system could not be delineated on the surface chart by a closed isobar, as the same had merged with the thermal low over the land which usually develops over the Peninsula during weak monsoon days due to differential heating effect. However, a pressure fall (2 to 3 mb) over Kerala and a slight pressure rise in the extreme southern parts of Tamil Nadu indicated that the low was probably moving towards Kerala (Fig. 5.3.5).

5.3.6 On the morning of 20th, the low pressure area emerged into southeast Arabian Sea off Kerala-South Mysore coasts; the low could be delineated by an odd isobar (Fig. 5.3.6). The general rise of pressure over Kerala, though small, was also indicative of the system moving into southeast Arabian Sea. The departures continued to be about -2 to -3 mb over Kerala and Coastal Mysore. The low pressure system became more marked in upper air and also extended from 2.1 to 6.0 km (Fig. 5.3.7). The only clue to this intensification appeared to be the pressure changes on the previous day. Below 1 km, the winds backed to west over southeast Arabian Sea, south Kerala and Srilanka and showed a tendency to strengthen. With the system becoming more marked the rainfall increased in the Arabian Sea Islands and Kerala. Punalur and Minicoy recorded 8 cm each and Androth 7 cm.

5.3.7 Again on the evening of 20th, as in the previous evening (vide para 5.3.5), the surface low, being feeble, could not be delineated on the surface chart. However, pressure falls along Konkan and south Coastal Mysore and rise over Kerala were significant, suggesting a north-westerly track of the low along the coast (Fig. 5.3.8). The upper air cyclonic circulation was also noticed from 2.1 km to 7.6 km with a southward slope with height towards the colder air as inferred from the wind changes over Trivandrum and Minicoy(Fig.5.3.9).

5.3.8 On the morning of 21st, the low pressure area moved further north-northwestwards along the west coast and lay off north Coastal Mysore (Fig.5.3.10). The circulation was seen from 3.1 to 7.6 km; the lower tropospheric westerlies over Arabian Sea Islands and Kerala became more organised (Fig. 5.3.11). The rainfall continued to be fairly widespread in Kerala and Arabian Sea Islands. By the next day (22nd), the low had weakened into a trough off Konkan coast; pressures also rose all along the coast upto 18°N. Rainfall increased over North Kerala, north Arabian Sea Islands, coastal Mysore and south Konkan. During the subsequent 24 hours, the system weakened, although the rainfall continued in Kerala and Arabian Sea Islands on account of the development of a fresh low pressure system in the west central Bay off Tamil Nadu-south Andhra coasts and the freshening of the westerlies over the south Arabian Sea and south Peninsula.

5.3.9 To sum up, the following were the chief features of the situation:

i) During 'break monsoon' periods, low pressure systems may form over south Bay and move westwards across south Peninsula causing active monsoon conditions in Kerala and Arabian Sea Islands. Such low pressure systems are seen better in the upper air (700-500 mb) than in the lower levels or on the sea level chart. Those seen on the surface are well-marked though they are rather rare.

ii) In the present case, the low pressure system was mainly noticeable in the upper air (particularly between 2 and 4 km); in the later part of the sequence, the system extended upto about 7.6 km. Below 1.5 km the system, when it was over the south Peninsula, could hardly be distinguished from the northsouth trough in the south Peninsula, which normally develops during weak monsoon periods.

iii) On the surface chart, the low could be seen clearly only when it emerged into southeast Arabian Sea. When the low was over south Peninsula, it could not be distinguished in the afternoon charts from the low that develops over these areas in the afternoon during the weak monsoon periods, on account of diurnal heating effect. On some charts however, the pressure changes and departures were useful indicators for tracing the low pressure area. Hence, the upper air charts provided a better chart-to-chart continuity.

v) In tracing these lows, there is a need to separate such feeble moving systems from the quasi-stationary trough in south Peninsula, which forms during weak monsoon periods and becomes more pronounced in the evenings.

v) As the low moved into southeast Arabian Sea and travelled subsequently along the coast northwestwards, the earlier lower tropospheric northwest/northerlies over Kerala and Arabian Sea Islands were replaced by strong westerlies, thus reverting to the seasonal monsoon flow and a revival of the monsoon along the west coast. With the development of a fresh low pressure area in the west Central Bay on the 23rd, rainfall in Arabian Sea Islands and Kerala continued.

vi) Though the system may be feeble, it is capable of giving heavy rainfall. Thus in the 'break' monsoon period, though the rainfall over the major part of the country may be scanty, south Peninsula may experience moderate to strong monsoon activity.

vii) Satellite pictures showed that although there was general cloudiness over the south Bay and south Arabian Sea during this period, the heavy clouding associated with the westward moving low could be identified as a patch of heavy overcast which sequentially moved west from southwest Bay to south Arabian Sea. The area of heavy cloudiness associated with the low and its progressive westward movement could be clearly seen from the daily satellite pictures. This area agrees well with the 700 mb level circulation.

viii) During this spell there was no significant change in the upper tropospheric Easterlies. They were generally strong, with maximum near Lat. 8°N (Trivandrum-Minicoy) at a height of 15-16 km; the speeds were of the order of 100 kt (Fig. 5.3.12).

6. Weak Monsoon – Typical Situation

6.1 A ridge of high pressure along the west coast of Indian Peninsula causing weak monsoon in Kerala — 12-15 August, 1969.

6.1.1 In earlier discussion (Sec. 5) the importance of a trough on the surface chart along and off north Kerala-Mysore coast, causing active monsoon conditions in Kerala, has been highlighted. In contrast, a ridge of high pressure along the west coast is often associated with weak monsoon conditions in Kerala, sometimes resulting in completely dry weather. Often, this ridge may extend north or northeastwards upto Gujarat State and occasionally even upto Rajasthan. A situation of this type (14-16 August, 1964) has already been discussed in Sec. 9.1 of FMU Rep. No.III-3.7 on Konkan and Coastal Mysore. Another case of this type prevailed between 12 and 16th August 1969, resulting in weak monsoon in Kerala and Arabian Sea Islands which will be discussed here.

6.1.2 On the morning of 11 August 1969, a trough of low pressure lay off north Kerala-Mysore coast on the surface chart (Fig. 6.1.1). However, the winds in the lower troposphere veered since the previous day and become west-northwest/northwest over the Arabian Sea Islands and Kerala and the speeds were of the order of 15-30 kts (Fig. 6.1.2). The axis of the seasonal trough was running from Punjab to Gangetic West Bengal through south Uttar Pradesh and its eastern end was extending into the northeast Bay of Bengal on the sea level chart. The 24-hour pressure changes all over the country were positive. Scattered light rain had fallen in the Arabian Sea Islands and weather was dry over Kerala.

6.1.3 On 12th morning, the trough of low pressure off North Kerala became unimportant (Fig. 6.1.3). The pressure gradient over Kerala and coastal Mysore was very weak, but the gradient was rather steep further north, the pressure difference being about 6 mb between Goa and Rajkot. Ships in west Arabian Sea reported southwesterly winds of the order of 20-35 kts and a ridge was developing over east Central and adjoining Southeast Arabian Sea. The 24-hour pressure changes were positive all over the country except over northeast India and the head Bay of Bengal and a trough of low was also forming over the head Bay of Bengal. The winds in the lower tropospheric levels over the Arabian Sea Islands and Kerala continued to be northwesterlies though they weakened since the previous day (Fig. 6.1.4). Mainly dry weather prevailed in Kerala and Arabian Sea Islands

6.1.4 On the morning of 13th, surface winds also over Arabian Sea Islands veered to northwesterlies with speeds ranging from 5 to 20 kts (Fig. 6.1.5). Ships in the southeast Arabian Sea, reported northwesterly winds of 15 kts and further west in the southwest Arabian Sea, they were strong southwesterlies of speed 20–35 kts. The ridge over the Arabian Sea south of Lat. 15°N had become pronounced. The pressure gradient along the west coast was very weak. In the lower troposphere also there was a further veering of winds over Kerala and the Arabian Sea Islands (Fig. 6.1.6). Northwesterly/northerly winds prevailed over coastal Mysore also. The wind speeds were about 20–30 kts. Weather was dry in the Arabian Sea Islands and Kerala. A depression also formed in the head Bay of Bengal on this day; it intensified into a cyclonic storm by the evening.

6.1.5 On 14th, the ridge was still persisting in the southeast Arabian Sea and extended northeastwards upto southeast Rajasthan (Fig. 6.1.7). The pressure gradient along coastal Mysore and Kerala was still very weak. Though there was a backing of the winds along Kerala coast in the lower troposphere, they veered again to northwesterly within the next 24 hours. The weather continued mainly dry in Kerala and Arabian Sea Islands. The Bay system move inland, weakened and lay as a deep depression over north Orissa and adjoining Bihar Plateau.

6.1.6 On the 15th the ridge in southeast Arabian Sea became less marked but persisted on 16th. In the lower troposphere, winds were northwesterly over Arabian Sea Islands and Kerala coast. Consequently weather continued mainly dry on these days also. But by 17th, rainfall commenced in Kerala and Arabian Sea Islands, with the approach of a low pressure area from across the extreme south Peninsula and Ceylon.

6.1.7 The main features to be noticed in this sequence are:-

i) For nearly a week, between 11 and 16th, monsoon was weak in Kerala and Arabian Sea Islands and weather was practically dry.

ii) During this period, southeast Arabian Sea was dominated by a well-marked ridge of high pressure. The pressure gradient was very slack over the area. The ridge could be delineated well by the moderate to strong southwesterlies in the southwest Arabian Sea and northwest/northerlies in the southeast Arabian Sea and Kerala coast. The ridge was most pronounced on 13th and 14th when it extended northwards upto southeast Rajasthan and the lower tropospheric winds were northwest/northerlies over Laccadives and Kerala coast. The northwest/northerly flow over Kerala and the absence of weather is in agreement with the earlier discussion presented in Para 3.4.3.

iii) Though the monsoon was very weak in Kerala and Arabian Sea Islands, monsoon activity was good over the other parts of the country with a monsoon depression moving from the head Bay to north Madhya Pradesh.

iv) The radiosonde data for Trivandrum showed relatively dry air over this area, with some evidence of a relatively stable layer in the lower troposphere (Fig. 6.1.8).

v) During this period, the upper tropospheric easterlies were quite strong and steady over the south Peninsula. The core of the easterly jet lay over the extreme south Peninsula, with speeds of the order 100 to 110 kts. The easterlies over the extreme south Peninsula weakened towards the end of this period. These features are brought out by the time section for Trivandrum (10-16 August 1969) given in Fig. 6.1.9

vi) The depth of the westerlies over the south Peninsula was not much. It hardly exceeded 3.0 kms. At 600/500 mb levels easterlies prevailed (see time section of Trivandrum).

vii) On some occasions even though the ridge pattern over southeast Arabian Sea may not be very pronounced, there can be a northwesterly/northerly flow over Kerala and Arabian Sea Islands in the lower troposphere, with the surface isobars running from northwest to southeast. On such occasions also the monsoon will be weak over Kerala and Arabian Sea Islands.

7. Conclusions

7.1 The main conclusions of this report are:-

i) The southwest monsoon season is the principal rainy season in Kerala and Arabian Sea Islands, when two-thirds of the annual rainfall falls. The major part of this rainfall is in the first half of the season - (i.e.) in in the months of June and July. Strong to vigorous monsoon conditions and heavy rains are also mostly in June and July.

ii) Northern districts of Kerala and northern Islands of the Arabian Sea Islands get more rainfall than the southern parts. Similarly heavy rain is also more frequent in north Kerala than in the southern districts. The anti-cyclonic lower tropospheric flow over south Kerala is perhaps partly responsible for this.

iii) The low level westerly jet and the high level easterly jet are significant features of the upper air circulation over the area. The low level westerlies over south Peninsula strengthen usually in association with the formation of low/depression in the Bay of Bengal.

iv) Though thunderstorm activity is pronounced in Kerala and Arabian Sea Islands in the pre-monsoon season, it progressively decreases after monsoon establishes and reaches a minimum in August. There is again a slight increase towards the end of the season.

v) The main features of synoptic situation causing active monsoon in Kerala and Arabian Sea Islands are

a) off-shore troughs

b) strong lower tropospheric westerlies

c) mid-tropospheric cyclonic circulation or trough and

d) low pressure systems moving westwards across the south Peninsula.

Off-shore troughs hardly extend upto 900 m. Most often the trough is associated with strong lower tropospheric westerlies which sometimes reach a strength of 40-50 kt. Usually a combination of features (a) to (c) is noticed on days of active monsoon.

vi) Lower tropospheric winds from southwest to westnorthwest are more favourable for rainfall in Kerala and Arabian Sea Islands than from west-northwest to north. Localised convergence or divergence due to speed variation in the wind field, causes variation in the rainfall distribution.

vii) Weak monsoon conditions are usually associated with a north-south oriented ridge over Laccadives-Maldives with pronounced northwesterly-northerly winds along Kerala. In contrast to the trough (on active monsoon days) which hardly extends upto 900 m, the ridge (on weak monsoon days) extends sometimes upto 2.1 or 3.1 kms.

viii) There is a large data gap to the west of Kerala and Arabian Sea Islands where there is no other meteorological data except surface observations reported by ships. Satellite pictures are very helpful in filling these data gap areas and provide useful hints for short range forecasting.

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APPENDIX

Specifications for the strength of Monsoon over land areas
(Taken from DDGF's Forecasting Circular 1 of 1973)

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 be necessary in general)
Active/strong monsoon	i) Rainfall $1\frac{1}{2}$ to 4 times the normal ii) The rainfall in at least two stations should be 5 cm, if that sub-division is along west coast and 3 cm, if it is else where. iii) Rainfall in that sub-division should be fairly widespread or widespread
Vigorous monsoon	i) Rainfall more than 4 times the normal. ii) The rainfall in at least two stations should be 8 cm if the sub-division is along the west coast and 5 cm if it is elsewhere. iii) Rainfall in that sub-division should be fairly widespread or widespread.

1. While describing the activity of the monsoon,

i) The normals of stations, wherever available should be used.
ii) Till normals for all the stations are available the following procedure should be adopted:

Number of stations in a sub-division with normals	a
Normal for these stations	b
Average normal for the sub-division	b/a
Total number of stations reporting rainfall	c
Actual total rainfall reported by these stations	d
Therefore, the average rainfall for the sub-division	d/c

Compare d/c with b/a and describe the activity of the monsoon accordingly, other conditions being fulfilled.

2. i) In the sub-divisions, where the percentage of hill stations is high, the hill stations must be also taken into account for describing the activity of the monsoon. In other sub-divisions, the hill stations will be excluded.

ii) The monsoon activity will be described in all the sub-divisions of north-east India as is done for sub-divisions of other regions.

iii) The monsoon activity need not be described over the Bay Islands and the Arabian Sea Islands.

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DIAGRAMS

FIG. 2·1 MONTHLY MEAN RAINFALL (cm)-KERALA

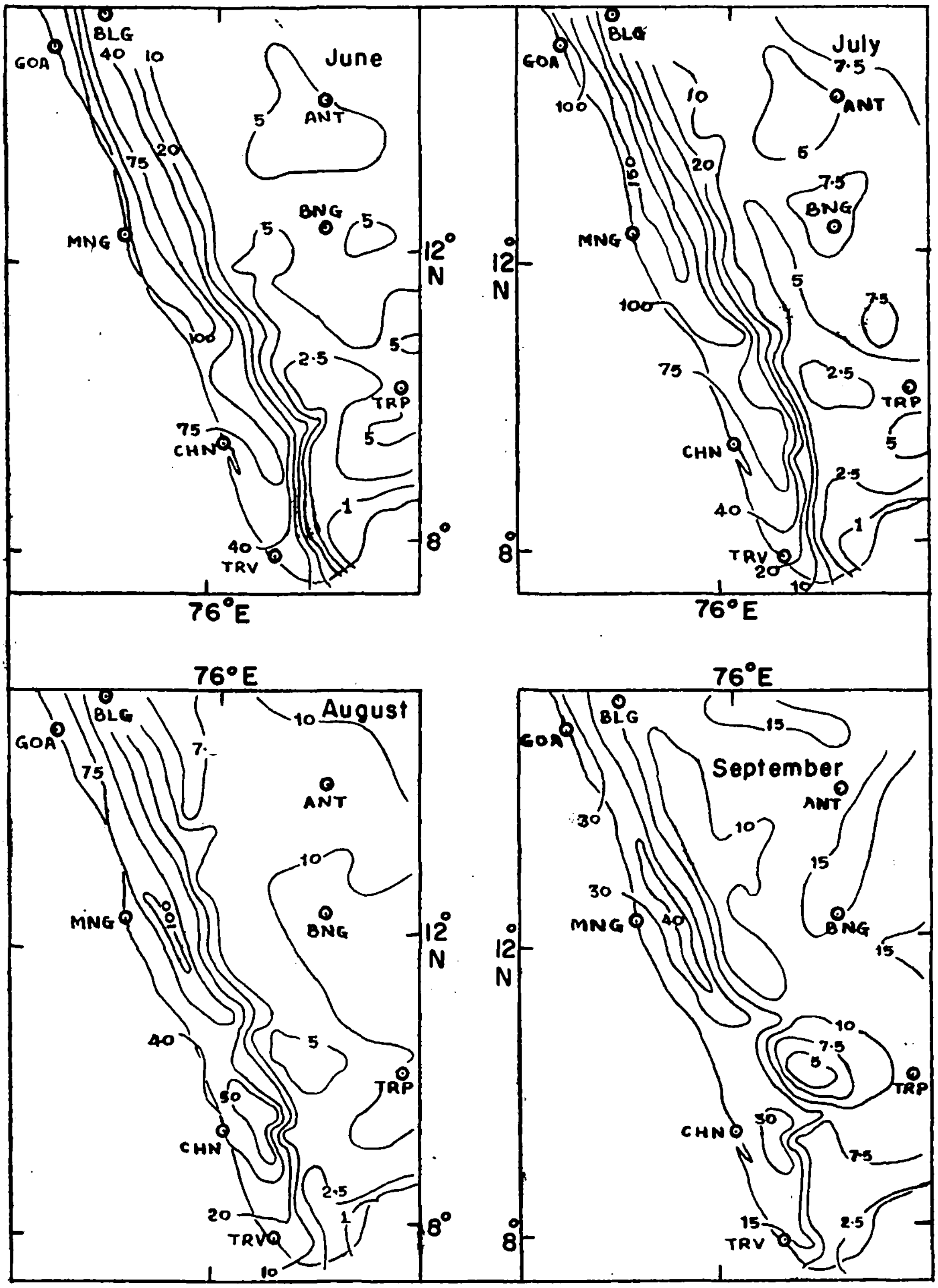


Fig.2·2 Percentage Frequency of Occurrence of Vigorous, Strong, Normal & Weak monsoon days over Kerala & Arabian Sea Islands. (Based on data – Jun. to Sept. 1966-70)

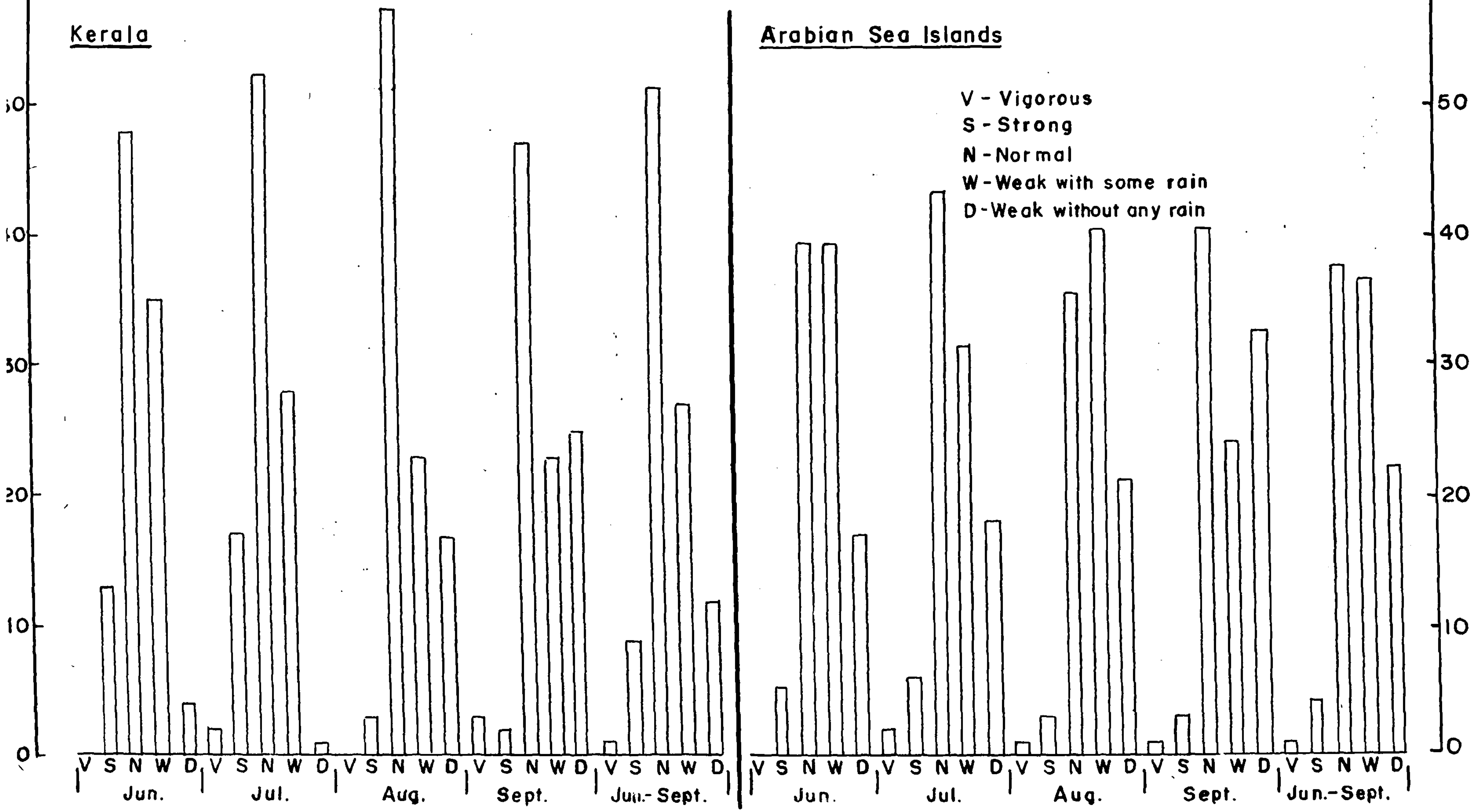


FIG. 2·3 VERTICAL PROFILE OF MONTHLY MEAN UPPER WINDS-12GMT

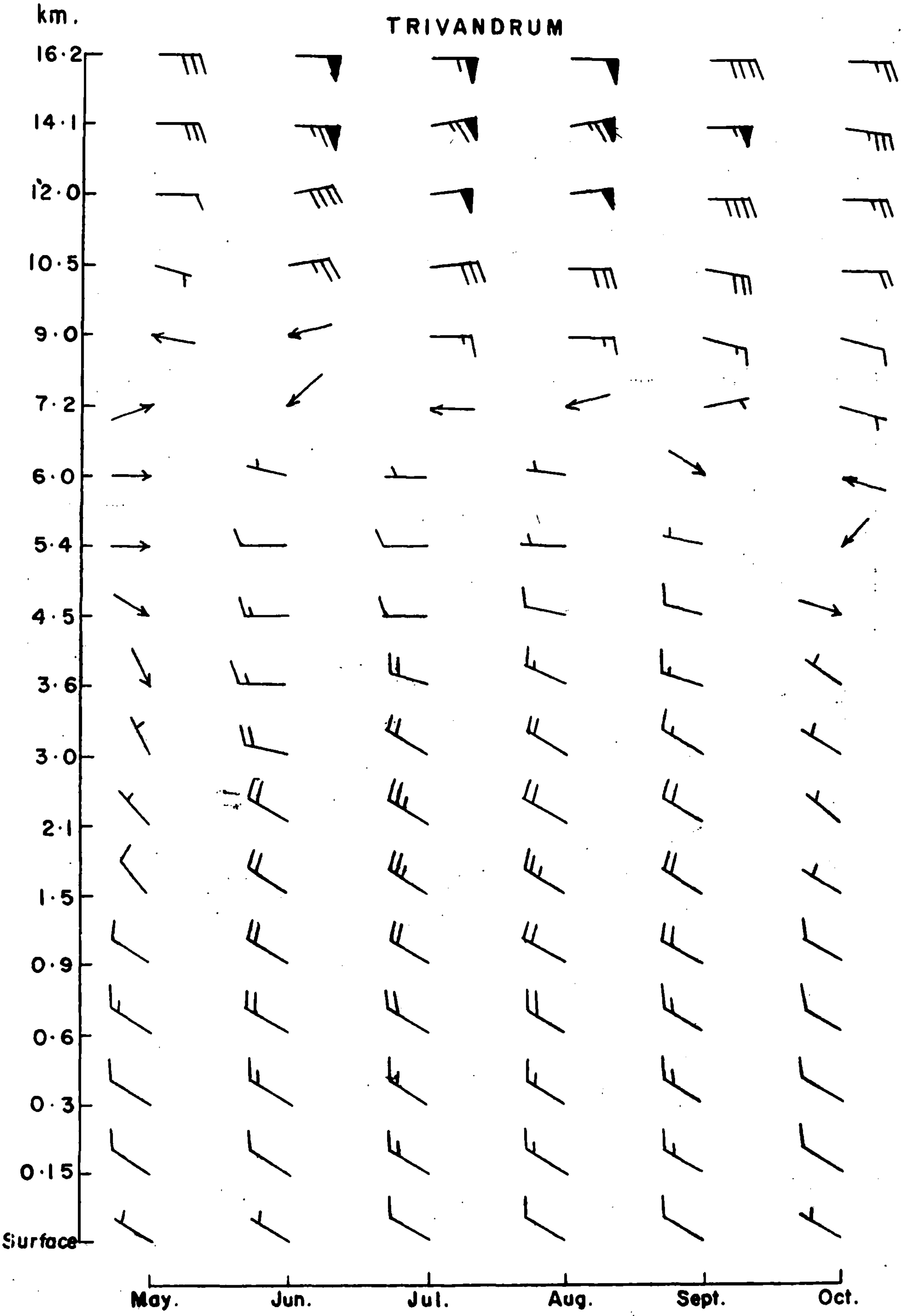


FIG. 2·4 MEAN TEPHIGRAMS OF TRIVANDRUM - 00GMT

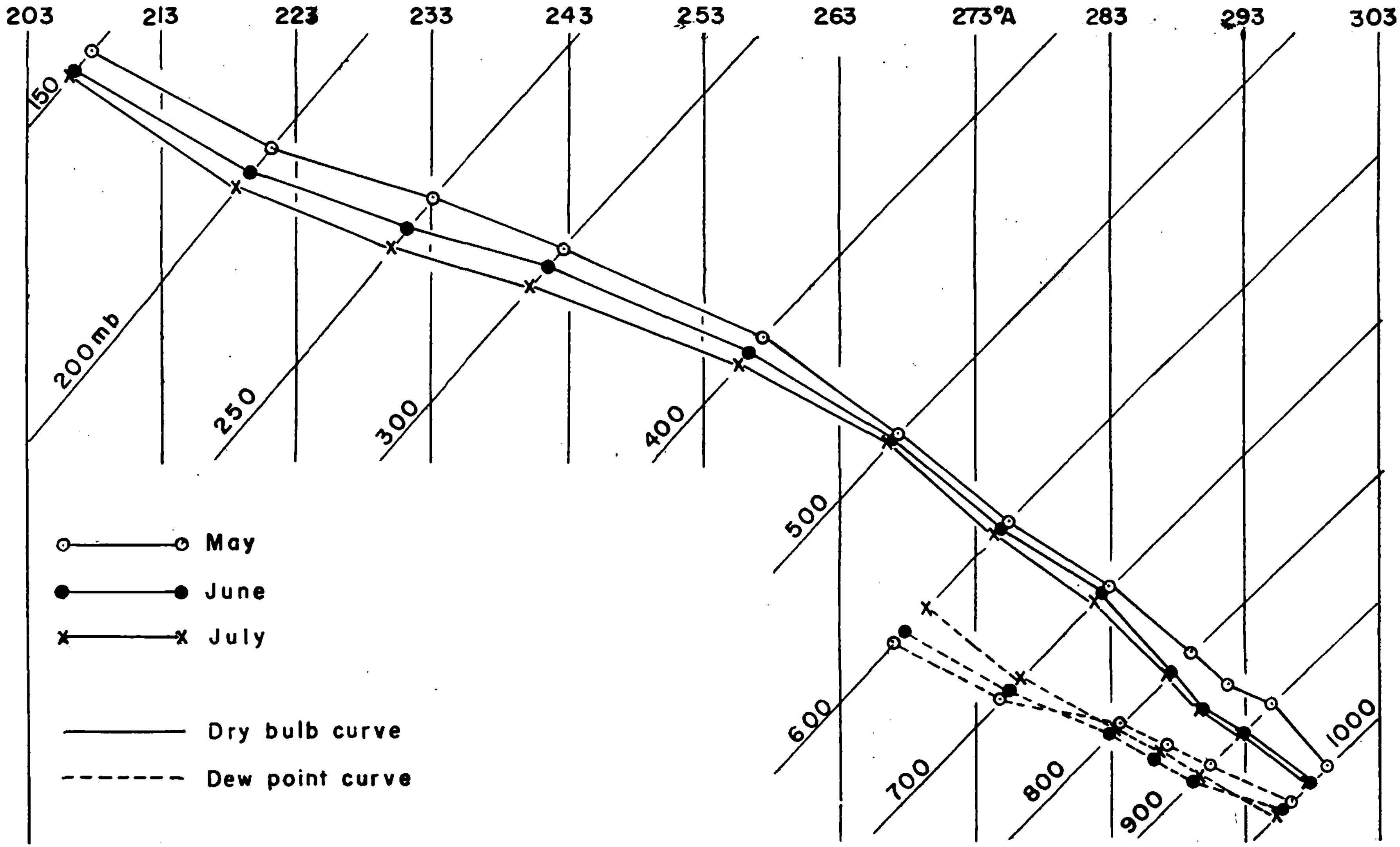


FIG. 2·5 MEAN TEPHIGRAMS OF BOMBAY & TRIVANDRUM FOR JULY - 00 GMT

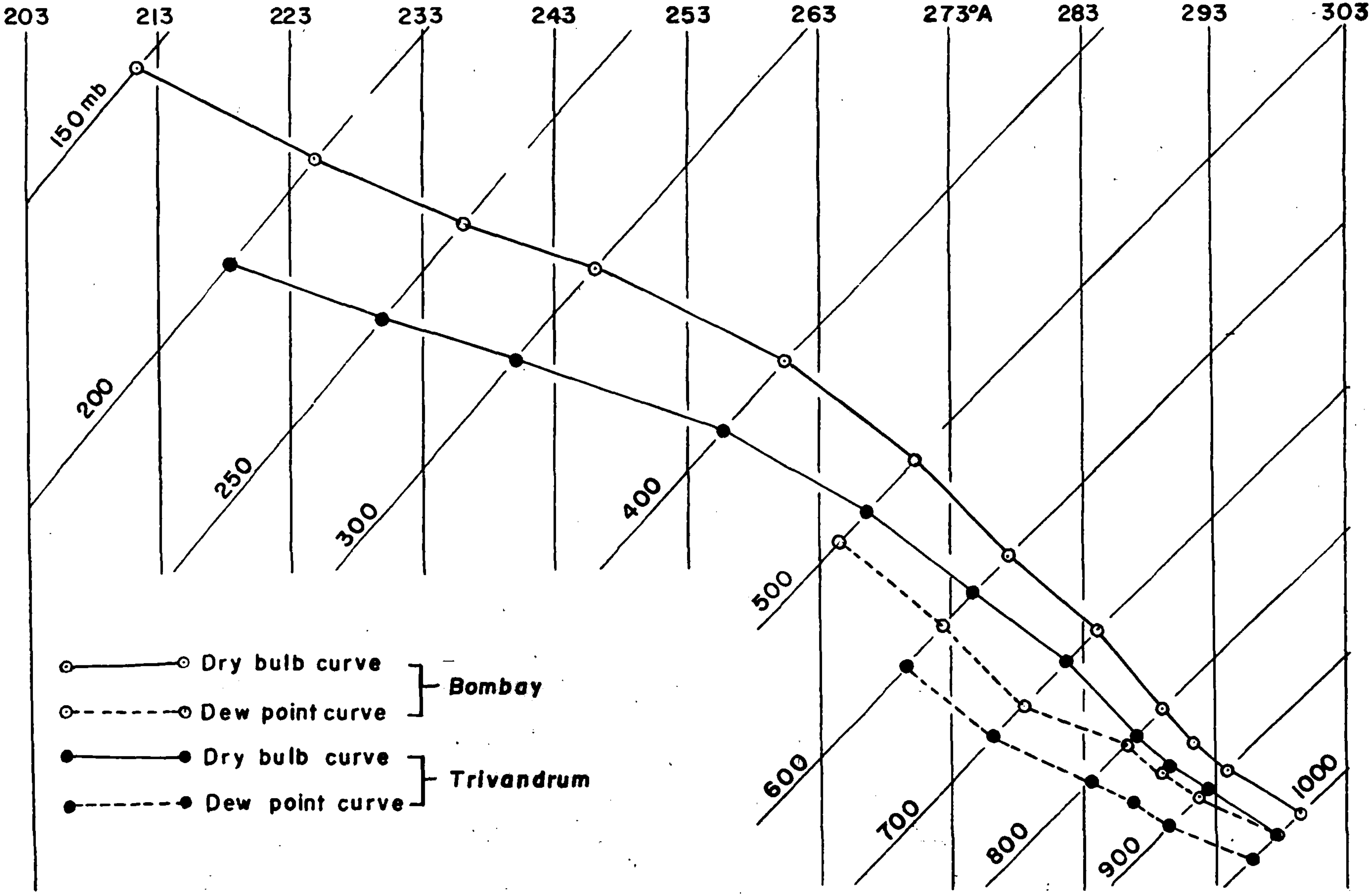


FIG. 2·6 MEAN TEPHIGRAMS OF TRIVANDRUM – JUL. & AUG. 1968-70 (00GMT)

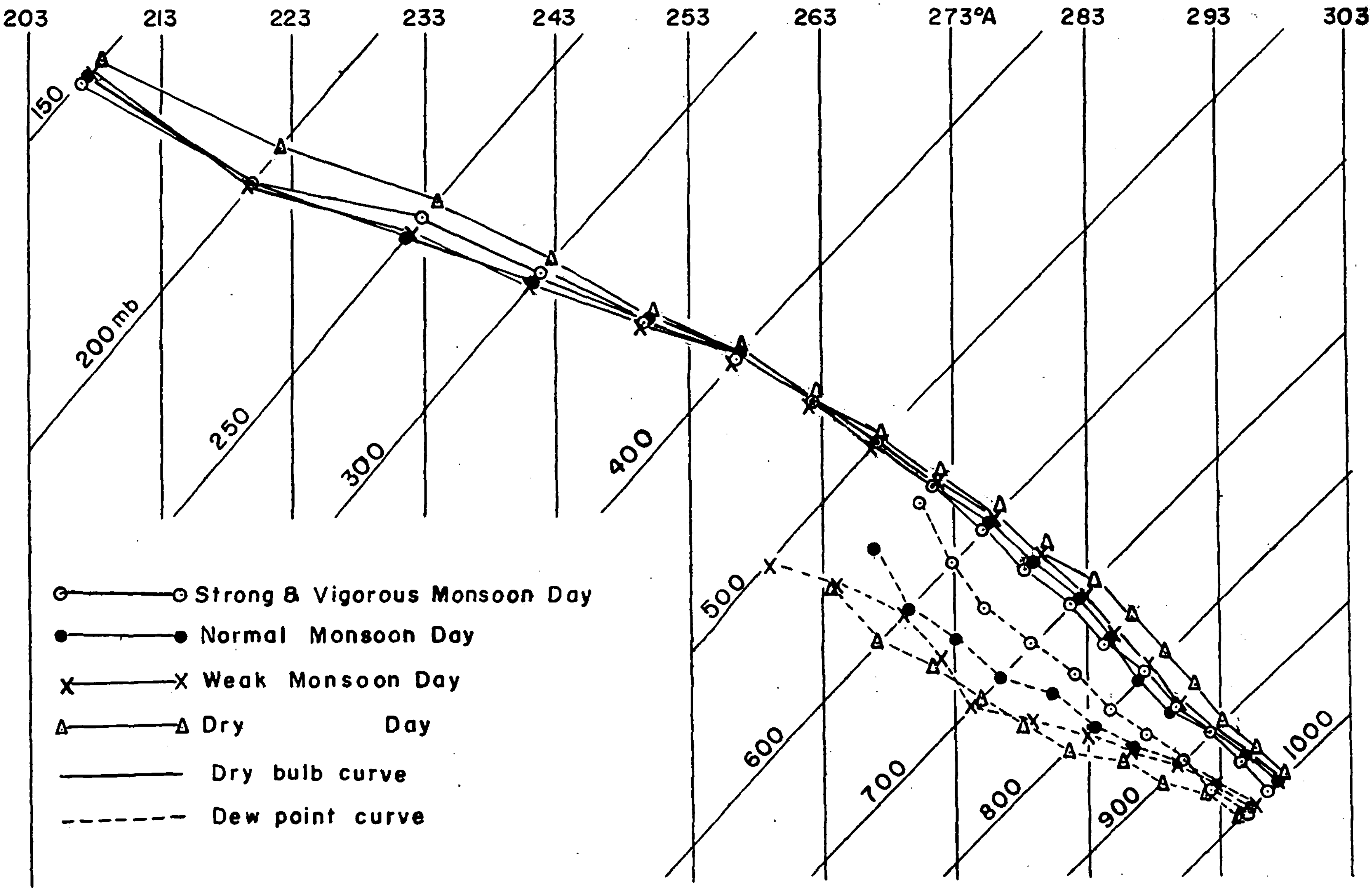


FIG. 2·7 (a) TYPICAL TEPHIGRAM FOR TRIVANDRUM - STRONG MONSOON DAY - 22 Aug. 71 - 00 GMT

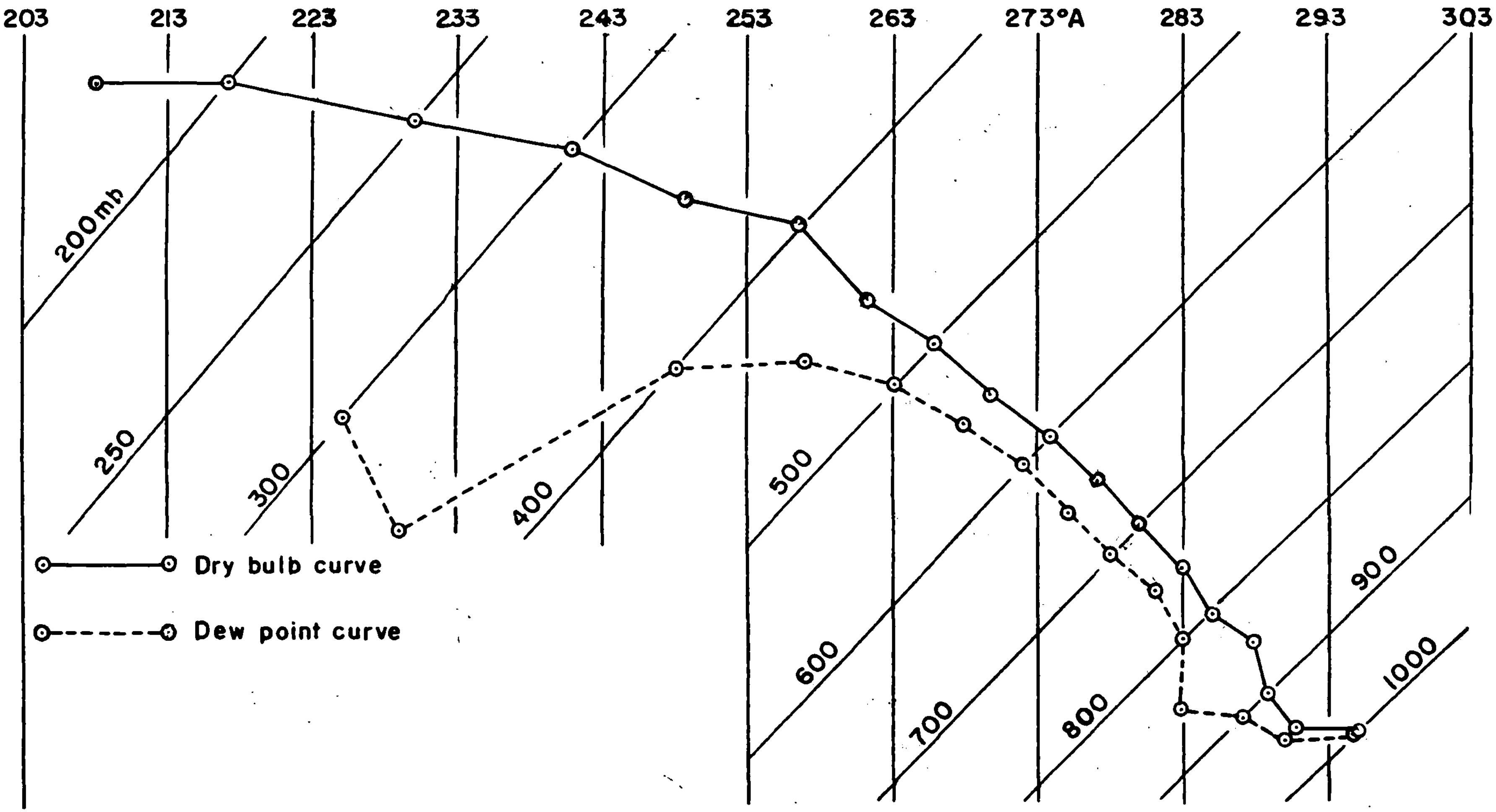


FIG.2·7(b) TYPICAL TEPHIGRAM FOR TRIVANDRUM - NORMAL MONSOON DAY- 18 JUL.70 OOGMT

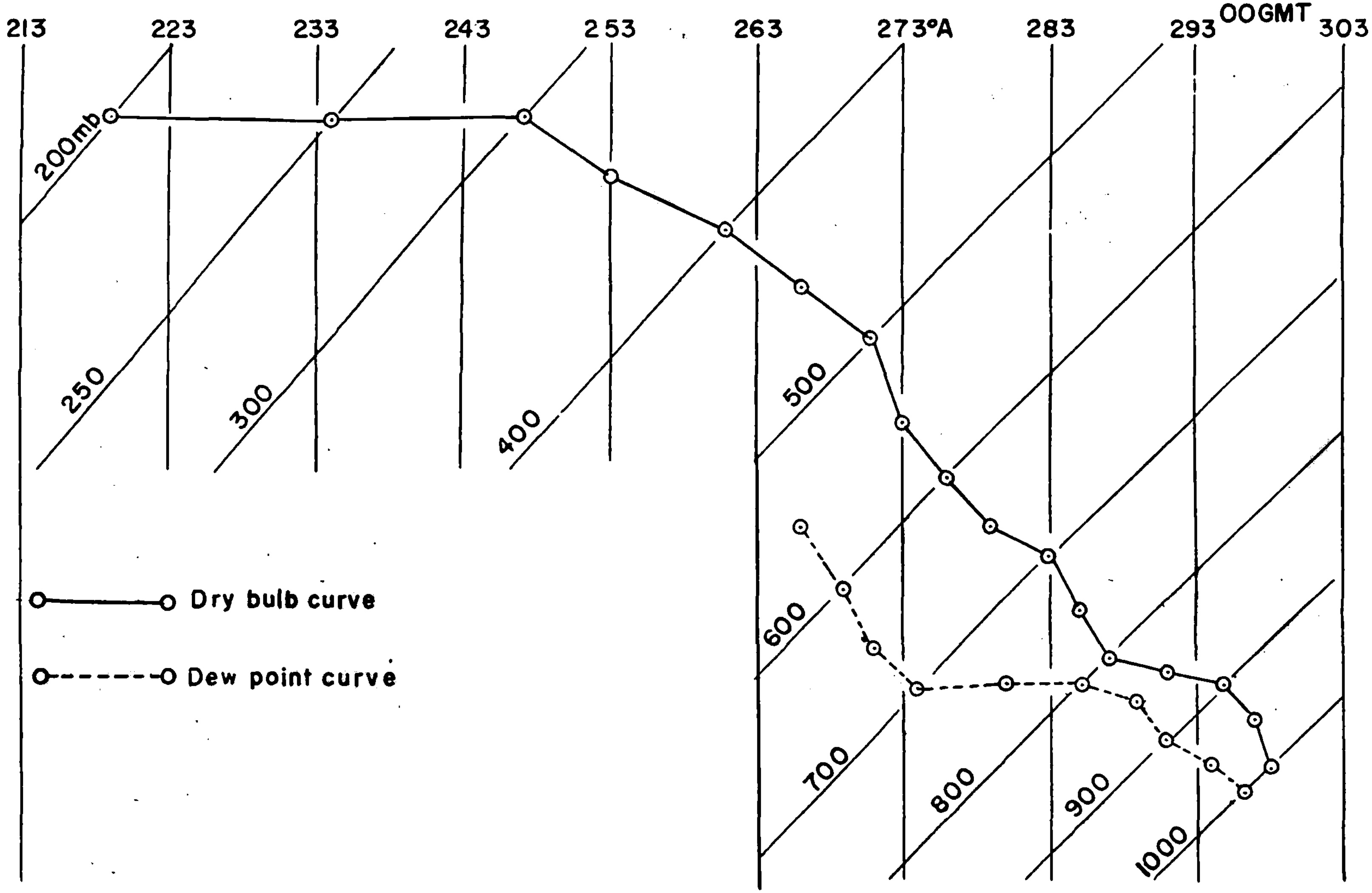


FIG. 2·7(c) TYPICAL TEPHIGRAM FOR TRIVANDRUM – WEAK MONSOON DAY - 12 Aug. 70-00 GMT

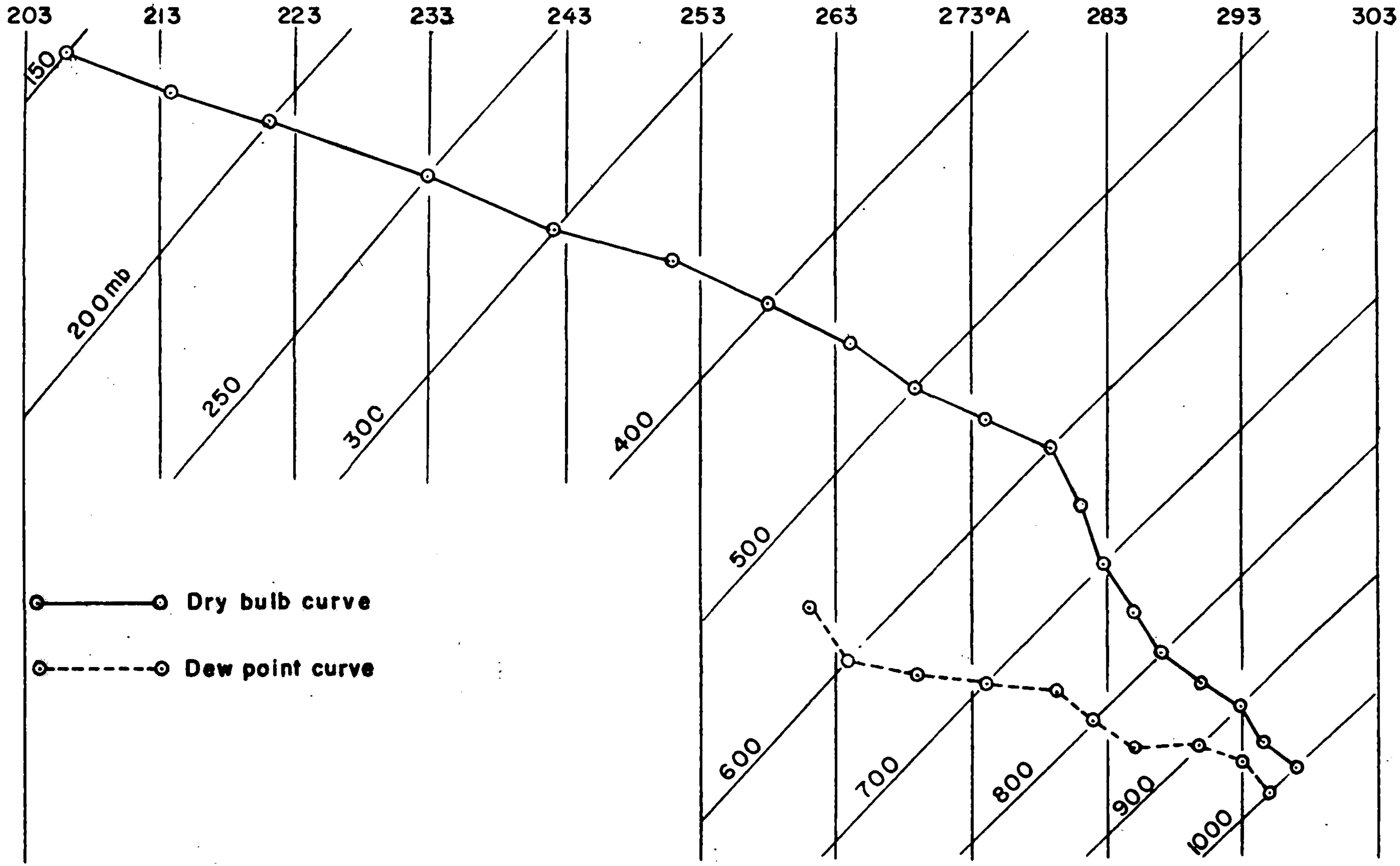


FIG 5·1·1 SYNOPTIC CHARTS 0300 GMT 3 JUL. 68

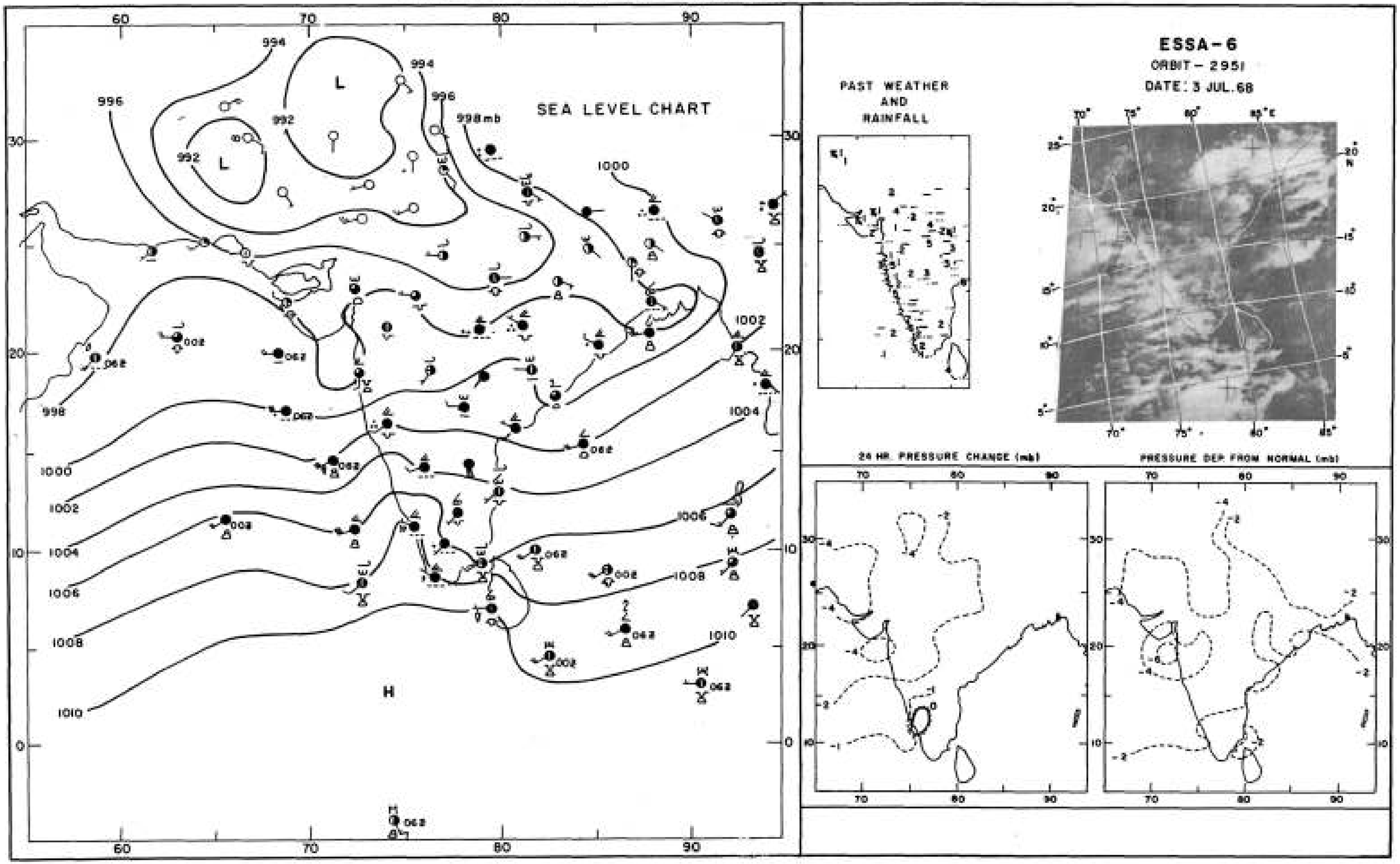
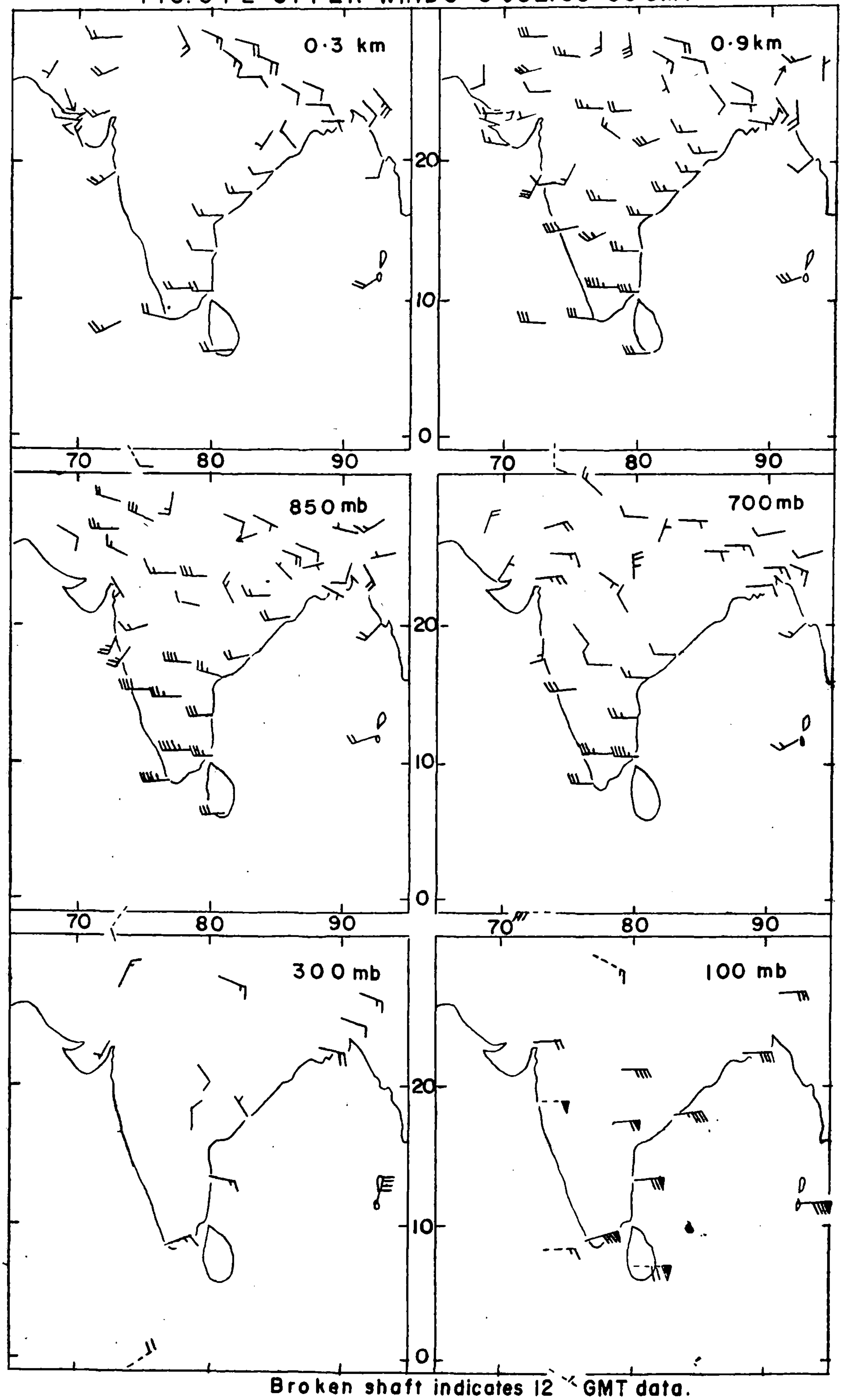


FIG. 5·1·2 UPPER WINDS 3 JUL. 68 00 GMT



Broken shaft indicates 12 GMT data.

FIG.5·1·3 SYNOPTIC CHARTS 0300 GMT 4 JUL. 68

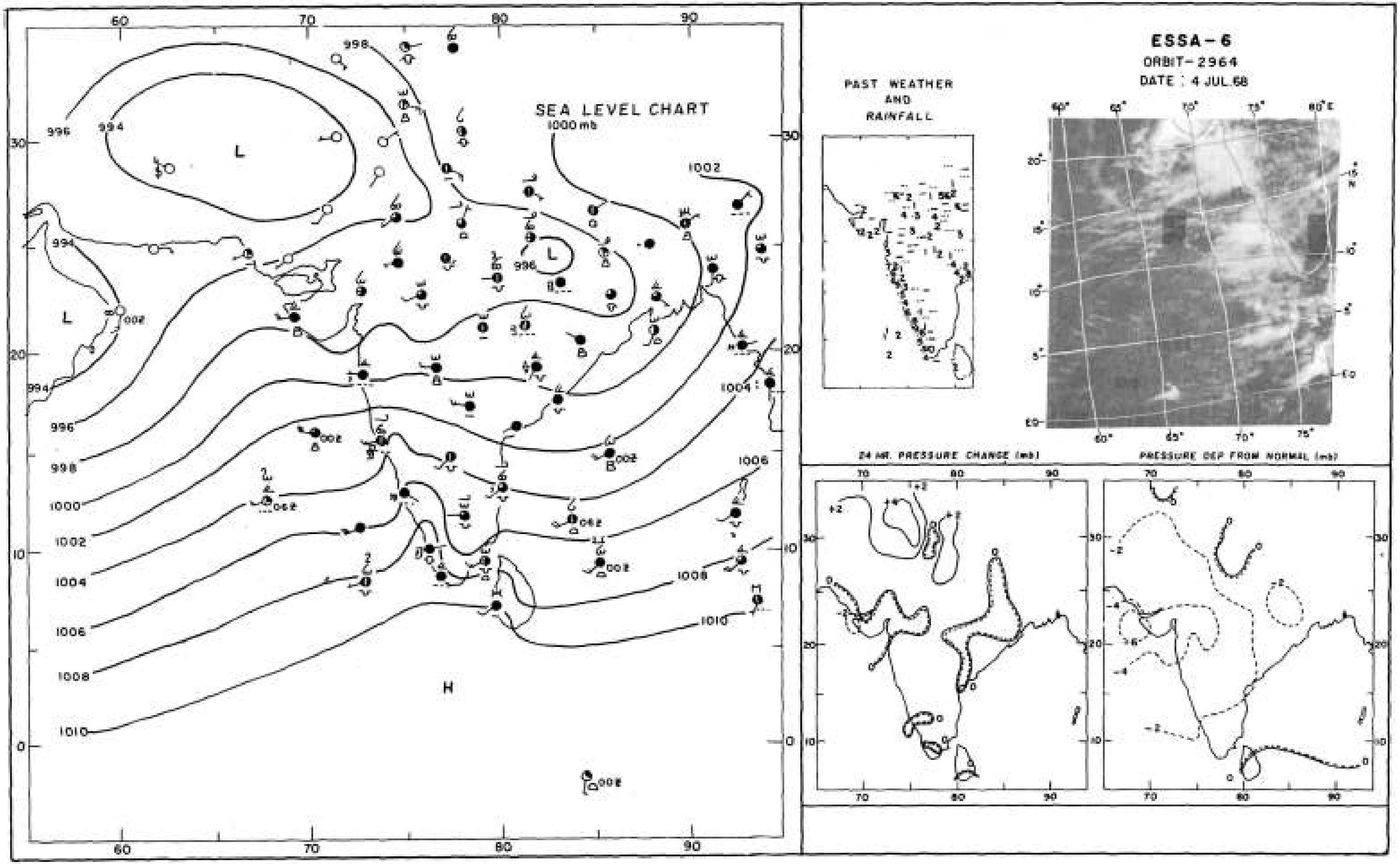
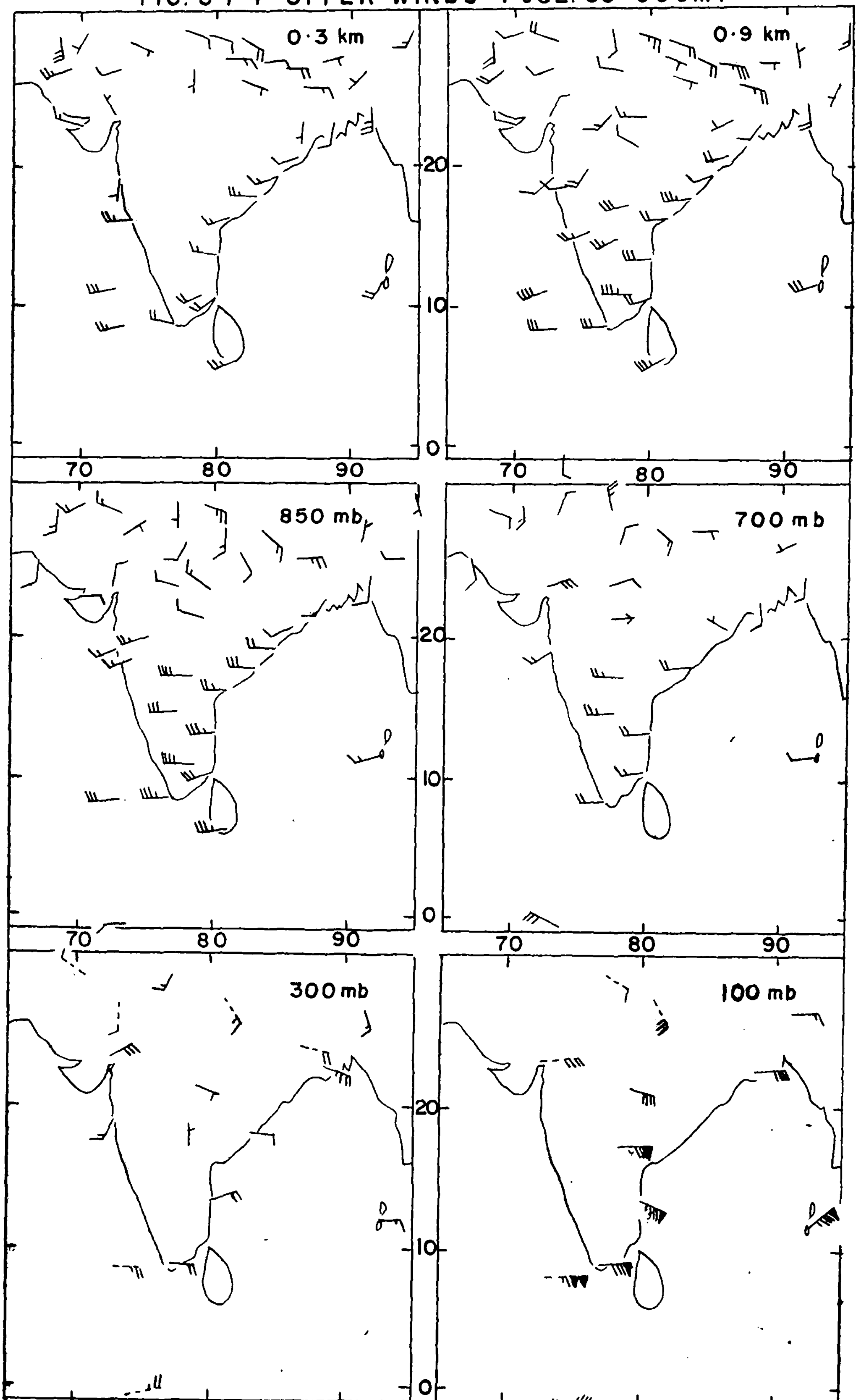


FIG. 5·1·4 UPPER WINDS 4 JUL. 68 00GMT



Broken shaft indicates 12 GMT data.

FIG. 5·1·5 SYNOPTIC CHARTS 0300 GMT 6 JUL. 68

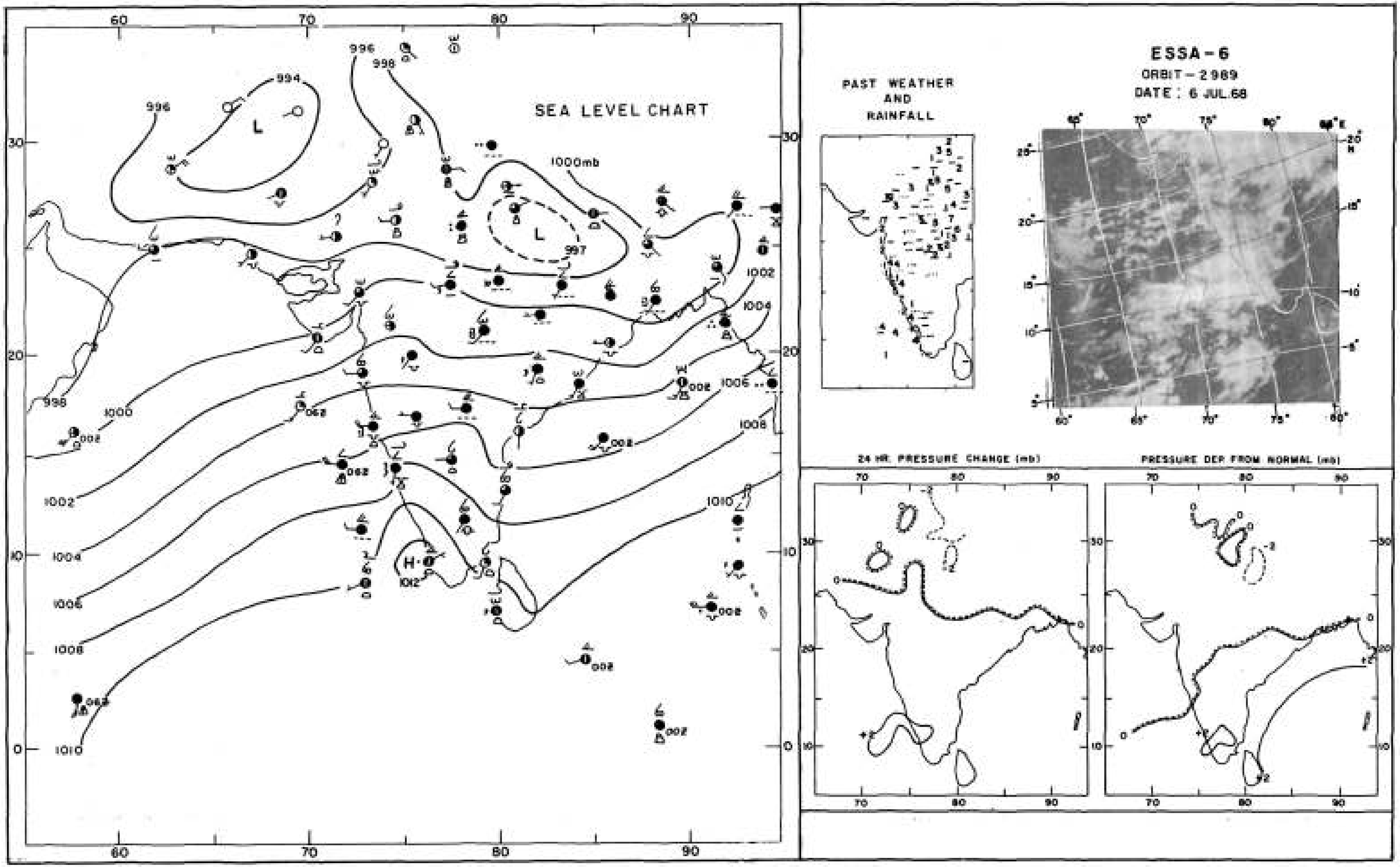


FIG. 5·1·6 UPPER WINDS 6 JUL. 68 00 GMT

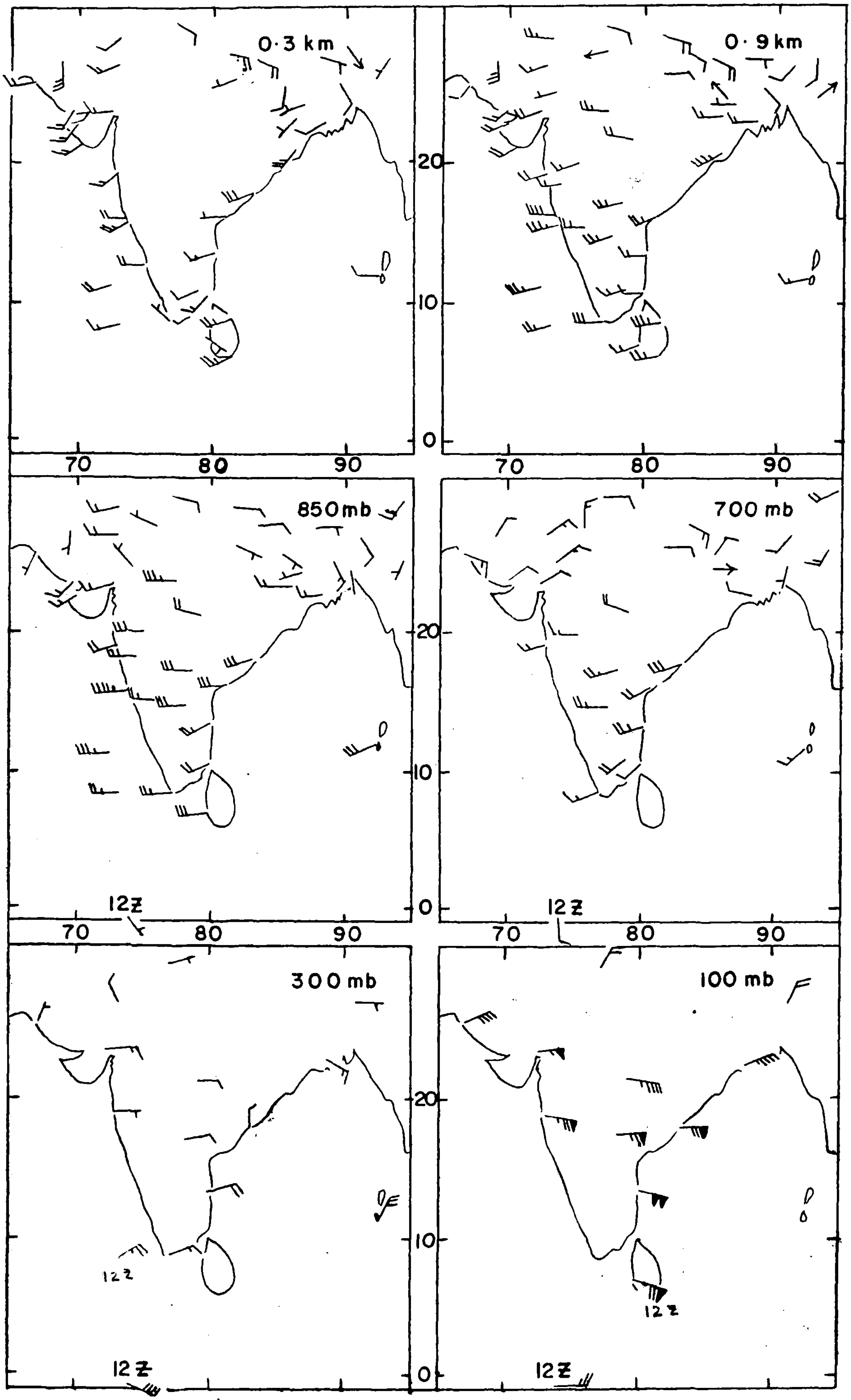


FIG5·2·1 SYNOPTIC CHARTS 0300 GMT 24 JUL. 71

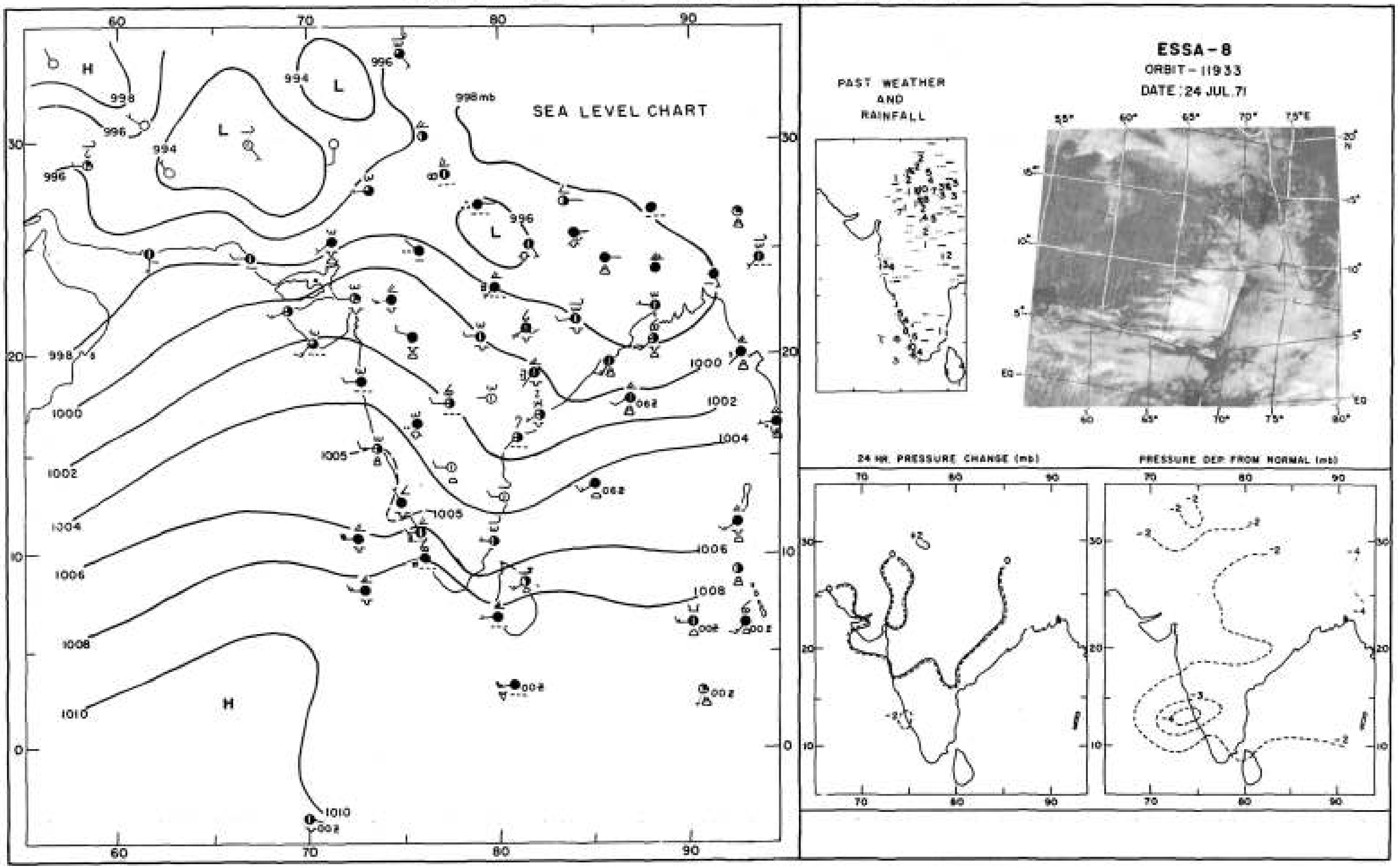
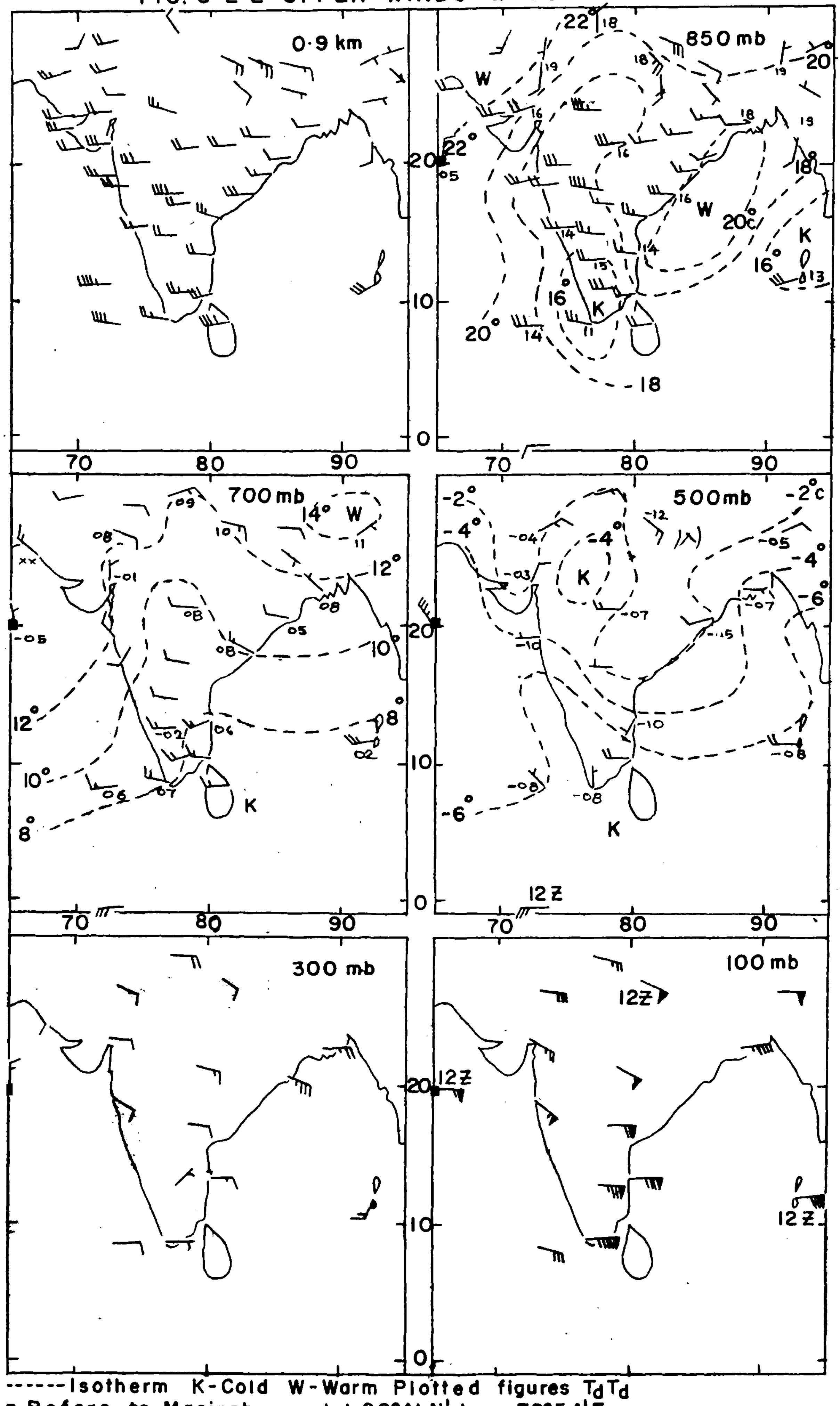


FIG. 5·2·2 UPPER WINDS 24 JUL. 71 OOGMT



------Isotherm K-Cold W-Warm Plotted figures $T_d T_d$
■ Refers to Masirah·········lat. 20°41 N' long. 58°54'E

FIG.5·2·3 SYNOPTIC CHARTS 0300 GMT 25 JUL. 71

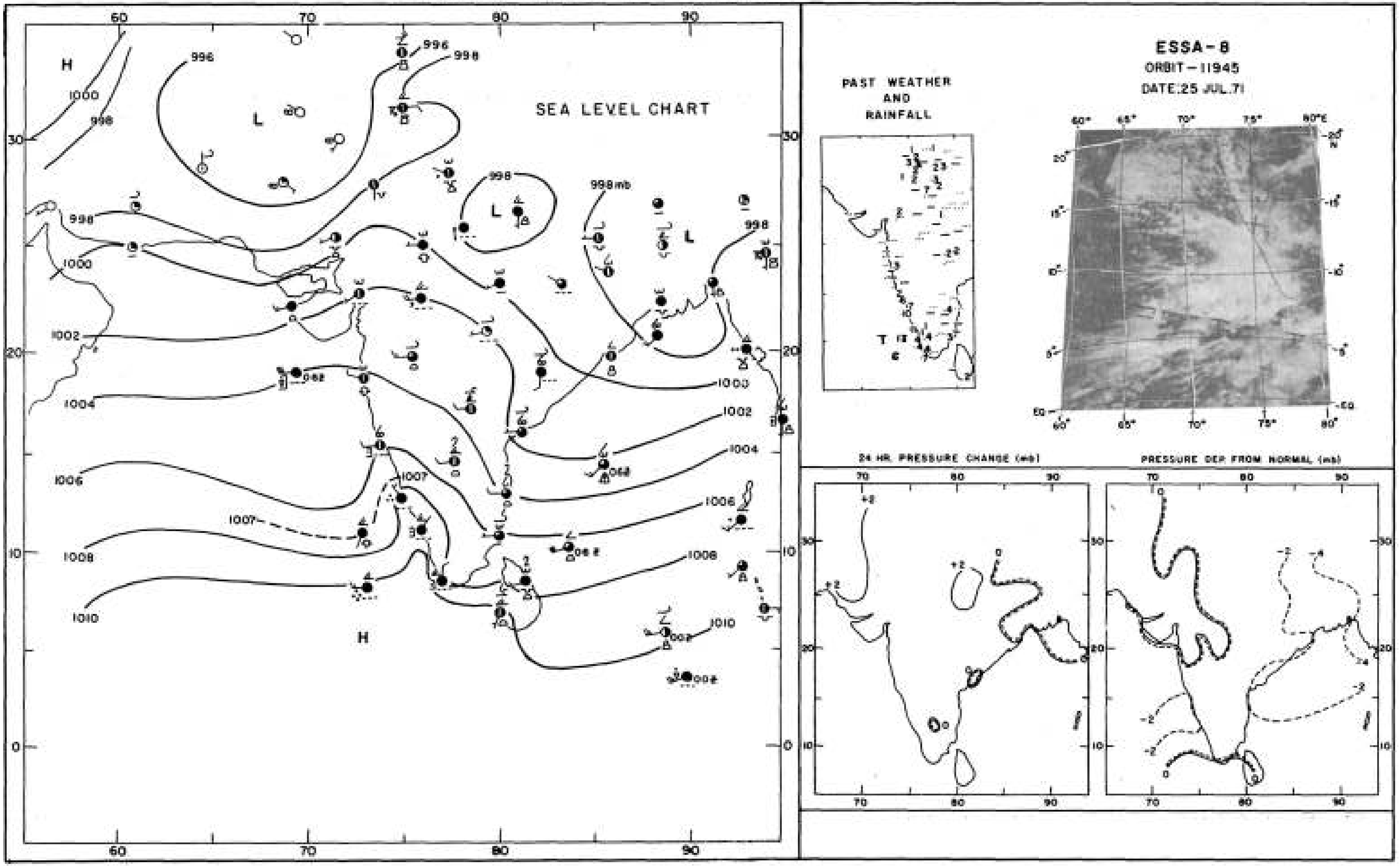
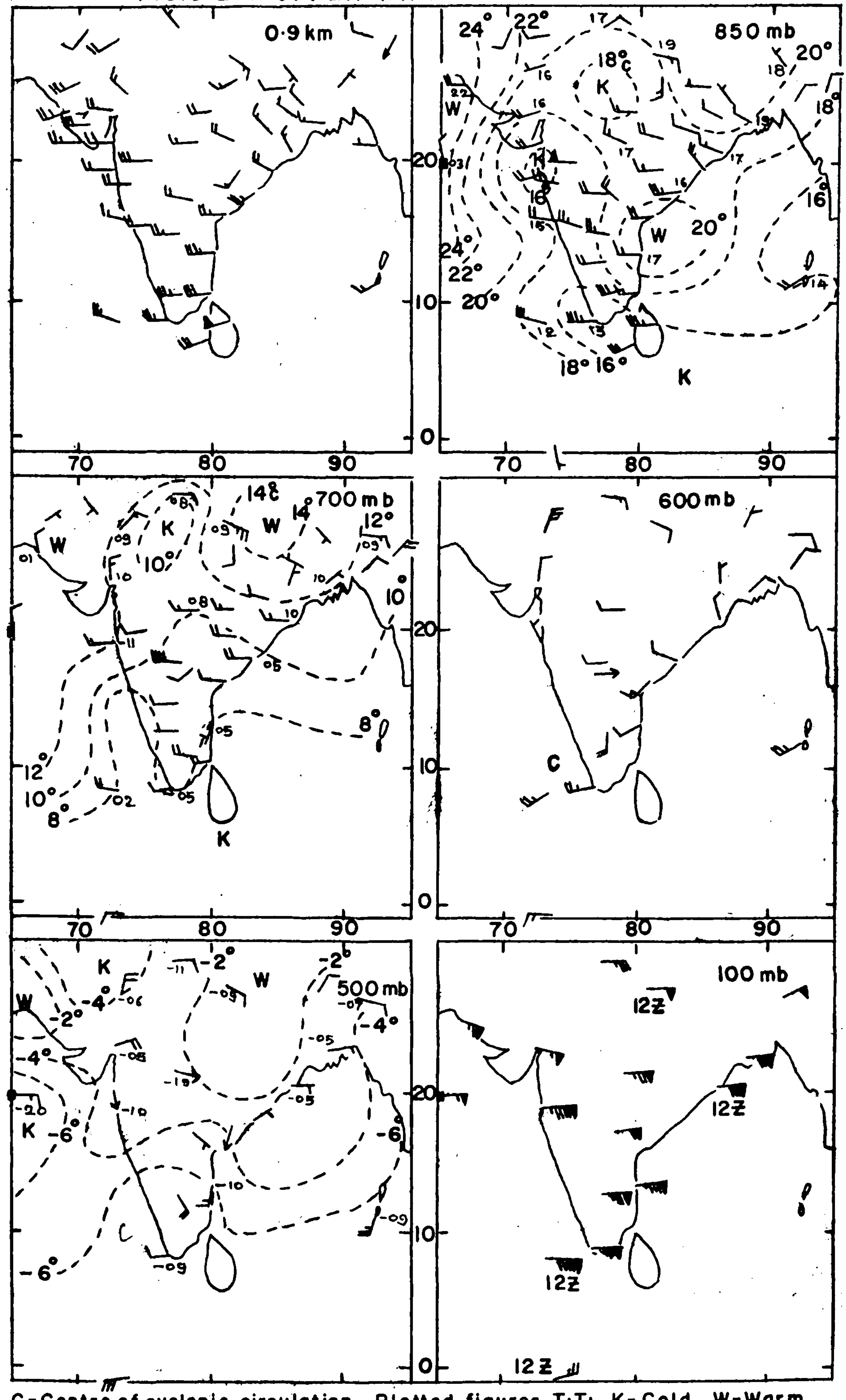
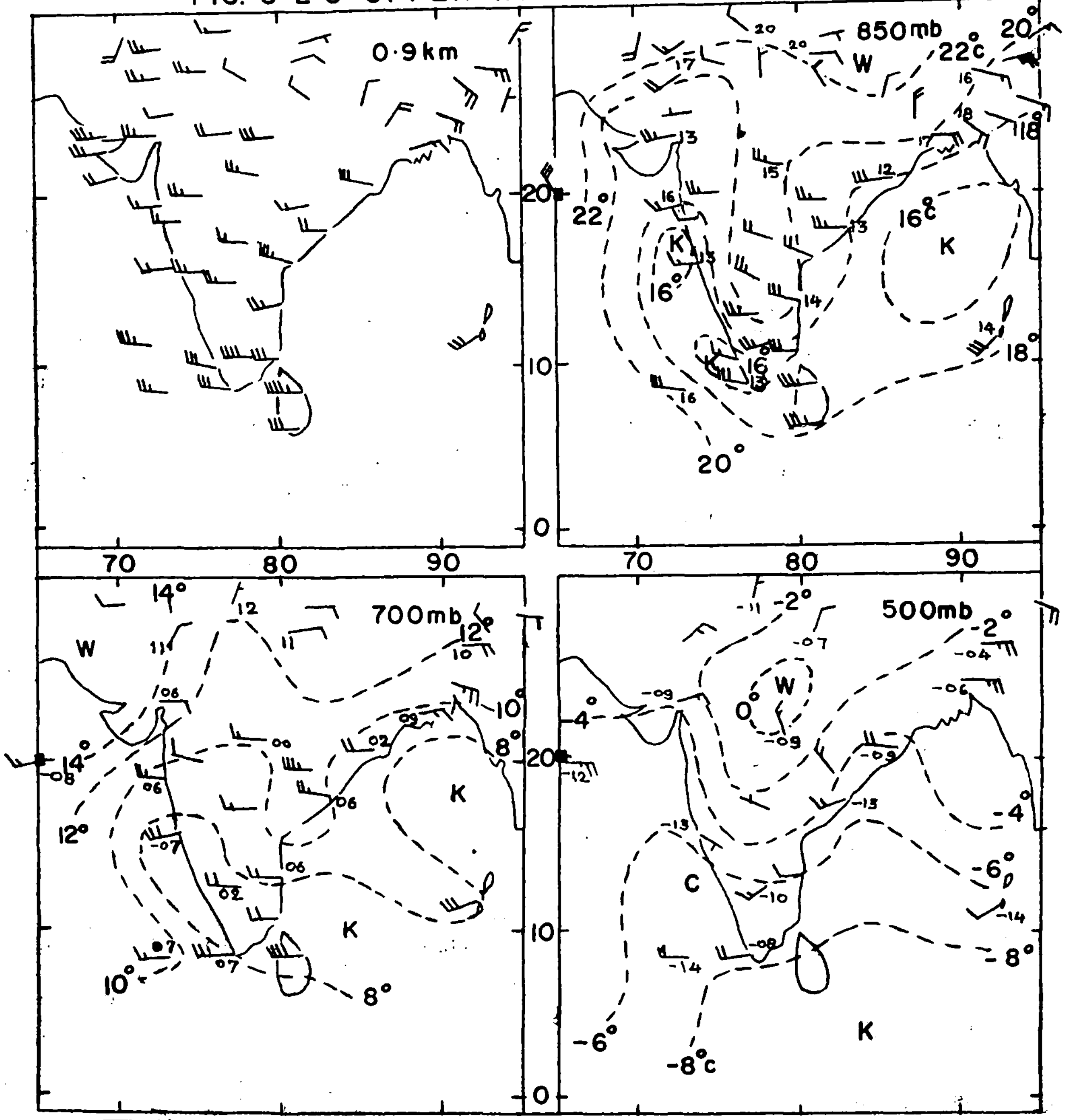


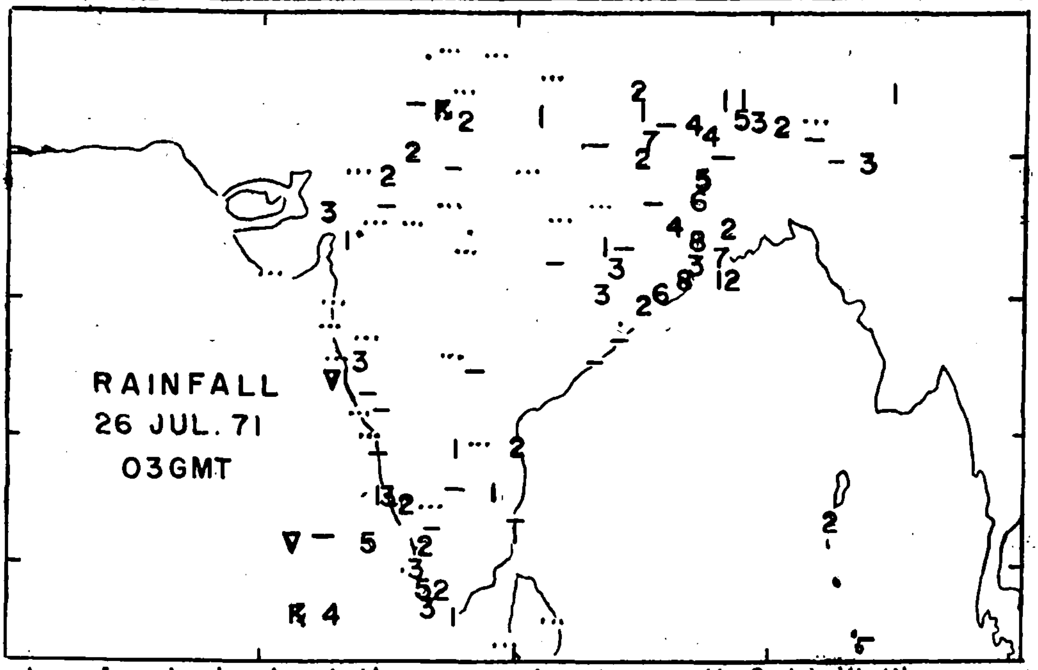
FIG.5·2·4 UPPER WINDS 25 JUL.71 00GMT



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

FIG. 5·2·5 UPPER WINDS 26 JUL. 71 00GMT





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

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

FIG5·2·6 SYNOPTIC CHARTS 0300 GMT 27 JUL.71

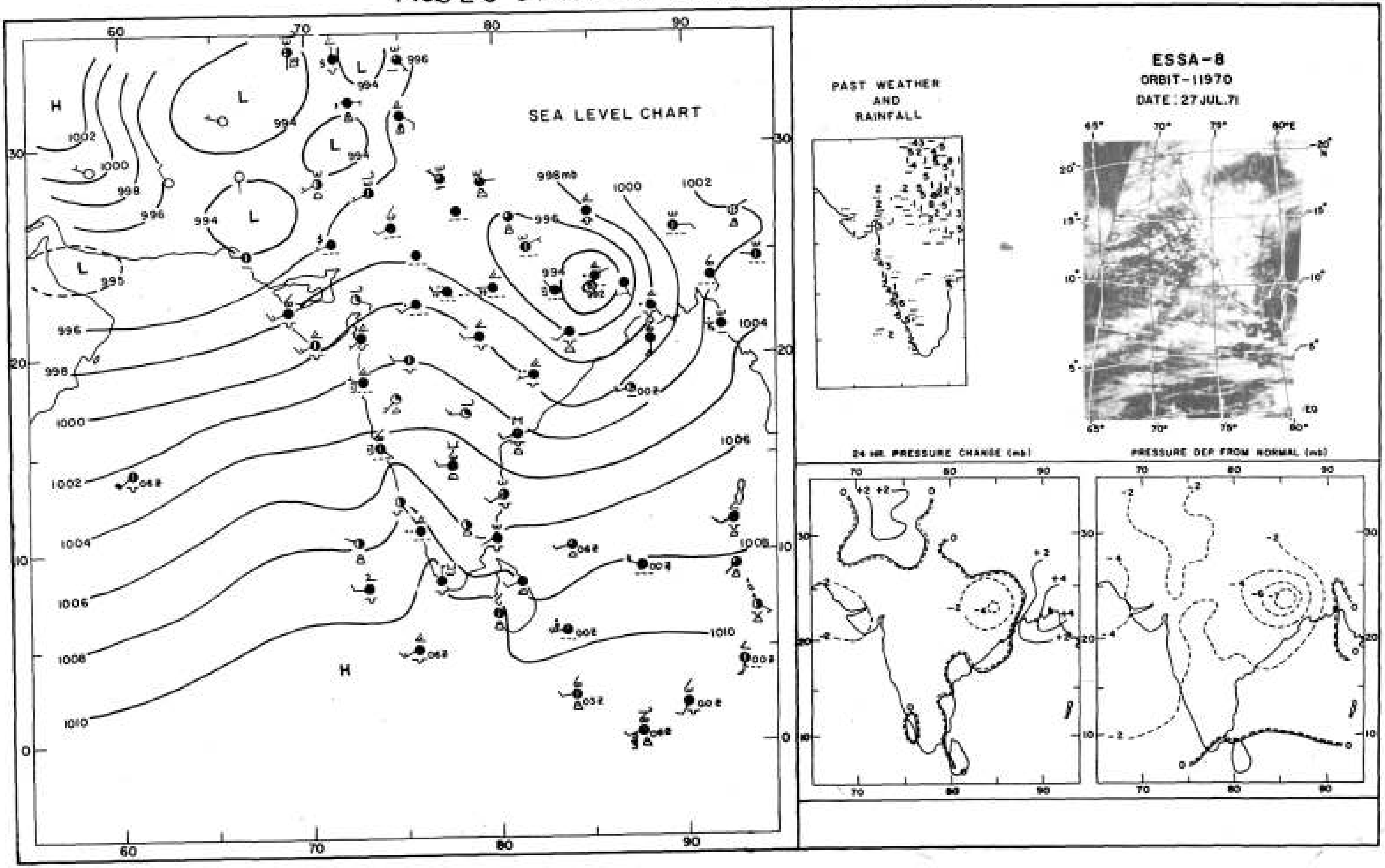
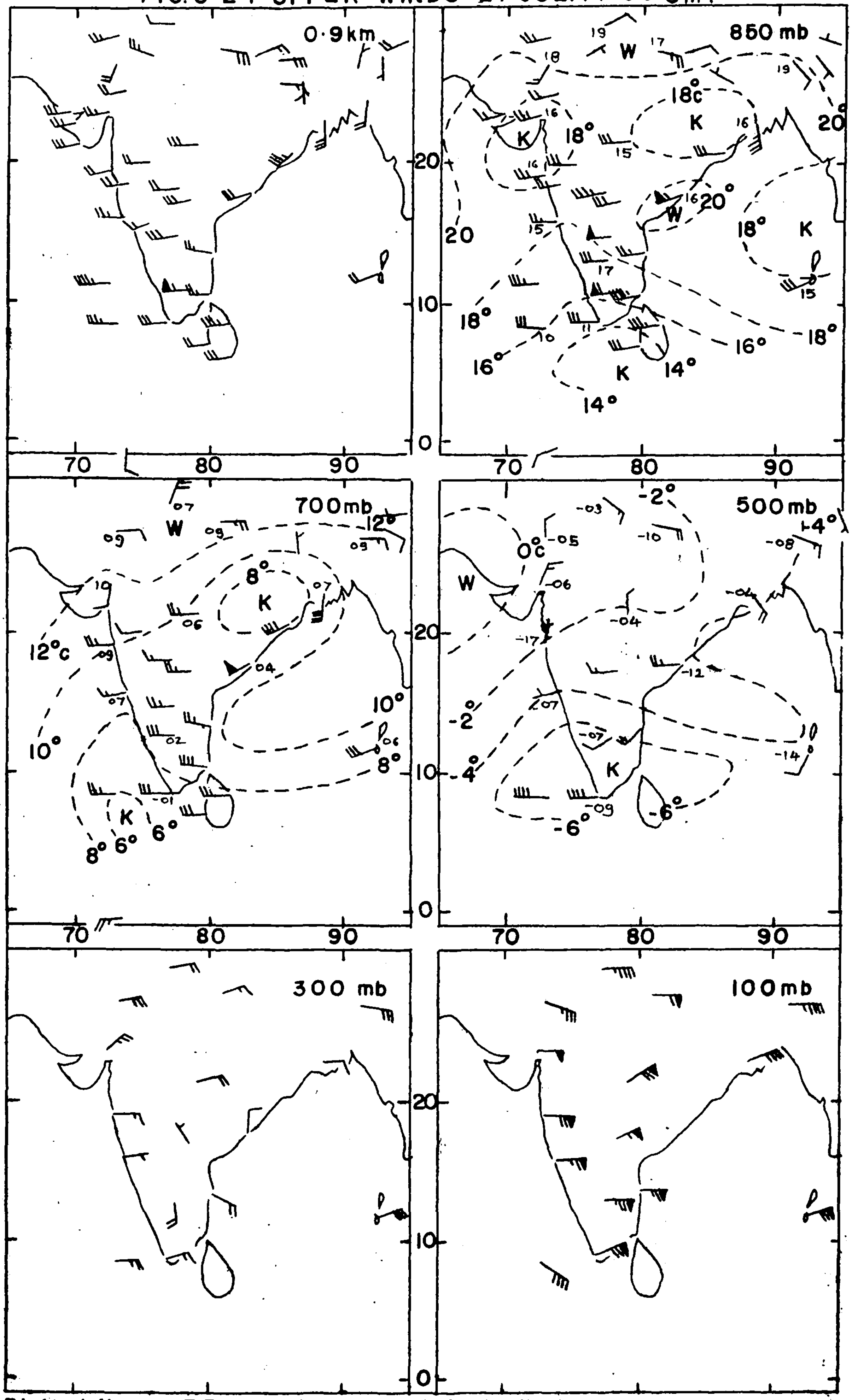


FIG. 5·2·7 UPPER WINDS 27 JUL. 71 00 GMT



Plotted figures T_dT_d ----- Isotherm K-Cold W-Warm

FIG. 5-2-8 CROSS SECTION OF UPPER WINDS: 23-28 Jul. 1971

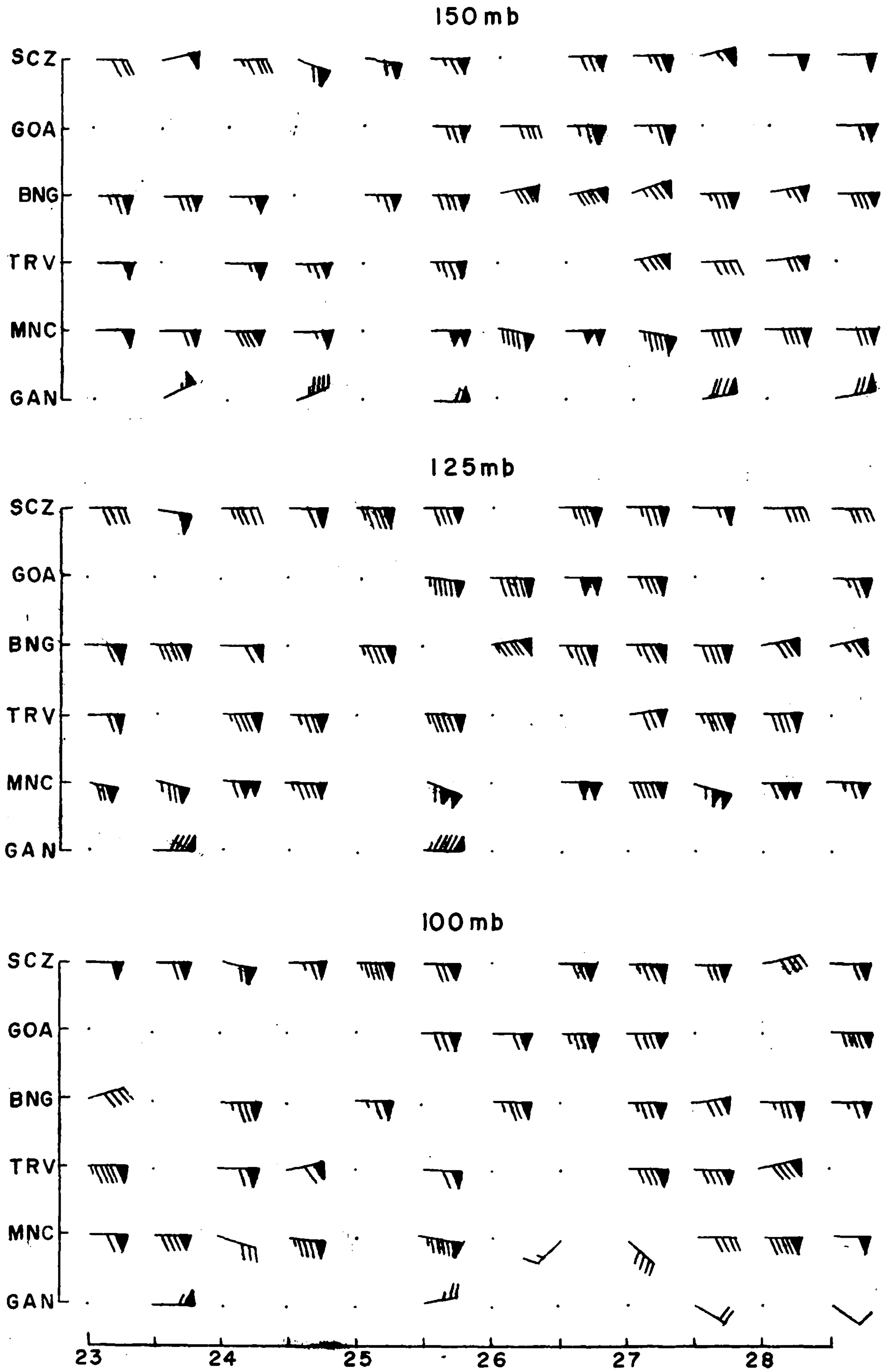


FIG5·3·1 SYNOPTIC CHARTS 0300 GMT 18 AUG. 71

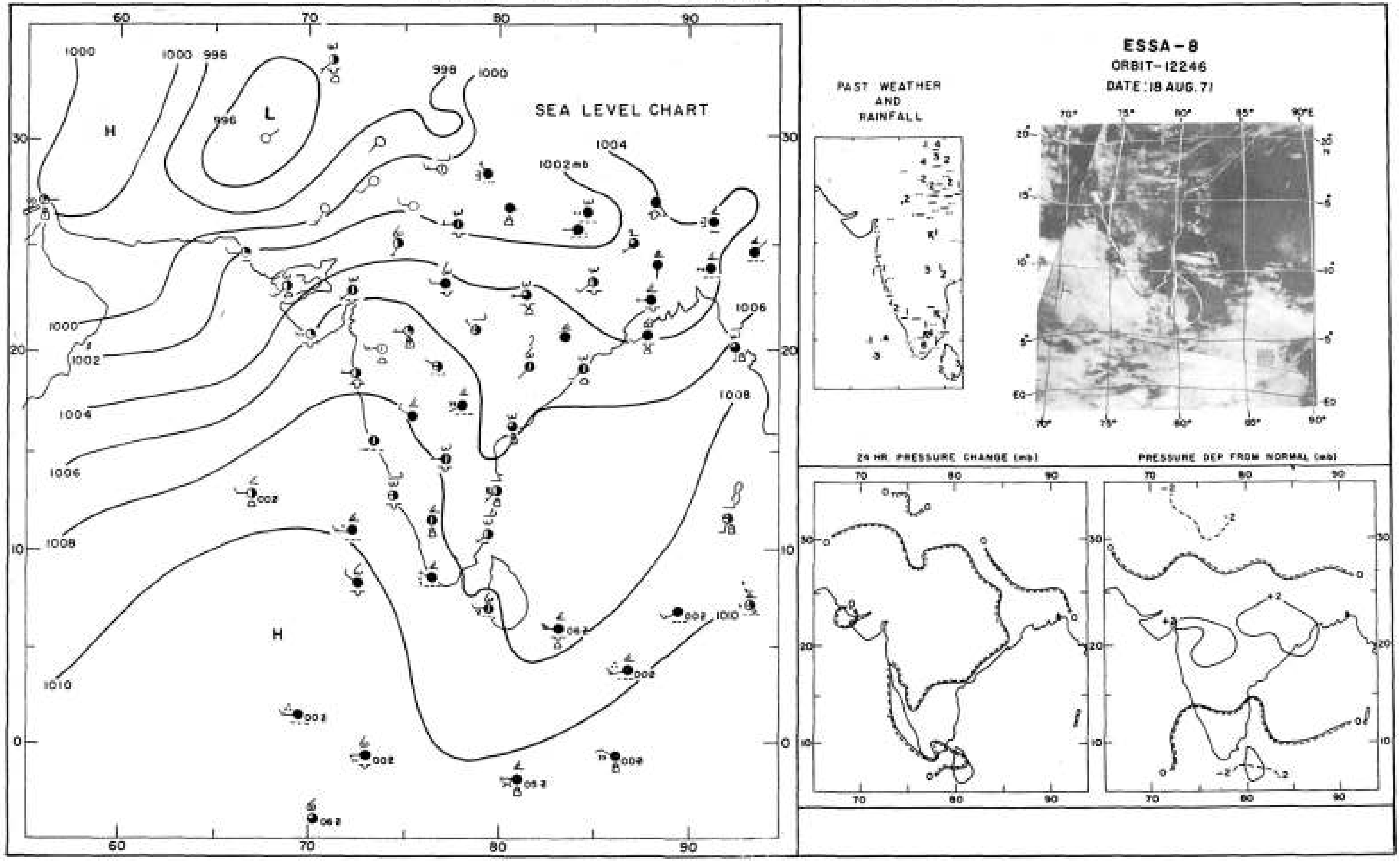
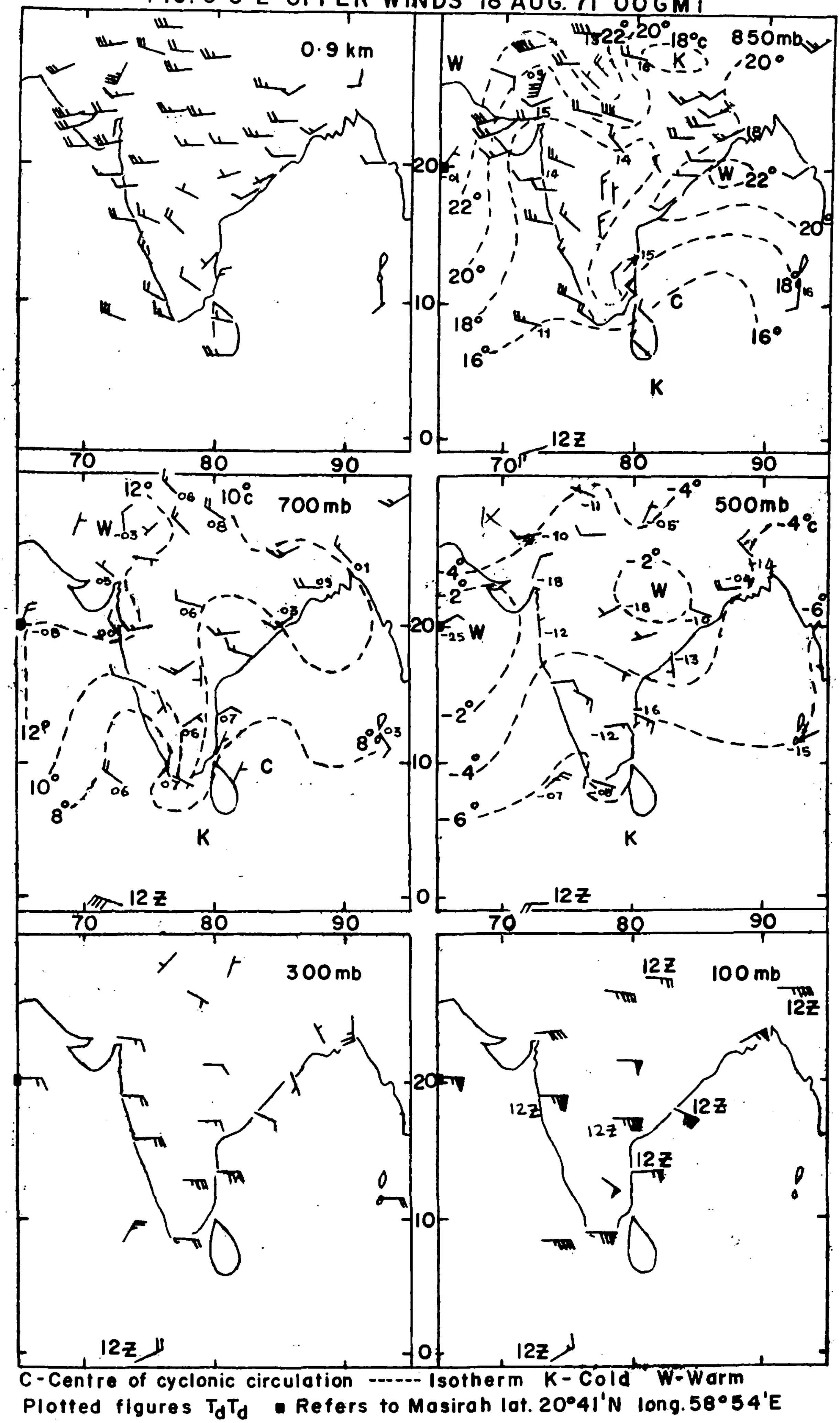


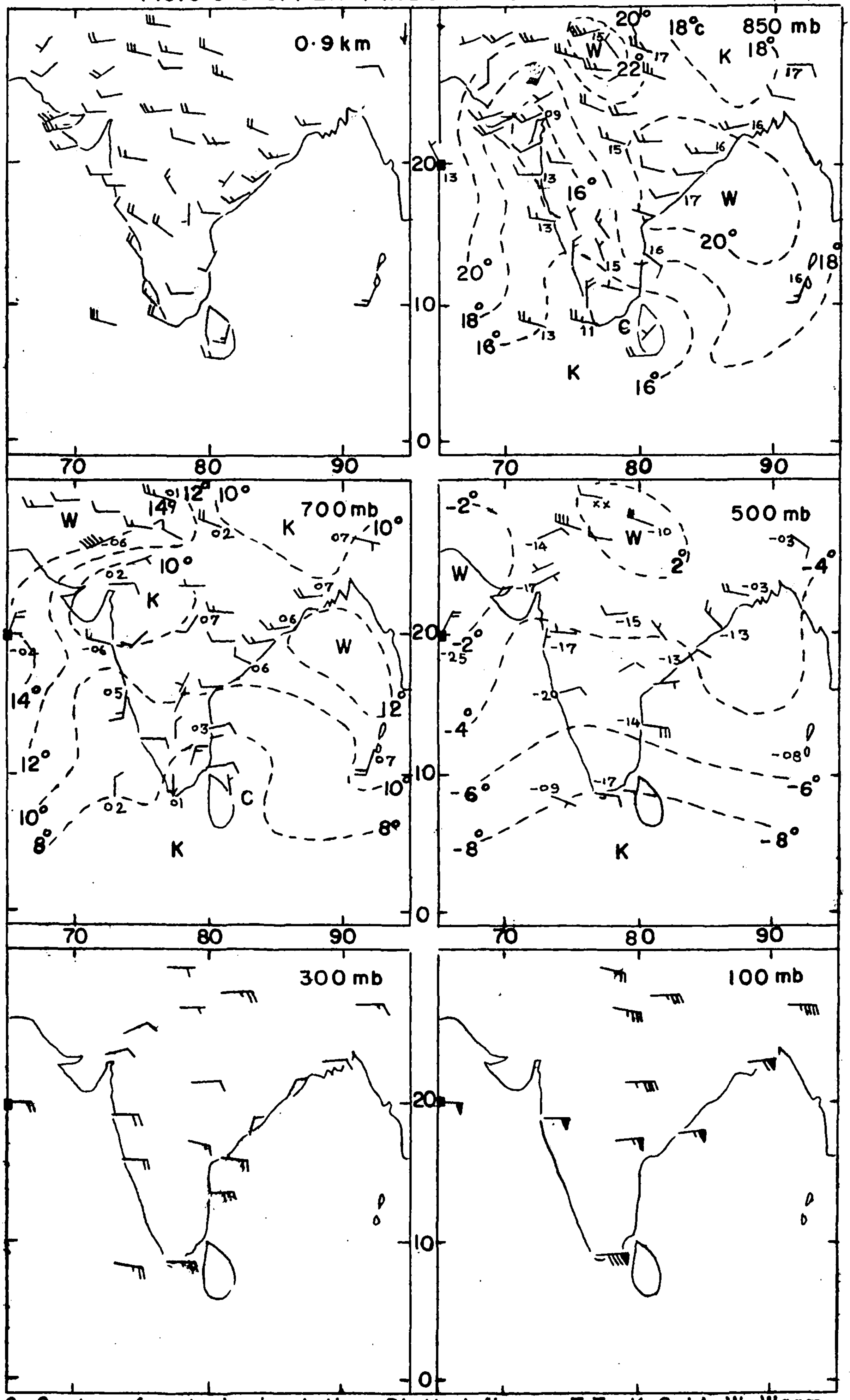
FIG. 5·3·2 UPPER WINDS 18 AUG. 71 00 GMT



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

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

FIG. 5·3·3 UPPER WINDS 19 AUG. 71 00 GMT



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

FIG.5·3·4 SYNOPTIC CHARTS 0300 GMT 19 AUG. 71

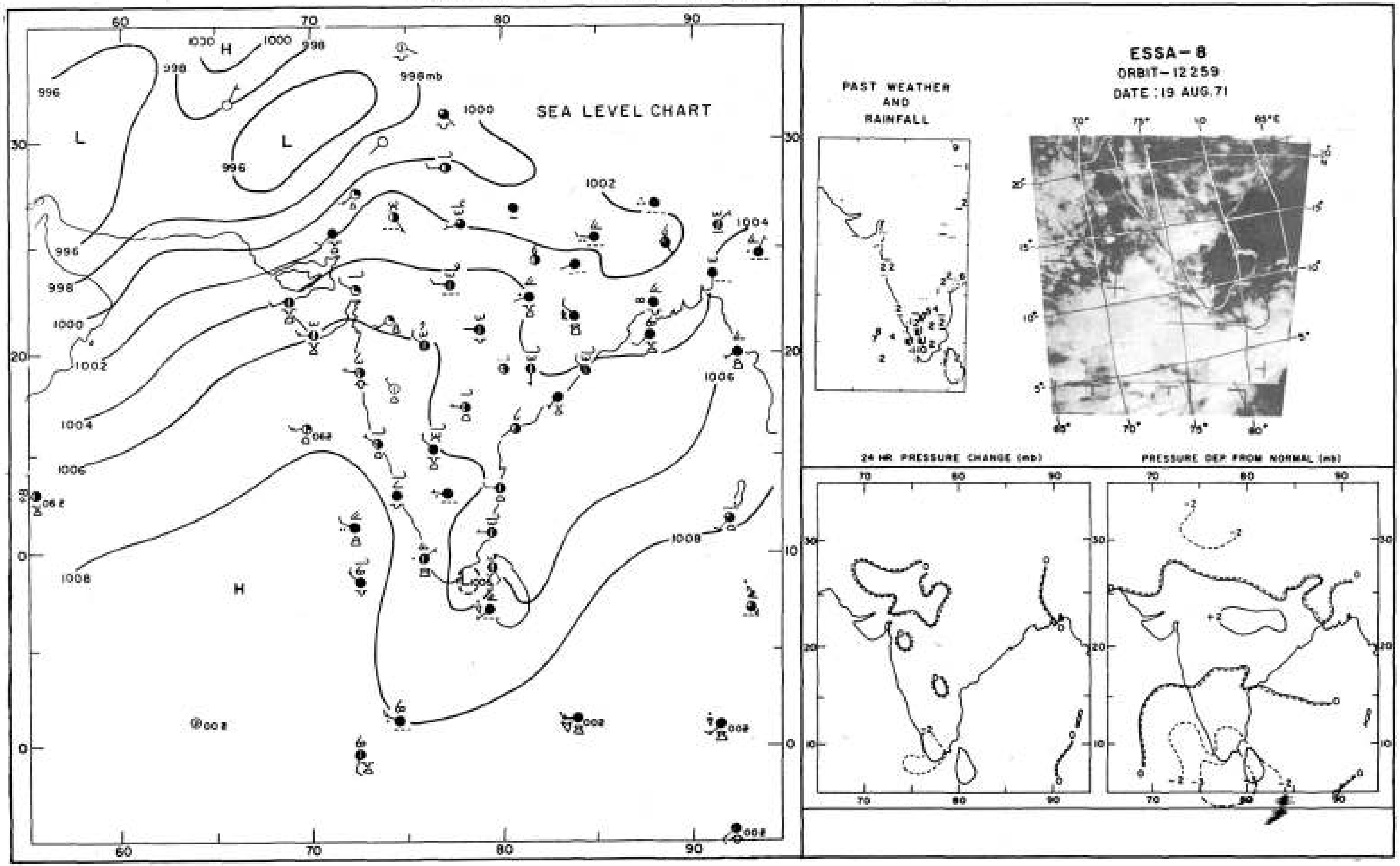


FIG. 5·3·5 19 AUGUST 1971 1200 GMT

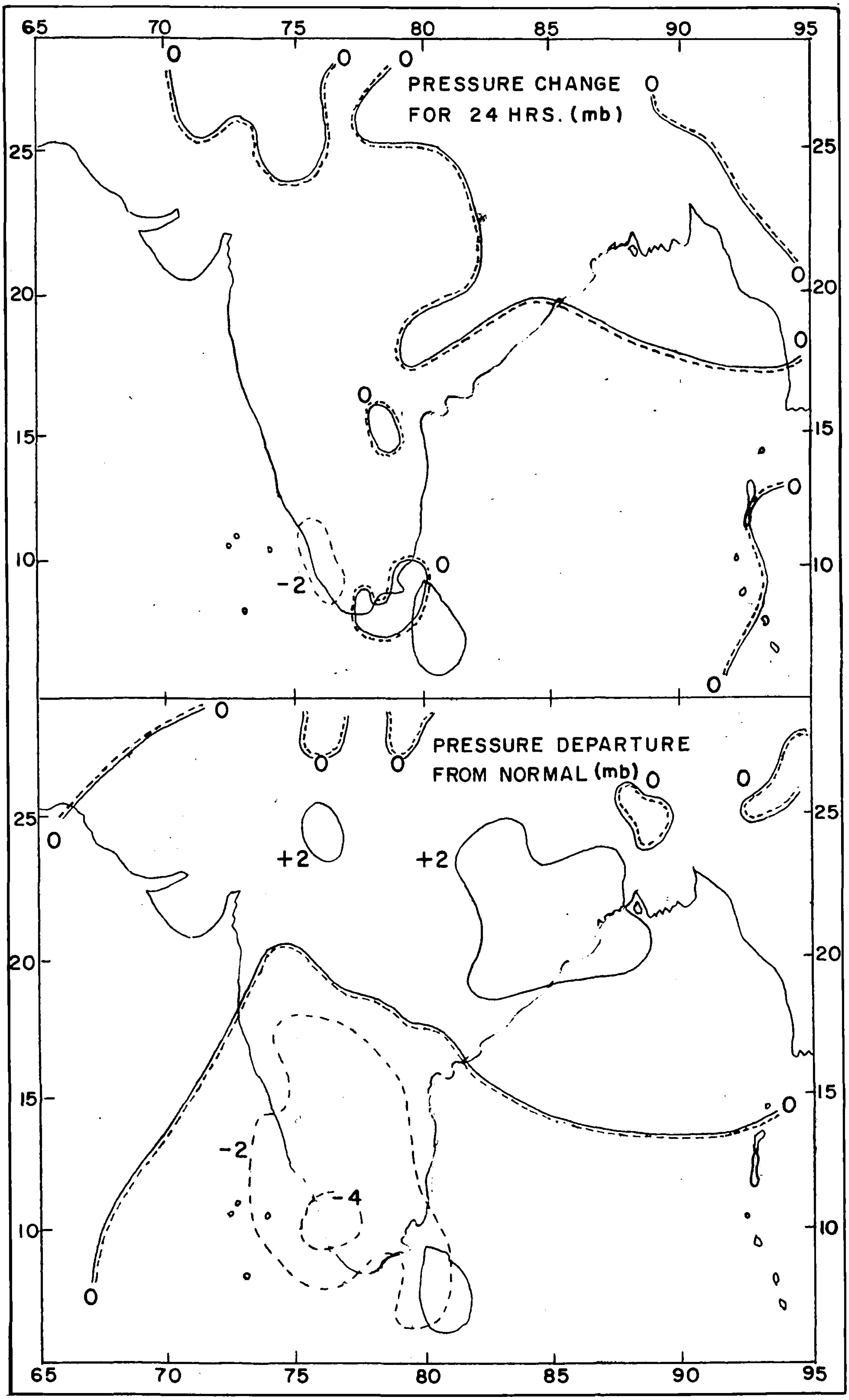


FIG5·3·6 SYNOPTIC CHARTS 03 00 GMT 20 AUG. 71

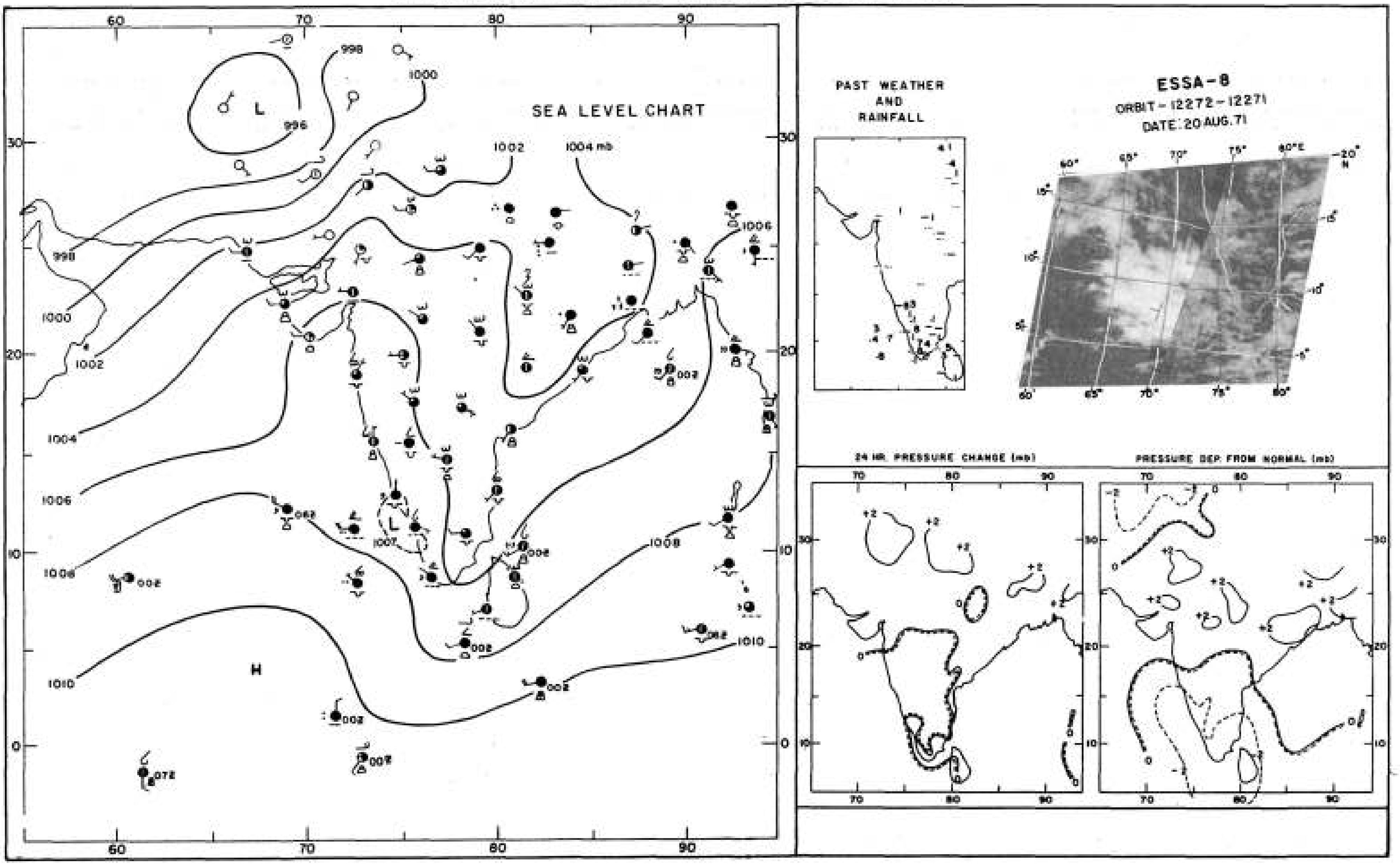
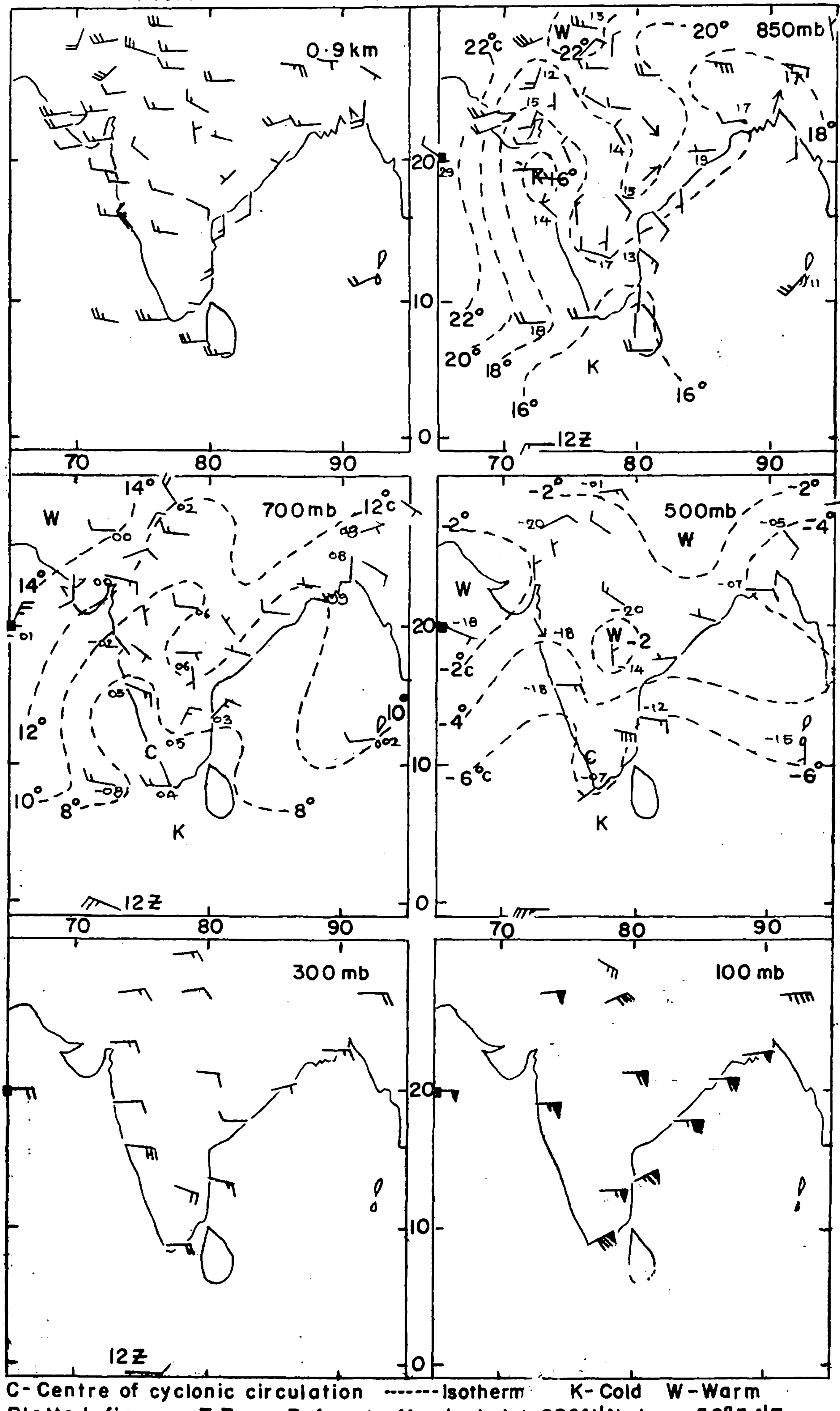


FIG. 5·3·7 UPPER WINDS 20 AUG. 71 00 GMT



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

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

FIG. 5·3·8 20 AUGUST 1971 1200 GMT

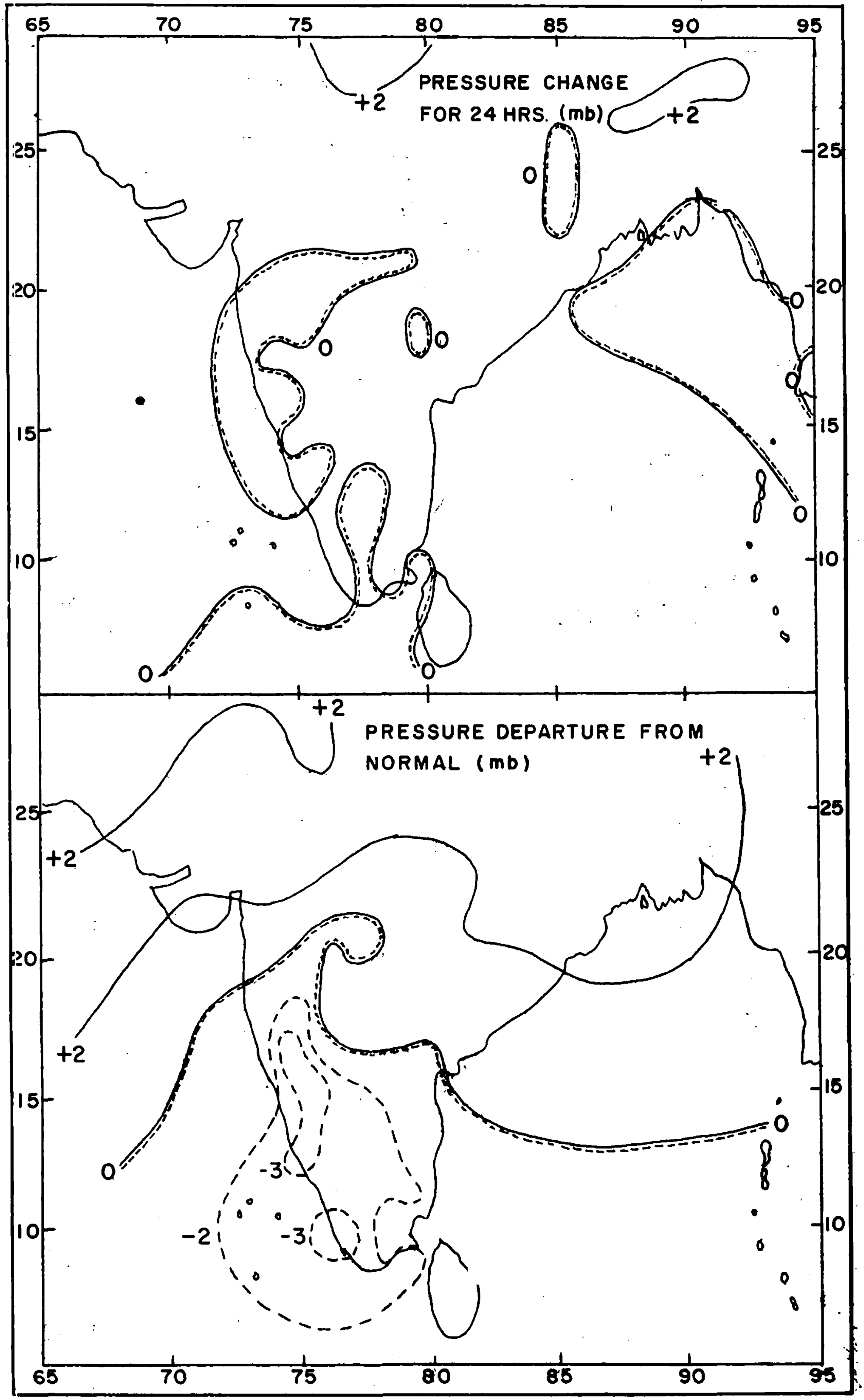
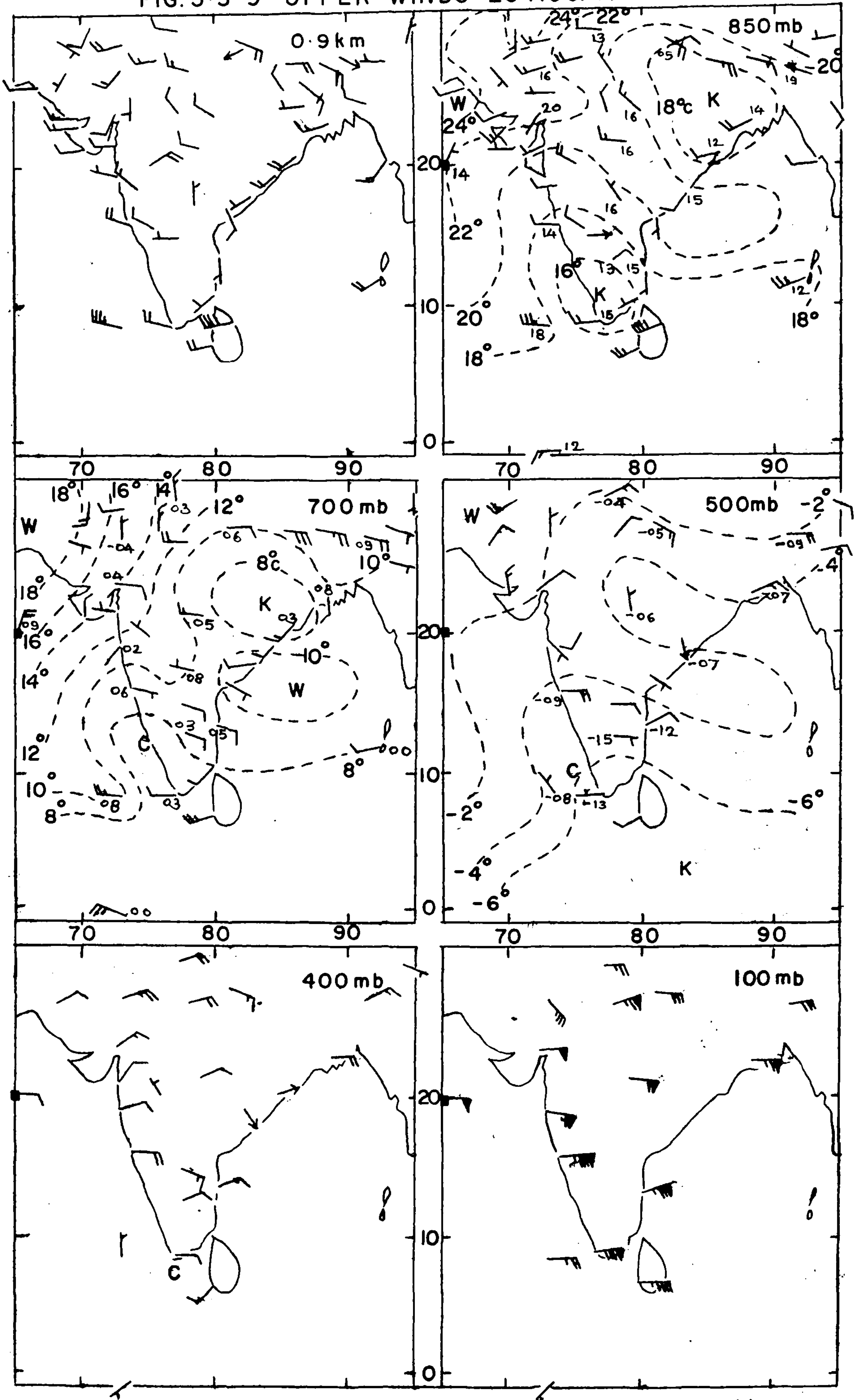


FIG. 5·3·9 UPPER WINDS 20 AUG. 71 12 GMT



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

FIG5·3·10 SYNOPTIC CHARTS 0300 GMT 21 AUG. 71

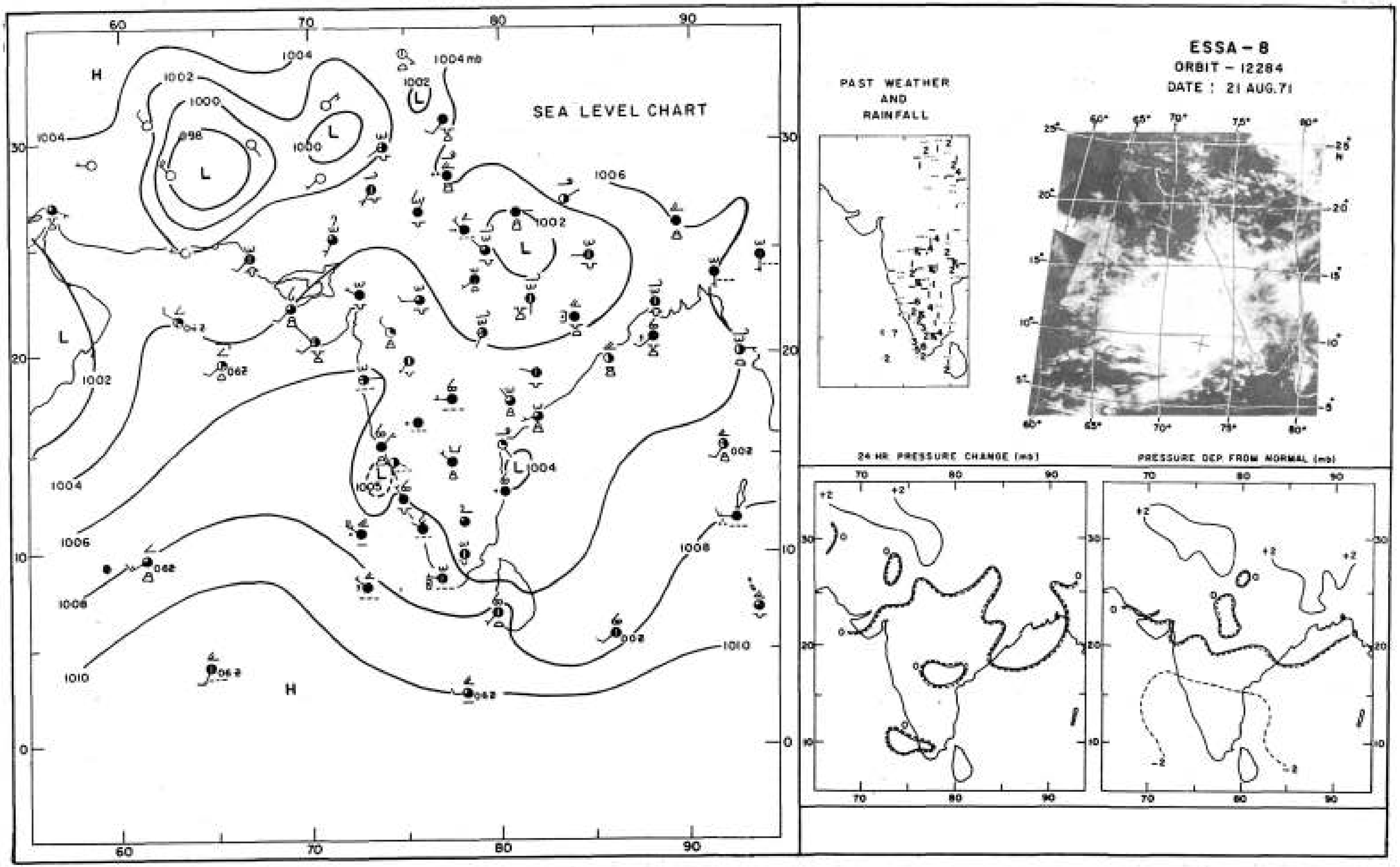
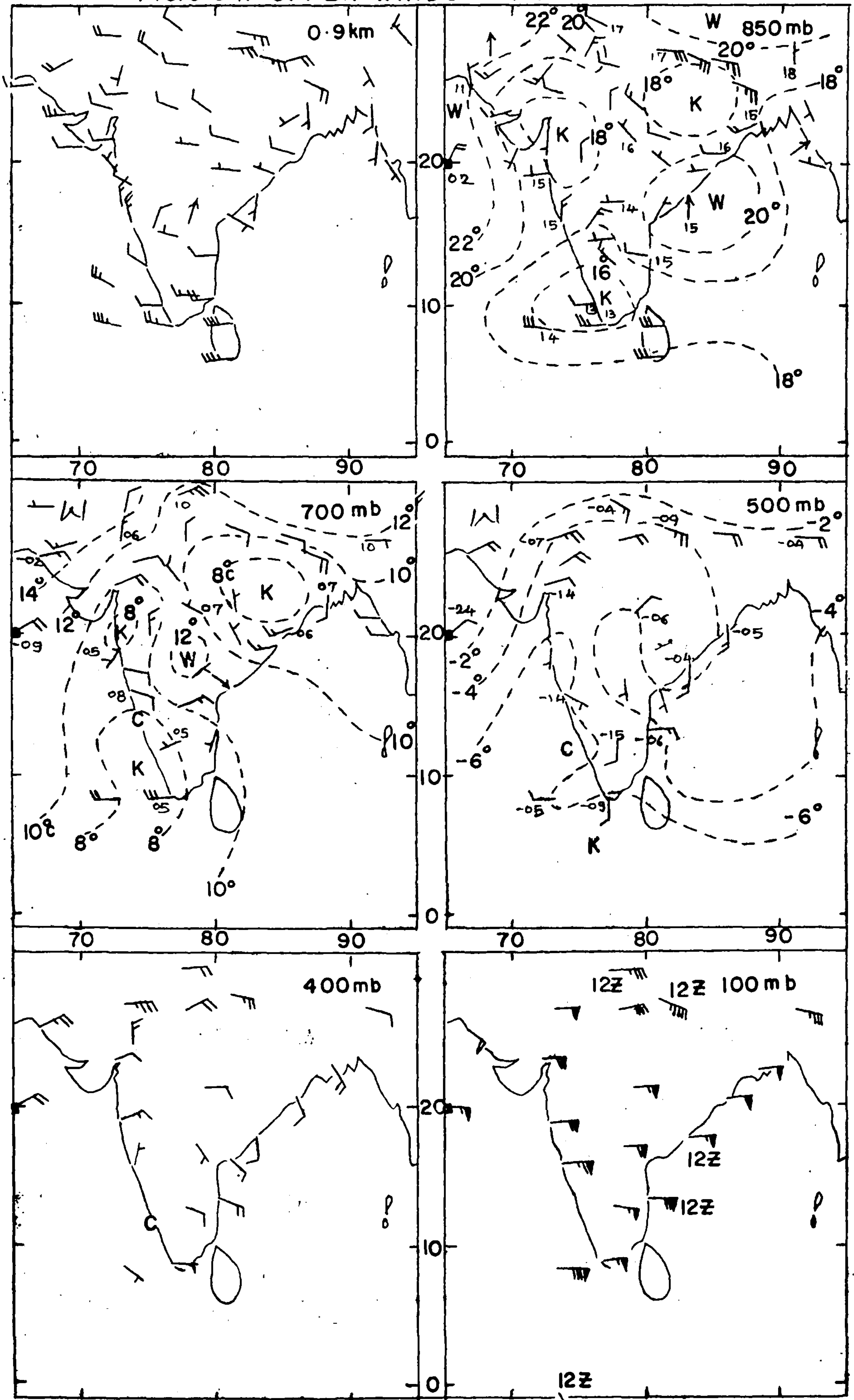


FIG.5·3·11 UPPER WINDS 21 AUG. 71 00GMT



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

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

FIG. 5·3·12 CROSS SECTION OF UPPER WINDS : 17-23 Aug. 1971

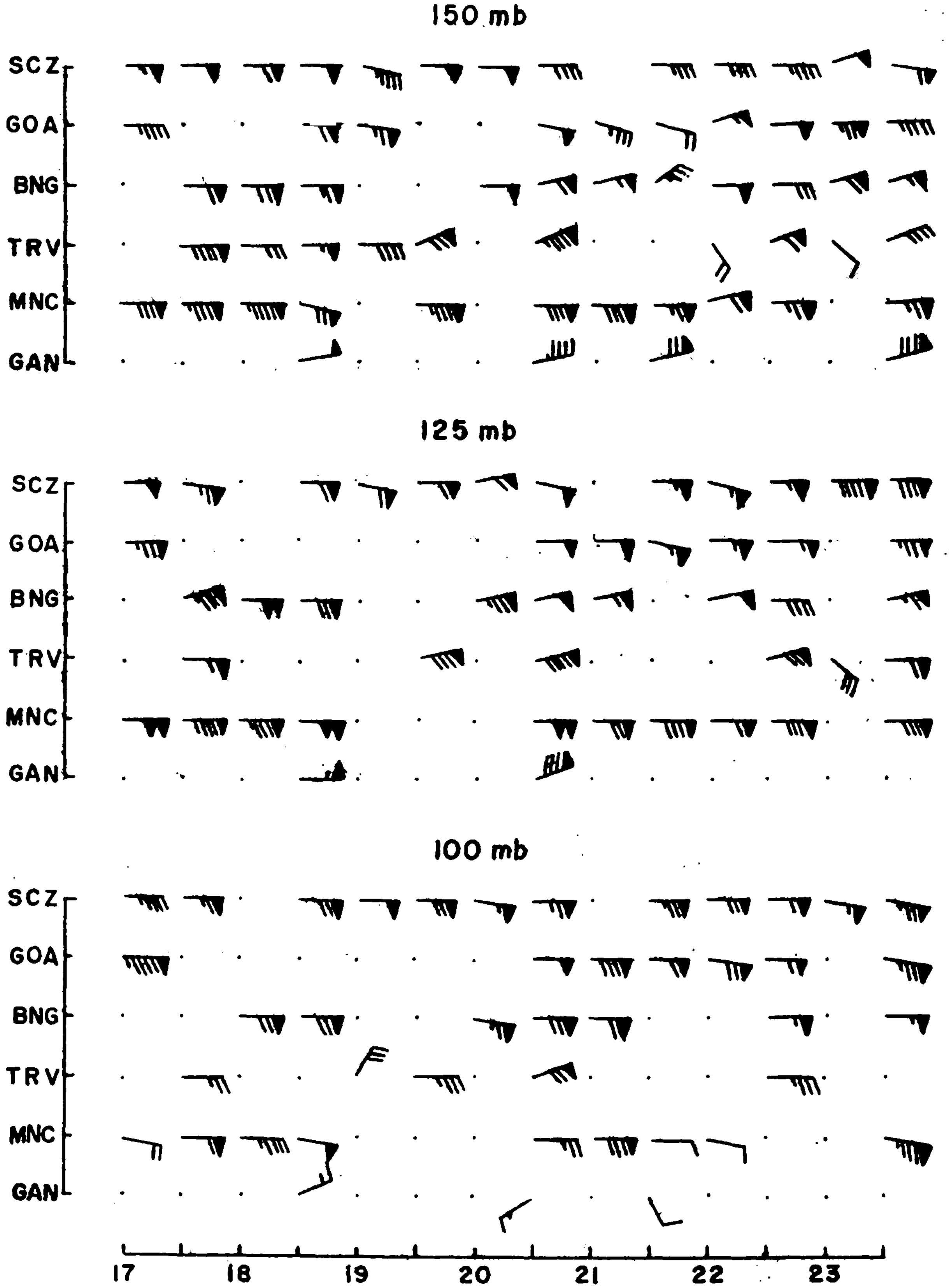


FIG. 6·1·1 SYNOPTIC CHARTS 0300 GMT 11 AUG. 69

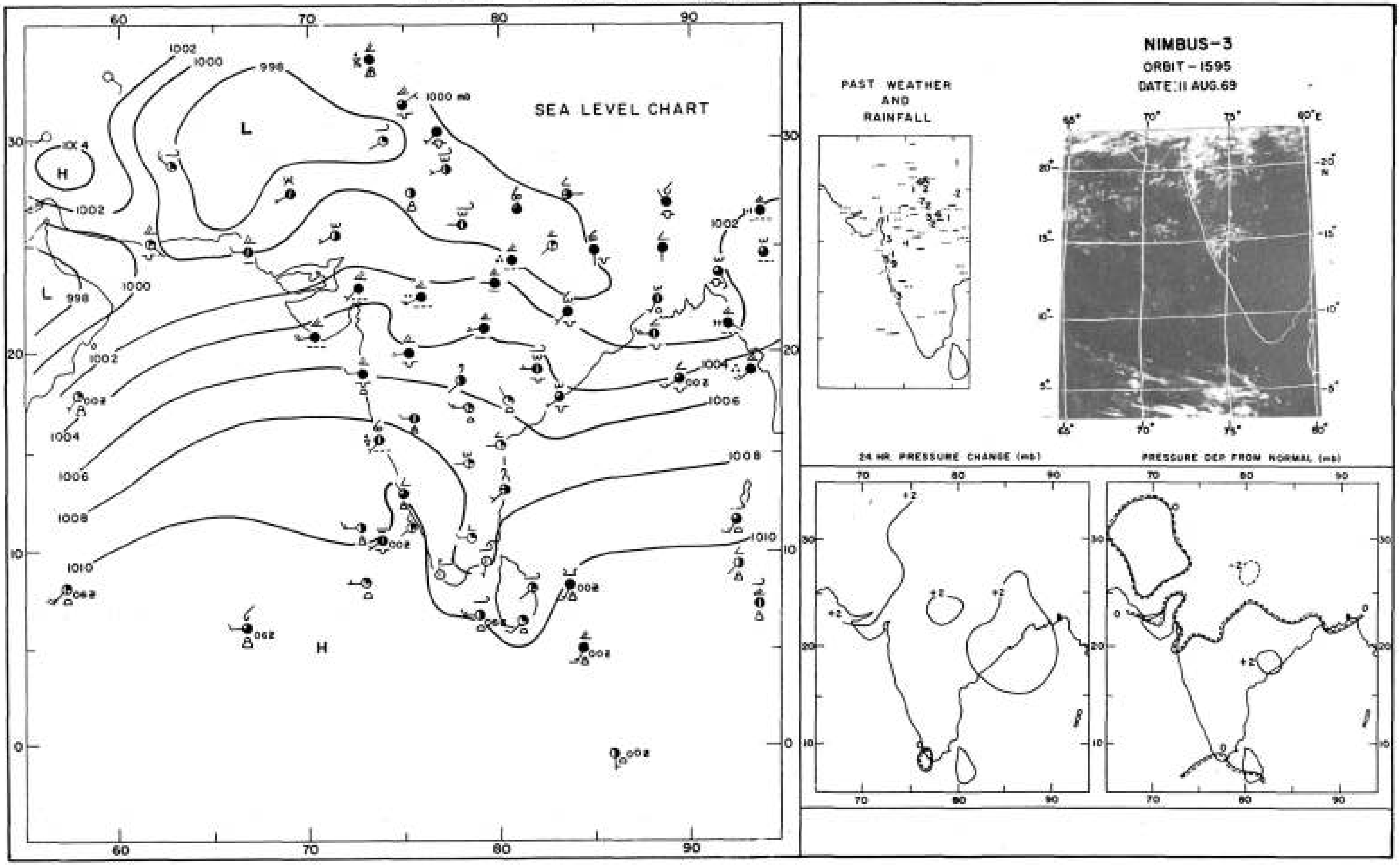


FIG. 6·1·2 UPPER WINDS 11 AUG. 69 00 GMT

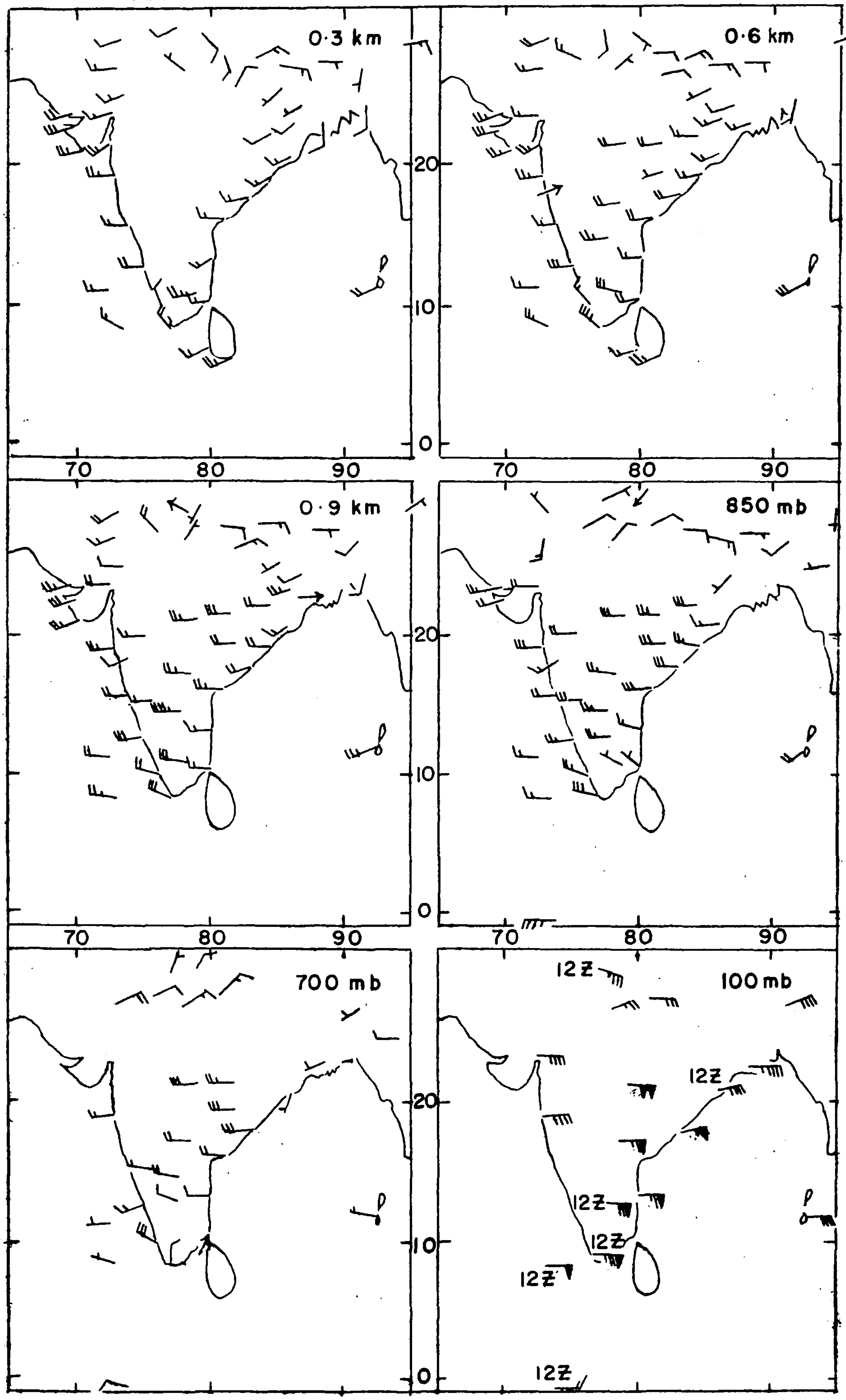


FIG.6·1·3 SYNOPTIC CHARTS 0300 GMT 12 AUG. 69

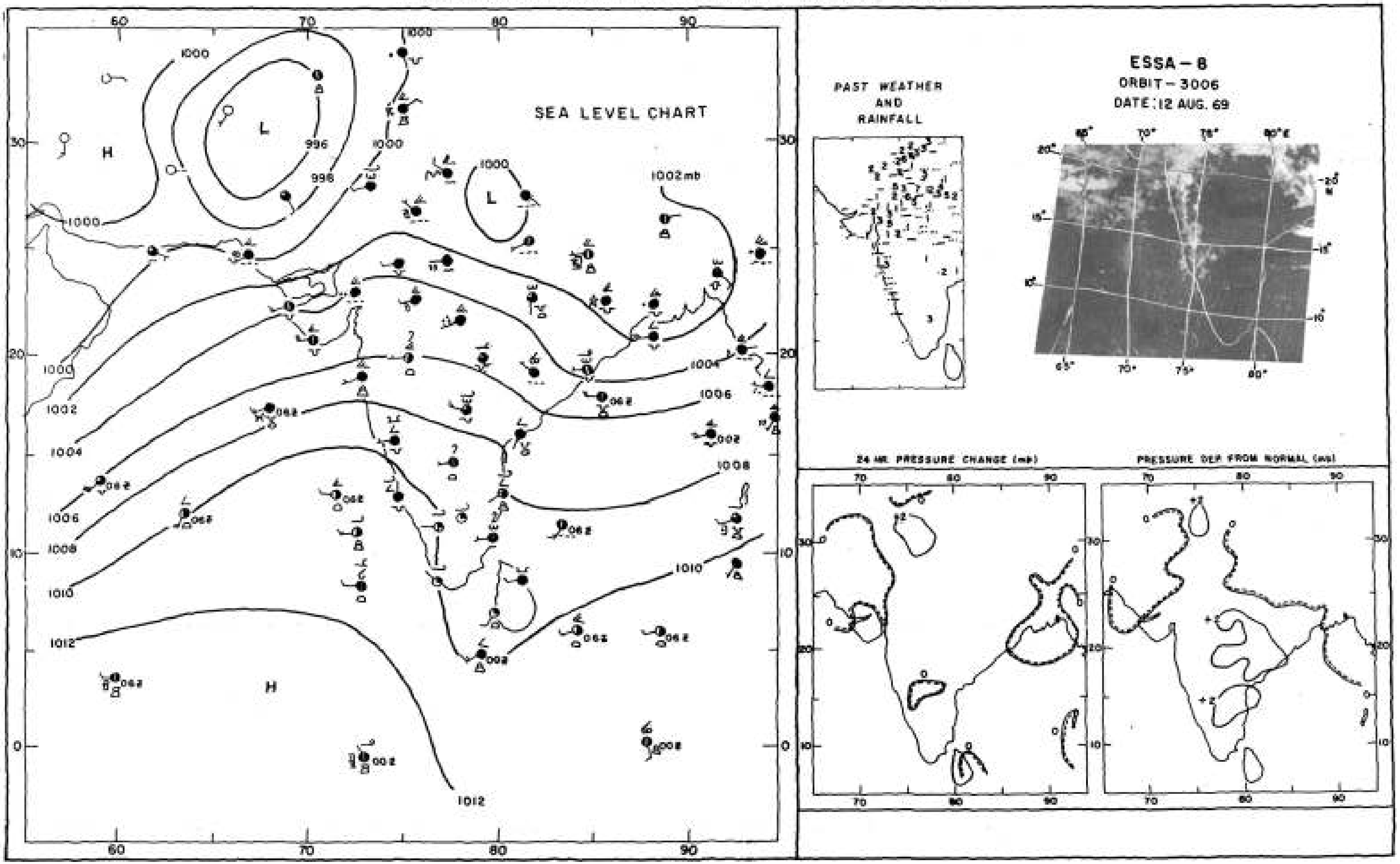


FIG. 6·1·4 UPPER WINDS 12 AUG. 69 00GMT

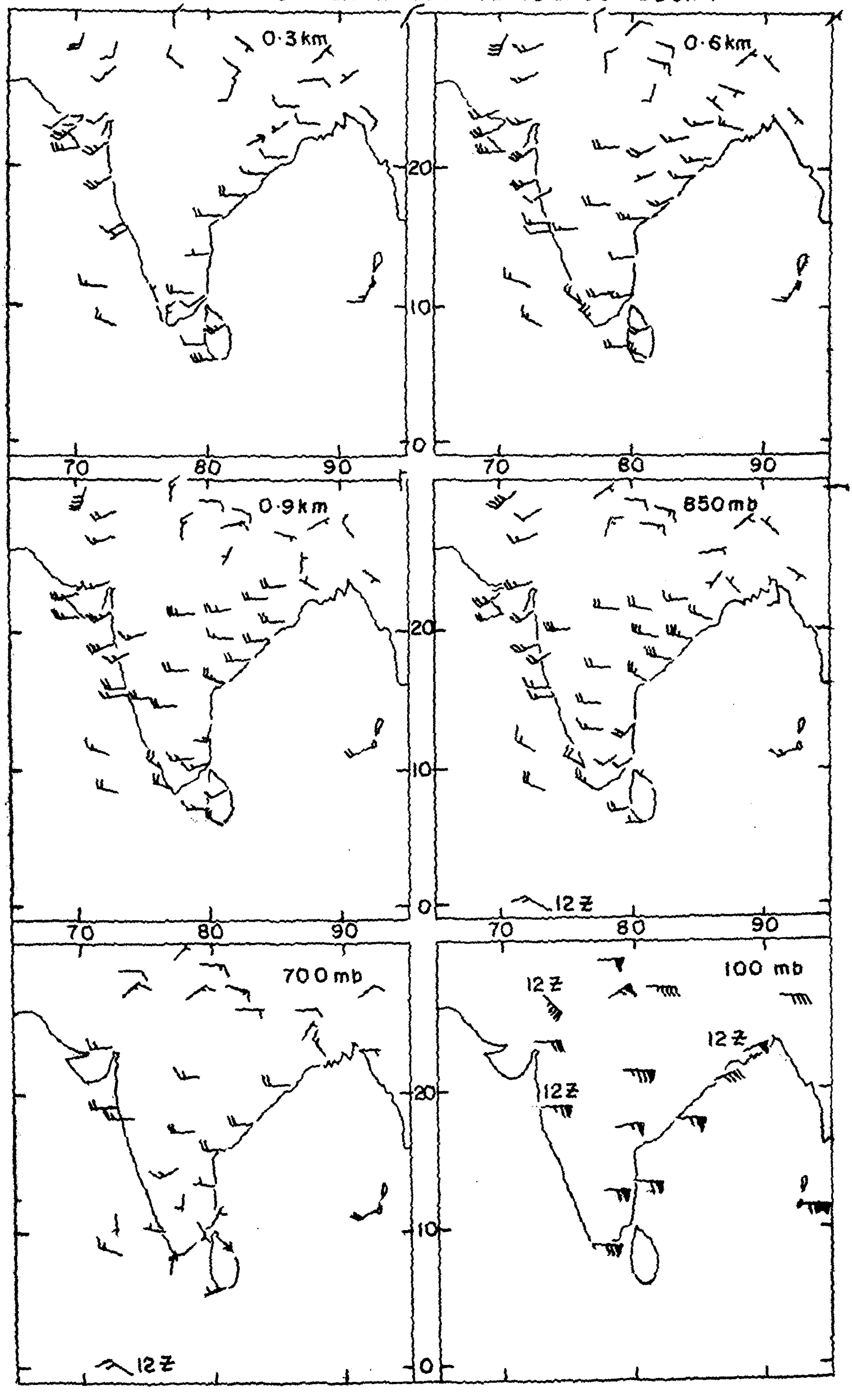


FIG.6·1·5 SYNOPTIC CHARTS 0300 GMT 13 AUG. 69

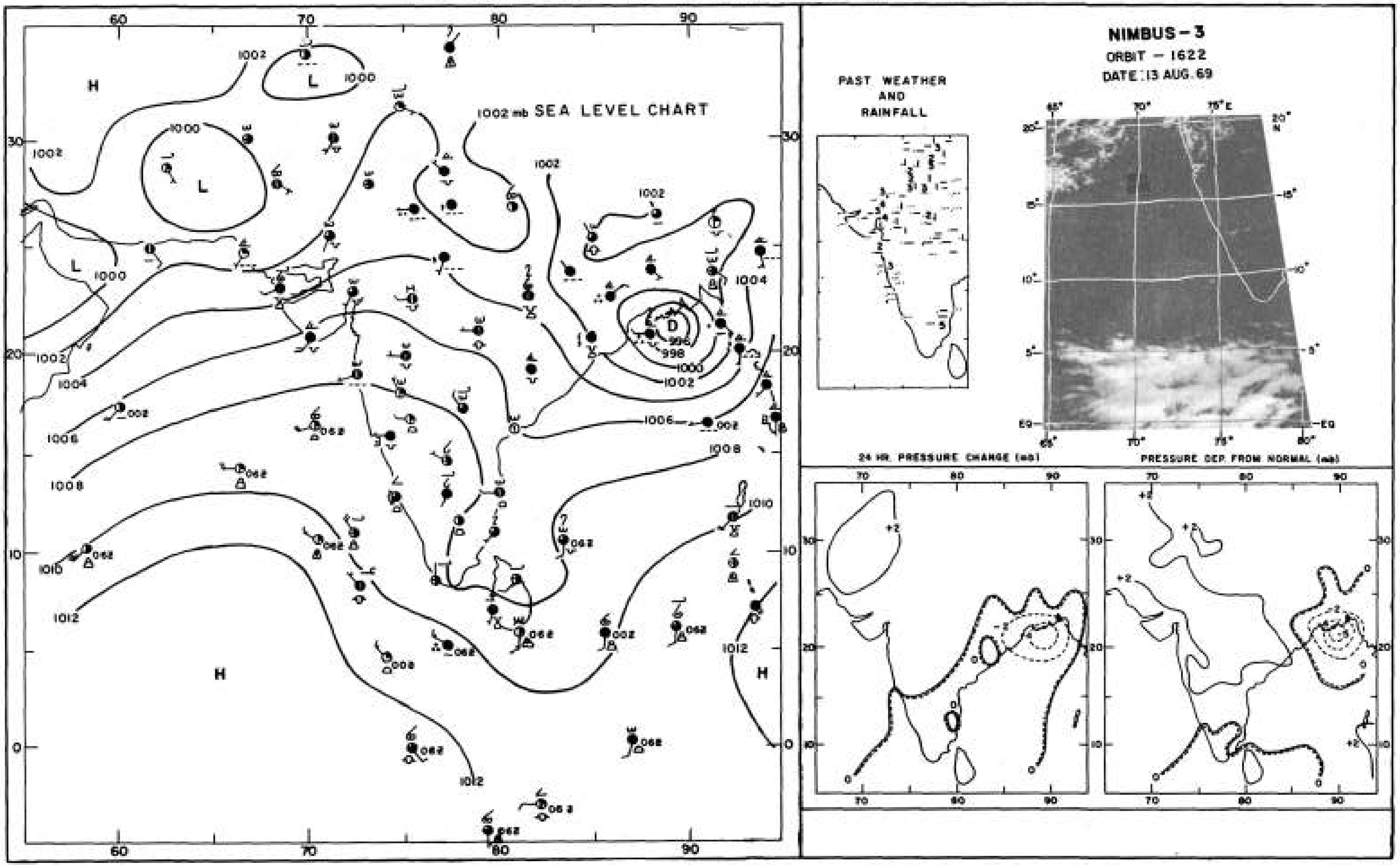


FIG. 6·1·6 UPPER WINDS 13 AUG. 69 00GMT

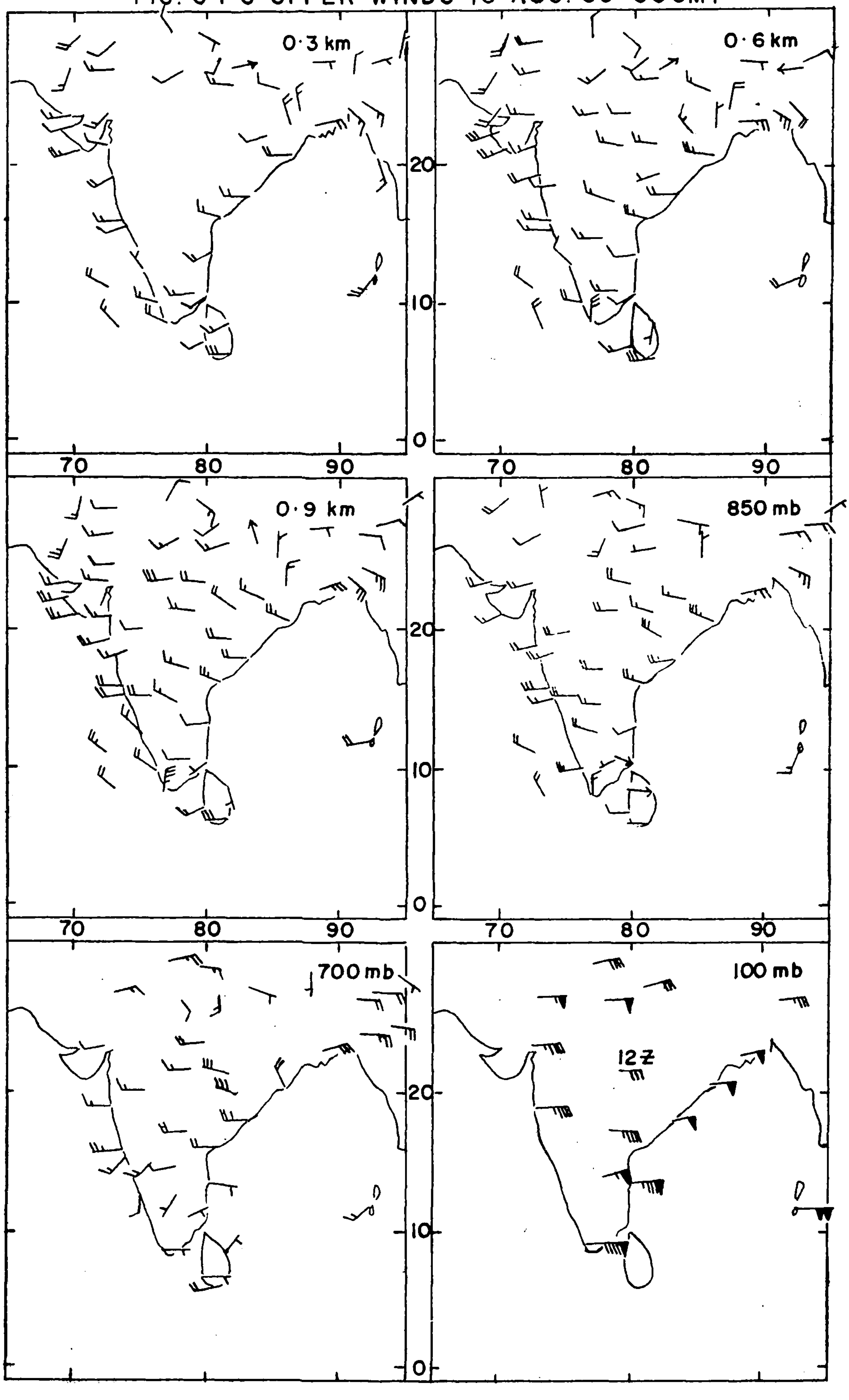


FIG.6·1·7 SYNOPTIC CHARTS 0300 GMT 14 AUG.69

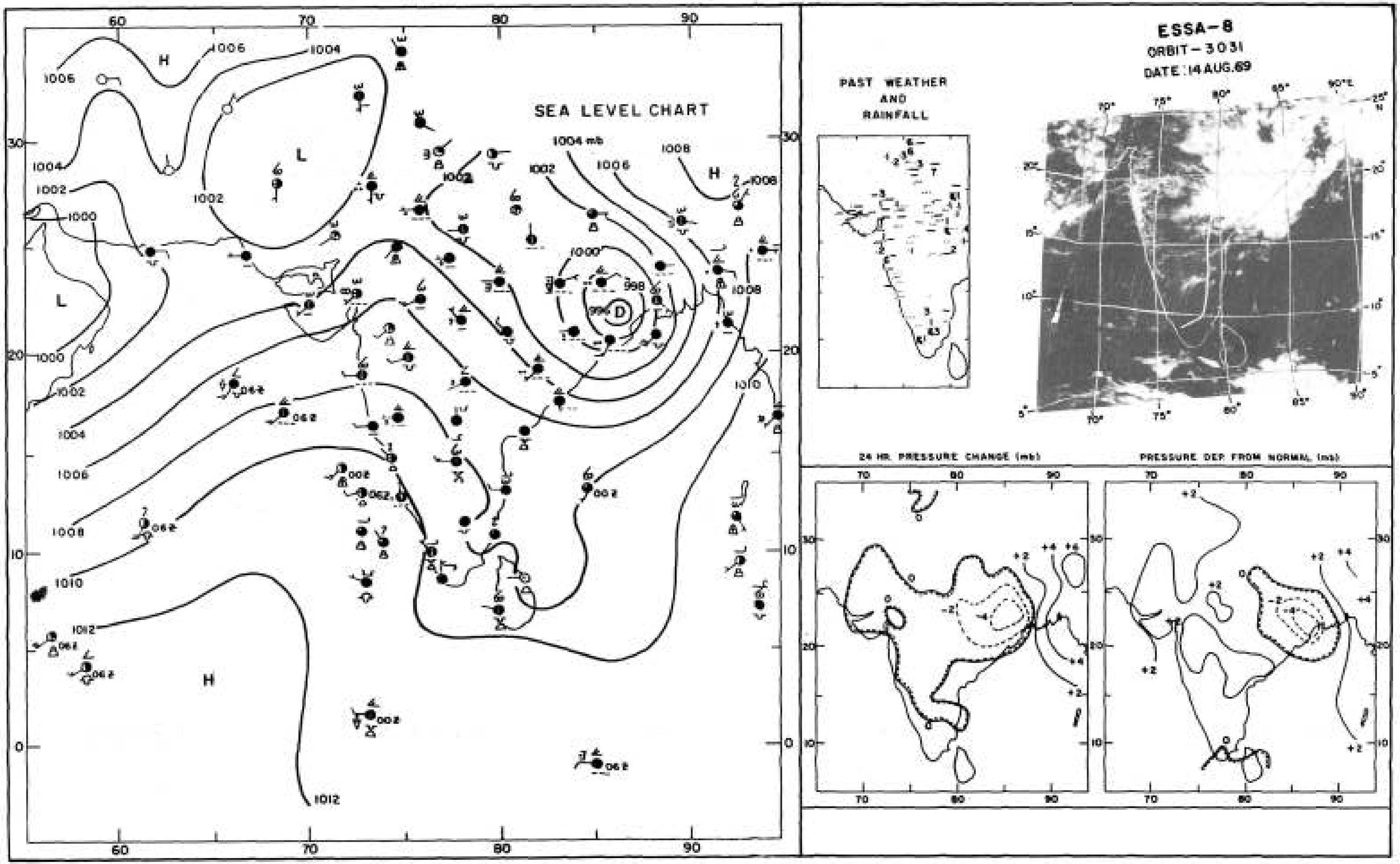


FIG. 6·1·8 TEPHIGRAM OF TRIVANDRUM FOR 1200GMT OF 13 AUG. 1969

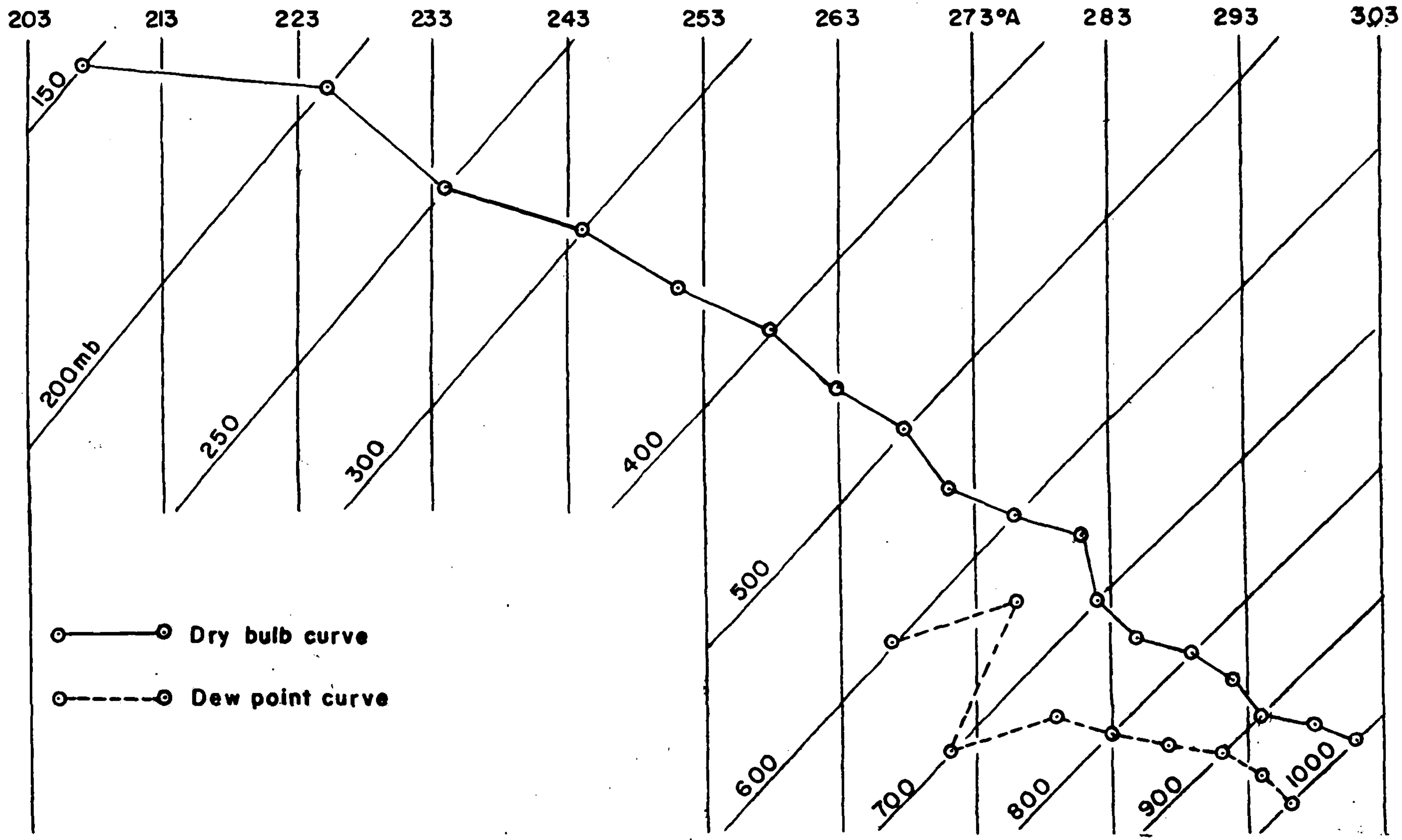


FIG. 6·1·9 TIME SECTION FOR TRIVANDRUM: 10-16 Aug.1969