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INDIA METEOROLOGICAL DEPARTMENT

FORECASTING MANUAL

PART IV

COMPREHENSIVE ARTICLES ON SELECTED TOPICS

18·4 NORTHEAST MONSOON

BY

V. SRINIVASAN AND K. RAMAMURTHY

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FORECASTING MANUAL

Part IV - Comprehensive Articles on Selected Topics

18.4 Northeast Monsoon

by

V. Srinivasan and K. Ramamurthy

Contents:

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1. Introduction

1.1 October to December is the major period of rainfall in south Peninsula, particularly the eastern half, comprising of the meteorological sub-divisions of Coastal Andhra Pradesh, Rayalaseema and Tamil Nadu. In Tamil Nadu, this is the main rainy season accounting for nearly 60% of the annual rainfall in the coastal districts, and about 40% to 50% in the interior districts of the state. Though the principal rainy season for South Interior Mysore, Kerala and Arabian Sea Islands is the southwest monsoon, still rainfall continues till almost December in these sub-divisions, the period October to December contributing about 20% of the annual total. In Rayalaseema, September and October are the rainiest months, contributing 36% of the annual total.

1.2 The term "Northeast Monsoon" is often used to describe the period October to December. However, according to the departmental classification of the year into seasons, these three months constitute the "Post-Monsoon season"; it is also known as "the Retreating Southwest Monsoon Season". As early as 1886, Blandford, in his Memoirs on "Rainfall of India", has raised the question about the term, 'Northeast Monsoon Rains'. He says ".....it is hardly correct to speak of the Carnatic rains as those of the Northeast Monsoon, in as much as the rainfall ceases as soon as the monsoon is established down to Ceylon. It falls only so long as the region in question is within or on the borders of the barometric depression towards which the winds blow, not from the north only, but also from east, southeast, and other quarters.....". Though the term 'Northeast Monsoon' has been in use for a long time to describe the rainfall season of the southeast Peninsula, the appropriateness of the term has often been discussed. As recently as 1972, the topic came up for discussion in the Seventh Conference of Forecasting Officers, which was in favour of the retention of the term and recommended* that "the term Northeast Monsoon should continue to be used for rainfall season over south Peninsula during middle October to December".

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* This recommendation is under examination.

1.3 In this report, we will deal with the weather over the south Peninsula during the "Northeast Monsoon" period (i.e.) October–December, illustrated with typical synoptic situations.

2. General Features

2.1 With the withdrawal of the southwest monsoon from northern and central India and the northern parts of Peninsula, between the second half of September and the first half of October, the pressure and upper wind circulation patterns over India rapidly change from the summer monsoon type and the winter monsoon type flow pattern makes its appearance. By October, a low pressure area establishes itself over the central and south Bay of Bengal, which shifts to south Bay in November and further southwards to the south of Lat. 5°N in December. The low is somewhat more marked over west central and southwest Bay, particularly in October and November. In the Arabian Sea, though no low pressure area is seen during these months, an east–west oriented trough is noticed in nearly the corresponding latitudes as in the Bay.

2.2 The trough system from south Bay to south Arabian Sea with the embedded lows in it extends in the upper air also upto 700 mb; higher up in the middle and upper troposphere, easterlies prevail over south Peninsula which gradually veer to southerlies and then to southwesterlies as the season progresses and the sub–tropical ridge at these levels shifts southwards. The Tropical Easterly Jet which is the main feature of the upper tropospheric circulation over the south Peninsula in the southwest monsoon season completely disintegrates with the withdrawal of the southwest monsoon from the country. The wind field in the entire troposphere over the south Peninsula is only light to moderate during this season.

2.3 The increase in rainfall activity along south Andhra–Tamil Nadu coasts which takes place sometime in first fornight of October has been generally understood as the "setting in of the northeast monsoon". However, there is, at

present, no well-defined criteria laid down for the withdrawal of the southwest monsoon from the south Peninsula and the ushering in of the northeast monsoon there.

3. Rainfall

3.1 The mean monthly rainfall, the mean number of rainy days etc. in the various meteorological sub-divisions in the south Peninsula during the period October-December, are given in Table I. (See also Fig. 3.1)

3.2 The Table shows that for the south Peninsula as a whole, October is the rainiest month. However, in Tamil Nadu, November is as much rainy as October. By December, the rainy season is practically over, when the rainfall becomes very small except in Tamil Nadu. The following are the details of rainfall distribution in the different sub-divisions:

TABLE – I

Mean monthly, seasonal and annual rainfall (cm) and number of rainy days *

	Oct.	Nov.	Dec.	Season's Total	Annual
1. Coastal Andhra Pradesh					
Rainfall (cm)	19	12	2	33	101
Rainfall as % of season's total	58	36	6		
Season's total as % of annual rainfall				33	
No. of rainy days	7	4	1	12	53
2. Tamil Nadu					
Rainfall (cm)	19	20	9	48	101
Rainfall as % of season's total	39	42	18		
Season's total as % of annual rainfall				48	
No. of rainy days	9	9	4	22	53
3. Rayalaseema					
Rainfall (cm)	11	8	2	21	68
Rainfall as % of season's total	52	38	10		
Season's total as % of annual rainfall				31	
No. of rainy days	6	4	1	11	41
4. South Interior Mysore					
Rainfall (cm)	15	7	1	23	124
Rainfall as % of season's total	65	31	4		
Season's total as % of annual rainfall				19	
No. of rainy days	9	4	1	14	67
5. Kerala					
Rainfall (cm)	31	19	5	55	300
Rainfall as % of season's total	56	35	9		
Season's total as % of annual rainfall				18	
No. of rainy days	14	9	3	26	126

*From Memoirs of I.M.D. Vol. XXXI Part III.

i) Coastal Andhra Pradesh:- Coastal Andhra Pradesh gets rainfall during both the southwest and northeast monsoon seasons, the rainfall in southwest monsoon season being more than in northeast monsoon season. Except in Nellore district, there is no abrupt increase in rainfall from September to October when the northeast monsoon sets in; rainfall in October remains practically the same as in September. It rapidly decreases from October to November and by December, rainfall becomes insignificant except in Nellore district.

ii) Tamil Nadu:- In contrast to the other four sub-divisions of the south Peninsula, Tamil Nadu gets more rainfall in October-December than during the southwest monsoon season. There is a considerable increase in rainfall from September to October and rainfall continues in November also. The interior districts get more rain in October than in November while the coastal districts get more rain in November than in October. By December, rainfall considerably decreases and becomes much less than half of the previous month. In December, it is only the coastal districts where rainfall continues in any significant fashion. Over the south Peninsula, the isohyets run parallel to the coast and the rainfall decreases from the coast towards the interior and the rate of decrease of rainfall with distance from the coast is very high over Tamil Nadu. The season's rainfall is highest in the coastal region between Cuddalore and Point Calimere. This feature is in contrast to the distribution along the west coast during the southwest monsoon season when rainfall increases as we go inland from the coast.

iii) Rayalaseema:- Just like Coastal Andhra Pradesh, Rayalaseema also gets rainfall during the southwest as well as the northeast monsoon season, the rainfall in southwest monsoon season being a little over one and a half times the rainfall in northeast monsoon season. September and October are the rainiest months, contributing to 36% of annual total. Rainfall decreases in November and by December it is practically insignificant.

iv) South Interior Mysore:- For South Interior Mysore, the southwest monsoon season is the principal rainy season, the rainfall during October-December being just 19% of the annual total; of this, a major portion falls in the month of October. The rainfall in October is practically the same as in September. By November, rainfall decreases considerably and in December the sub-division is practically dry.

v) Kerala:- Similar to South Interior Mysore, in Kerala also the principal rainy season is the southwest monsoon season, the northeast monsoon season rainfall being only 18% of the annual total. October is the rainiest month of the northeast monsoon season, the rainfall in October being more than in September. Rainfall decreases in November though it is still significant (35% of the season's total). In December, rainfall becomes much less, being confined mainly to the southern districts.

3.3 There is some suggestion that in the northern districts of coastal Tamil Nadu, the main period of rainfall begins a little earlier (by a week or ten days or so) and also ends a little earlier, compared to the southern districts.

3.4 Thus, the northeast monsoon rain is confined to October and November over the south Peninsula. It lingers on in Coastal Tamil Nadu and south Kerala in December. Comparing the rainfall distribution with the mean monthly pressure and lower tropospheric wind patterns, we notice that the rainfall in the south Peninsula is mainly in the months when the trough overlies the south Peninsula. Towards December, as the northeasterlies establish over the south Bay and south Arabian Sea and the trough shifts close to the equator (in other words, when the northeast monsoon is fully established) rainfall decreases considerably in the south Peninsula. As the trough shifts south, a ridge extends southwards over the Peninsula, leading to a decrease of weather over the interior of the Peninsula, with rainfall confined to the coastal districts of Tamil Nadu and south Kerala.

3.5 The rainfall in the south Peninsula at the end of the southwest monsoon season or the beginning of the northeast monsoon season is mainly in the interior of the Peninsula; it is also generally in the afternoon, evening or early part of night. Subsequently, as the season advances, the rainfall is mainly in the coastal districts of Tamil Nadu and in south Kerala, the interior districts getting only a little rain.

3.6 In contrast to the southwest monsoon rainfall along the west coast, where rainfall increases progressively from the coast towards inland upto the Western Ghats, in the case of northeast monsoon rainfall, even when it is not associated with a depression or a storm, the heaviest rainfall is along the coast and the rainfall decreases as we go towards the interior. Such a distribution in the mean rainfall pattern has already been referred in Sec. 3.2(ii).

3.7 In general, rainfall is more variable in the coastal districts than in the interior districts where rainfall is less. In Tamil Nadu, the co-efficients of variability are highest in the north coastal districts where the rainfall is also highest. This feature is in contrast to the general principle that variability in rainfall is more over areas where the seasonal total is small than vice versa.

3.8 The distribution of the northeast monsoon rainfall in the south Peninsula during the 77 year period (1875-1951) is given below:-

TABLE – II

Division	*Large excess	Mod. excess	Slight excess	Normal	Slight defect	Mod. defect	Large defect
Coastal Andhra Pradesh	11	16	9	11	15	7	8
Malabar	2	16	14	20	14	9	2
Tamil Nadu	5	18	10	15	12	12	5
Rayalaseema	11	10	11	12	9	11	13

Total No. of occasions 77

* Large excess	Percentage departure	+ 51 and above
Moderate excess	,,	+ 26 to + 50
Slight excess	,,	+ 11 to + 25
Normal	,,	+ 10 to – 10
Slight defect	,,	– 11 to – 25
Moderate defect	,,	– 26 to – 50
Large defect	,,	– 51 and above

(From 'Rainfall in Madras State with special reference to Tamil Nadu and Rayalaseema – by P.R. Krishna Rao, I.Met.D. Memoirs Vol.XXX Part I).

3.9 It is seen from the Table that the rainfall is nearly normal (slight excess to slight defect) in nearly two-thirds of the years in Kerala and in half the number of years in the other divisions. Moderate to large deficient rainfall years are high in Rayalaseema (33%) and Tamil Nadu (25%). On the basis of 81 years-data, it was found that even in the worst famine years, the rainfall in any district of Tamil Nadu, does not go below 1/7 of the normal and even in the worst flood years, the rainfall does not exceed $2\frac{1}{2}$ times the normal in any district. In Tamil Nadu as a whole, the extreme abnormalities have been from –61% to+83%.

4. Heavy Rainfall

4.1 Heavy to very heavy falls occur in Tamil Nadu and Coastal Andhra Pradesh during the northeast monsoon season. They also occur in the Kerala, though their frequency may be less. In South Interior Mysore and Rayalaseema, they are

still less common. The heaviest falls are generally along coastal Tamil Nadu and Coastal Andhra Pradesh where rainfall amounts as high as 40 cm to 50 cm have been recorded. Such high falls are usually in association with the passage of cyclonic storms and depressions across the area. Record heavy falls at the observatories are given in the departmental publication - India Weather Review, Oct.-Dec. 1963.

4.2 Heavy falls in south Peninsula occur mainly in the months of October and November. In December, they are very rare except in the southern parts of coastal Tamil Nadu, though even here the frequency is small compared to November.

4.3 In Tamil Nadu itself, the south coastal districts get the maximum frequency of heavy rains; compared to the coastal areas, the interior districts get heavy rains on a considerably less number of occasions although in the hill districts, the frequency is larger particularly in November. Even in south Tamil Nadu, the highest frequency of heavy rain is only about 2 days in November. In contrast, during the southwest monsoon season, along the west coast, Mangalore gets about 3-4 days of heavy rain in a month at the height of the monsoon season there.

4.4 During the northeast monsoon season, rainfall spells extend upto 3-4 days; spells exceeding 4 days are very much smaller in number (about 20%), though spells even longer than 10 days have occurred. There are sometimes long spells with little or no rain, which on some rare occasions have been even longer than in the non-monsoon months.

5. Diurnal Variation of Rainfall

5.1 During the post-monsoon season except in the beginning, rainfall is generally more during night and early morning (1730 to 0830 IST) than during the rest of the period. In the eastern portions of south Peninsula (i.e. in Tamil Nadu), maximum rainfall is mostly between 2100 and 0300 IST and in the western por-

tions between 0300 and 0900 IST. Along the east coast, rainfall during late night and morning (2400–0900) is an usual feature, particularly when there is no depression or cyclonic storm close by when rainfall can be throughout the day.

6. Thunderstorms

6.1 Thunderstorms are common in south Peninsula during the Northeast Monsoon season. They are most frequent in Kerala and the adjoining parts of Tamil Nadu and South Interior Mysore where orography is marked. A large number of occasions of rainfall is associated with thunderstorms. Thunderstorm activity is also more in the earlier part of the season than the later half. During the northeast monsoon season, although thunderstorms may occur during any part of day or night, thunderstorm activity during early morning and forenoon hours is considered to be a characteristic of this season. Thunderstorm sometimes lasts for a long time – as much as six hours or more.

7. Monsoon activity in the various sub-divisions

7.1 The distribution of monsoon activity in the five sub-divisions of the south Peninsula, monthwise, during the northeast monsoon period is given in Table III.

TABLE – III

Percentage frequency of occurrence of Vigorous*, Strong, Normal and Weak Monsoon days (based on data of October to December: 1967—1971)

Sub-division	Oct.					Nov.					Dec.				
	V	S	N	W	D	V	S	N	W	D	V	S	N	W	D
1. Coastal Andhra Pradesh	4	5	30	23	38	2	1	17	15	65	3	1	12	4	80
2. Tamil Nadu	4	12	41	24	19	6	8	35	24	27	6	6	28	14	46
3. Rayalaseema	2	8	24	15	51	0	1	16	3	80	0	1	10	1	88
4. South Interior Mysore	0	8	28	18	46	0	1	19	3	77	0	0	10	0	90
5. Kerala	1	3	48	28	20	0	0	23	12	65	0	0	24	5	71

* V – Vigorous; S – Strong; W – Weak Monsoon with some rain; N – Normal; D – Weak monsoon without any rain.

The strength of northeast monsoon over land areas is also described only in terms of rainfall as in the case of the southwest monsoon and the specifications for the same are given in Appendix I.

7.2 It will be seen from the table, that the monsoon activity (vigorous, active and normal) over south Peninsula as a whole is a maximum in October. By November, it rapidly decreases, except in Tamil Nadu where it continues in December also. Coastal Andhra Pradesh, Rayalaseema and South Interior Mysore are predominantly dry in November and December. Even in Tamil Nadu, dry days are considerably more in December (nearly 50%) than in November (about 25%). Except along the east coast - in the sub-divisions of Tamil Nadu and Coastal Andhra Pradesh - vigorous monsoon is very rare; in Coastal Andhra Pradesh, active to vigorous monsoon is mainly in October and decreases rapidly thereafter. In Tamil Nadu, however, it continues in November and December also.

7.3 It is a point of interest to note that while along the west coast, active to vigorous monsoon conditions occur on 20% to 25% of the occasions at the height of the southwest monsoon season, along the east coast during the northeast monsoon, the corresponding figure is only about 15%.

8. Sea Level Pressure

8.1 The sea level pressure distribution during this season is characterised by a low in central Arabian Sea and central Bay connected across the Peninsula by a trough. A dumb-bell shaped isobar connecting the two lows over the sea areas is characteristics of the mid-season. When we examine the pentad mean sea level isobaric charts, we find a gradual southward progression of the dumb-bell shaped trough system through nearly 10 degrees of lat. during the months of October and November. By end of November or beginning of December, the seasonal trough shifts to the south of the Indian Peninsula and isobars become almost east-west with minor trough patterns off the east and west coasts. Even after the seasonal trough had shifted well to the south of Indian Peninsula, it may

temporarily shift north and come over south Peninsula, when a depression or storm develops in the trough and moves in a northwesterly direction.

8.2 An appreciable cross-isobaric flow of the current to the north of the axis of the trough can be noticed on the daily charts, when the trough is at very low latitudes (south of 8-10°N). The angle between the wind direction and isobar may be as much as 40° in these latitudes. This point may be borne in mind while drawing isobars and contour lines over these areas during these months.

8.3 Rainfall activity is pronounced over the south Peninsula during the two months period (October-November) when the trough system lies across the area (of course, on individual days the trough position may vary much from the normal pattern). Subsequently rainfall is confined to coastal Tamil Nadu and south Kerala. When the trough is well-defined over the Peninsula with the seasonal low well-marked over the Bay, there is good rainfall activity over south Peninsula.

8.4 The mean pressure gradient along the Andhra-Tamil Nadu coast, as judged by the difference in pressure between Visakhapatnam and Nagapattinam is about 2 to 2.5 mb in 7 degrees of latitude in November and December and about 1.5 mb in 7 degrees latitude in January. On nearly a third of the days in November and December, the pressure gradient between Visakhapatnam and Nagapattinam is 2 to 3 mb. Stronger than normal gradients is more frequent in December than in November or January.

9. Upper Winds

9.1 The mean upper winds of Madras, Bangalore and Trivandrum for the months of September to January are given in Fig. 9.1.

9.2 The mean upper wind flow over the south Peninsula during the northeast monsoon season is one of north/northeasterly in the lowest levels (upto about

1.5 km) which is over-lain by an easterly flow of weak to moderate strength. Earlier in the season, when the seasonal trough is at a more northerly latitude, the winds are westerly in the lowest levels which subsequently veer to north/northeasterly, as the trough progressively shifts southwards with the advance of the season. In the upper troposphere, the flow becomes southerly to southwesterly which is the part of circulation around the anticyclonic cell over the Bay of Bengal. The easterly jet stream which is characteristic of the southwest monsoon season over the Peninsula, completely disappears in the northeast monsoon season. At 150 mb and 100 mb levels, even in the mean, the easterlies decrease from about 50 kts to weak southerly/easterly between September and November. Strong upper tropospheric westerlies (50 kts or more at 12 km) rarely come down to the latitudes of Madras and Trivandrum. On an examination of the data in respect of the last 10 years, it has been noticed that only on 8 occasions, the west winds at 12 km were 50 kts or more over Madras and on 5 occasions at Trivandrum at the same level during October-December.

9.3 There are wide variations from the mean winds in day-to-day charts. The variations are even more pronounced than in the southwest monsoon season. As a general rule, winds are weak, when there is no well defined synoptic system and consequently the monsoon is also weak over the south Peninsula. When a well defined system develops, the wind field strengthens. Both northeasterlies/easterlies and westerlies (over the Peninsula) may strengthen, particularly earlier in the season, when the trough line runs across the south Peninsula. Late in the season, lower tropospheric northeasterlies may strengthen along the Tamil Nadu coast (sometimes even reaching 30-40 kt) either with the intensification of the seasonal low over the south Bay or development of a system over southwest Bay. This is also sometimes called the "strengthening" of the northeast monsoon. Examination of the upper winds of Madras at 3.1 km for the months of October-December, shows that generally a veering of the wind from the normal direction upto 180° is favourable for rainfall over North Tamil Nadu and adjoining south

Coastal Andhra Pradesh.

9.4 In all the synoptic systems approaching the coast, it is usually observed that the lower tropospheric northeasterlies in the northwest quadrant are much stronger than the winds in the other quadrants.

9.5 The upper tropospheric easterlies which are only weak to moderate during the season, sometimes temporarily (for 1 or 2 days) strengthen to 50–60 kts in association with the formation and movement of intense systems like depressions/ cyclonic storms. This feature is more likely in the earlier part of the season.

9.6 The location of the anticyclonic cell in the middle and upper troposphere appears to have an influence over the rainfall activity in south Peninsula. A southeasterly/southerly flow over the south Peninsula corresponding to the western end of the sub-tropical anticyclonic cell over the south Bay of Bengal has been noticed to be more favourable for rainfall over south Peninsula, than a northwesterly/northerly at these levels, corresponding to the location of the eastern end of the Arabian Sea anticyclonic cell.

10. Upper Air Temperatures and Humidity

10.1 The mean monthly tephigrams of Madras from September to December are given in Fig. 10.1. Between September and October there is hardly any difference either in the temperatures or humidities. Thus the heralding of the northeast monsoon does not bring about any change in the thermodynamic structure of the atmosphere over Madras.

10.2 Significant changes take place from October to November. They are:-

i) a cooling in the lower troposphere (below 700 mb)

ii) decrease of moisture at all levels, the decrease being more above 850 mb

iii) a tendency to build a stable lapse rate between 850 mb and 700 mb levels.

10.3 These features progressively become more marked till January when the northeast monsoon is completely established over the whole Bay. In January, the

moist layer is confined to 900 mb, above which,air becomes quite dry and the layer between 900 mb and 700 mb is more stable than even November or December. The cooling and the decrease of the moisture are associated with the extension of the dry continental air from the north progressively into more southerly latitudes in the winter. Similar characteristics are noted over Vizag and Bangalore also.

10.4 Further south, over Trivandrum, the decrease in moisture content is appreciable only by January. The cooling of the lower troposphere and the formation of a stable layer noticed further north (Madras) is not seen over Trivandrum.

10.5 The mean tephigrams of Madras for days of strong to vigorous and weak monsoon conditions are given in Fig. 10.2. It is seen that:

i) during strong to vigorous monsoon days the air has a lapse rate which is nearly saturated adiabatic. A high degree of saturation extends upto 450 mb. and

ii) there is no difference between the dry bulb curves on strong and weak monsoon days. But, on weak monsoon days the air is much drier; the dryness is more above 750 mb.

10.6 A typical day's Tephigram of Madras for active and weak monsoon is given in Fig. 10.3.

11. Typical synoptic situations affecting weather over South Peninsula during the Northeast Monsoon period

11.1 The typical synoptic situations affecting weather over south Peninsula during the northeast monsoon season are:-

i) Storms and depressions which form over the sea areas and move towards the coast

ii) Low pressure areas (surface and/or upper air) and low pressure waves

iii) East-west oriented trough line across the Peninsula, seasonal trough over Bay well-marked or a trough of low pressure off Kerala coast

The percentage frequencies of occurrence of vigorous, active and normal monsoon in the five sub-divisions associated with the above-mentioned synoptic situations are given in Table IV.

TABLE IV

Percentage frequency of Vigorous, Active and Normal Monsoon days associated with various synoptic situations
(Based on data of October to December 1967-71)

(a) Coastal Andhra Pradesh

	Oct.			Nov.			Dec.		
	V	A	N	V	A	N	V	A	N*
1. Storms and depressions	33	25	20	100	100	22	75	—	17
2a. Low pressure areas (including low pressure waves)	50	12	23	—	—	41	—	—	33
b. Upper air cyclonic circulation or trough	-	13	5	—	—	—	—	50	—
3. East-west oriented trough across Peninsula, seasonal trough over Bay well-marked, trough of low pressure off Kerala coast	17	50	52	—	—	37	—	—	39
4. Other features	—	—	—	—	—	—	25	50	11

(b) Tamil Nadu

	Oct.			Nov.			Dec.		
	V	A	N	V	A	N	V	A	N*
1. Storms and depressions	83	15	7	45	8	15	57	10	14
2a. Low pressure areas (including low pressure waves)	17	53	39	55	67	31	43	50	42
b. Upper air cyclonic circulation or trough	0	5	5	—	—	—	—	10	—
3. East-west oriented trough across Peninsula, seasonal trough over Bay well-marked, trough of low pressure off Kerala coast	0	27	49	—	25	54	—	30	37
4. Other features	—	—	—	—	—	—	—	—	

* V - Vigorous Monsoon; A - Active Monsoon; N - Normal Monsoon

(c) Rayalaseema

	Oct.			Nov.			Dec.		
	V	A	N	V	A	N	V	A	N*
1. Storms and depressions	67	—	8	—	100	9	—	50	33
2a. Low pressure areas (including low pressure waves)	—	16	23	—	—	41	—	—	27
b. Upper air cyclonic circulation or trough	—	25	10	—	—	9	—	50	13
3. East-west oriented trough across Peninsula, seasonal trough over Bay well-marked, trough of low pressure off Kerala coast	33	59	59	—	—	41	—	—	27
4. Other features	—	—	—	—	—	—	—	—	—

(d) South Interior Mysore

	Oct.			Nov.			Dec.		
	V	A	N	V	A	N	V	A	N*
1. Storms and depressions	—	—	7	—	—	21	—	—	16
2a. Low pressure areas (including low pressure waves)	—	31	26	—	—	18	—	—	16
b. Upper air cyclonic circulation or trough	—	8	7	—	—	11	—	—	7
3. East-west oriented trough across Peninsula, seasonal trough over Bay well-marked, trough of low pressure off Kerala coast	—	61	60	—	100	46	—	—	61
4. Other features	—	—	—	—	—	4	—	—	—

(e) Kerala

	Oct.			Nov.			Dec.		
	V	A	N	V	A	N	V	A	N*
1. Storms and depressions	—	—	1	—	—	8	—	—	6
2a. Low pressure areas (including low pressure waves)	—	50	32	—	—	37	—	—	27
b. Upper air cyclonic circulation or trough	—	—	3	—	—	—	—	—	—
3. East-west oriented trough across Peninsula, seasonal trough over Bay well-marked, trough of low pressure off Kerala coast	100	50	64	-	100	55	—	—	67
4. Other features	—	—	—	—	—	—	—	—	—

* V – Vigorous Monsoon; A – Active Monsoon; N – Normal Monsoon.

11.2 Some details of the rainfall caused by the above synoptic systems are discussed sub-divisionwise, in the following paragraphs.

11.2.1 Coastal Andhra Pradesh

i) Coastal Andhra Pradesh, particularly the southern parts, is in many respects similar to Tamil Nadu. In the earlier part of the season the east-west oriented trough line across the Peninsula is a normal feature causing rainfall. Intensification of the seasonal low over the west Central Bay also brings increased monsoon activity to this sub-division. Next in importance, is the low pressure area. As in the case of Tamil Nadu, depressions and cyclonic storms also affect Coastal Andhra Pradesh. Active to vigorous monsoon days in November and December occur only with a depression or a cyclonic storm.

ii) In view of the large northward extension of the rainfall belt associated with low pressure areas, depressions and storms in the Bay during the northeast monsoon season, though these systems may be only off Tamil Nadu coast, they still produce rainfall in Coastal Andhra Pradesh* (see Fig.12.1). Some of the record falls (of the order of 20 cm to 50 cm) during this season have been in association with storms and depressions.

iii) Heavy rains occur in Coastal Andhra Pradesh even when a depression or a storm crosses coast near Madras or even south of Madras, and persist for 3-4 days, long after the disturbance passes out into Arabian Sea. Some workers who have studied this aspect of heavy rainfall far away from the storm, have attributed it to the presence of an upper anticyclone over Coastal Andhra Pradesh and the continued maintenance of the anticyclone due to the release of latent heat by the heavy rain (Fig. 11.1).

iv) Depressions and storms over Coastal Andhra Pradesh and the adjoining north Tamil Nadu or within about 2 degrees of the coast of these areas, cause active to vigorous monsoon conditions in Coastal Andhra Pradesh. When they are farther away the activity may only be normal. Also depressions or storms

* Also see para 12.1.4

as far south as 10°N have caused normal monsoon in Coastal Andhra Pradesh. While depressions and storms crossing Coastal Andhra Pradesh have caused active to vigorous monsoon there, those recurving northeastwards even if they come within 2 to 4 degrees of the coast, have often caused only normal monsoon (Fig. 11.2).

11.2.2 Tamil Nadu

i) Tamil Nadu gets rainfall when storms and depressions or low pressure areas affect the sub-division. In the case of storms and depressions, the monsoon may be active to vigorous or normal depending upon the location of the system and its movement during the preceeding 24 hrs. Low pressure areas cause active to vigorous monsoon if they are well-marked; otherwise they cause only normal monsoon. Tamil Nadu also gets rainfall when the seasonal low in the west central Bay/ southwest Bay is well-marked or a trough line runs east-west across the south Peninsula. On such occasions, monsoon activity may be only normal.

ii) By far the most common systems causing rainfall in this sub-division are, low pressure areas, well-marked seasonal low over Bay or an east-west oriented trough line across the south Peninsula, in the surface and lower troposphere. Next in frequency, are the depressions and storms; although less in number than low pressure areas, storms and depressions cause heavy to very heavy rains and contribute substantially to the season's total rainfall.

11.2.3 Rayalaseema

i) Rayalaseema gets most of its rain in association with the east-west trough across the Peninsula in the lower troposphere becoming well-marked or with a low pressure area/wave moving westwards across the Peninsula Over this sub-division, the low pressure area may not be seen on the surface chart, but only in the lower tropospheric wind field as a cyclonic circulation. All these disturbances generally cause normal monsoon, except in October when they may cause active monsoon also.

ii) Depression and storms affect this sub-division in all the three months though their frequency is small.

11.2.4 South Interior Mysore

South Interior Mysore is similar to Rayalaseema. This sub-division being further away from the coast than Rayalaseema, depressions and storms affecting this sub-division cause at best normal monsoon. This sub-division gets rainfall even if the low pressure area is over southeast Arabian Sea.

11.2.5 Kerala and Arabian Sea Islands

i) A very large number of days of rainfall in Kerala are due to a trough of low pressure in the southeast Arabian Sea or an east-west trough line running across the south Peninsula. Under such conditions, the lower tropospheric westerlies to the south of the trough line may also strengthen. Next in importance is the low pressure area; it may be either moving across the south Peninsula or be over Laccadives-Maldives region. Even under these two synoptic conditions, monsoon activity is usually only normal; active to vigorous conditions prevail hardly on 5% of the occasions and they are also only in October when the trough system across the Peninsula is marked. Depressions and storms affecting Kerala may be either those travelling westwards from the Bay across the Peninsula, or those that form off Kerala coast. They are hardly one or two in a year, and are also mainly in November and December.

ii) Arabian Sea Islands are also affected by the same systems that cause weather over Kerala, although the distribution and intensity of weather, may be, in general, slightly less than in Kerala.

11.3 Synoptic situations (i) to (iii) given in para 11.1, are those noticed in the surface chart and in the lower troposphere. A few workers have studied the mid- and upper tropospheric flow patterns during active and weak northeast monsoon periods over Tamil Nadu and found that during periods of active north-

east monsoon conditions, the high pressure cell at 6.0 km and 9.0 km over the Bay and the adjoining Peninsula is well-marked and the one over the Arabian Sea is ill-defined, whereas during weak monsoon conditions, the anticyclonic cell over Arabian Sea and the adjoining Peninsula becomes dominant and the one over the Bay becomes diffuse. A deep easterly flow pattern is also usually associated with rainfall in south Peninsula while a mainly dry northerly stream upto 6.0 km and 9.0 km results in weak monsoon.

11.4 The synoptic situations enumerated in para 11.1 together with the above mentioned mid- and upper tropospheric flow patterns may be looked into for forecasting rain spells in the south Peninsula.

12. A few details of the various synoptic systems that affect south Peninsula during this season will be discussed now.

12.1 Storms and Depressions

12.1.1 During the northeast Monsoon season, storms and depressions are considerably more in the Bay than in the Arabian Sea. Since the Bay disturbances move towards the south Peninsula and the Arabian Sea disturbances generally move away from the south Peninsula, it is the former class of disturbances (viz. Bay disturbances) that are important from the point of view of rainfall in south Peninsula.

12.1.2 A brief description* of the storms during the period are given below monthwise:

i) October: In this month storms in the Bay of Bengal originate between 8°N and 14°N. They move initially in a northwesterly direction. Most of them later recurve and move towards northeast. The north Tamil Nadu and Andhra coasts and the coastal belt of Bangla Desh are particularly vulnerable to

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* From 'Tracks of Storms and Depressions in the Bay of Bengal and the Arabian Sea 1877-1960", India Meteorological Department, 1964.

the incidence of storms in this month. Most of the storms that strike the coast south of 15°N enter the Arabian Sea and reintensify. In the Arabian Sea, the direction of movement of storms is generally westerly. However, east of 70°E some of the storms move northnorthwestwards and later recurve northeast to strike the north Maharashtra-Gujarat coasts.

ii) November: The source region of the majority of storms in this month is between 8°N and 13°N. Those which move in a westnorthwesterly direction, strike Tamil Nadu coast and emerge into the Arabian Sea where they re-intensify. Bay storms which form in more northerly latitudes move northwest and later recurve towards the northeast. In the Arabian Sea, the initial movement is northwesterly. Storms which go north of 15°N recurve towards the northeast and strike the north Maharashtra-Gujarat coasts.

iii) December: There is an appreciable decrease in the frequency of storms from November to December. Most of the storms originate over the Bay of Bengal between 5°N and 10°N. Those which originate over the southwest Bay move initially in a northwesterly direction and strike the south Tamil Nadu coast or the northeast coast of Sri Lanka. A few of these enter the Arabian Sea. However, they do not intensify but dissipate. Storms which originate in the southeast Bay generally move in a northnorthwesterly direction and later recurve towards northeast. During their northeasterly course they show a tendency to weaken and dissipate. Storms in the Arabian Sea are very few in December and almost all of them are of Bay origin.

12.1.3 Table V gives the monthly frequency of cyclonic storms and depressions in the Bay of Bengal and Arabian Sea.

TABLE – V*

Monthly frequency of Cyclonic Storms and Depressions – in the 70 year period 1891–1960

	Oct.	Nov.	Dec.
Bay			
Storms	53	56	26
Depressions	56	32	18
Arabian Sea			
Storms	17	21	3
Depressions	11	10	5

* (From "Tracks of Storms and Depressions in the Bay of Bengal and the Arabian Sea – 1877–1960". India Met. Department, 1964).

The table shows that while in October, storms and depressions are nearly equal in number, storms are more numerous than depressions in November and December.

12.1.4 The characteristic features of rainfall associated with storms and depressions during this season are,

i) heavy to very heavy heavy rainfall along the coast and its decrease inland

ii) a considerably large extension of rainfall to the north of the centre than to the south. On the northern side, rainfall may extend over a distance as much as 10 degrees latitude from the centre of the storm/depression, while on the southern side, it extends hardly a few degrees. On the southern side the gradient of isohyets is very steep.

iii) Heavy to very heavy rainfall occurs close to and to the north of the track. In typical cases the area of heavy rainfall in the north extends upto about 4–5° latitude from the centre of storm (or depression) while in the south it may be hardly about one degree of lat. or so. This is in contrast to the distribution in the southwest monsoon season when rainfall is mainly to the south of the depression track. Two typical days' isohytal charts showing the distribution of rainfall over the Peninsula in association with two cyclonic storms are given in Fig. 12.1(a) and (b).

iv) Phenomenally heavy rains may occur near the place when the storm strikes the coast. In the months of October and November in particular, the record falls along the east coast of the Peninsula (Coastal Andhra Pradesh and Tamil Nadu) have occurred mainly in association with storms and depressions.

v) In a general way, the rainfall associated with storms are heavier than those with depressions.

12.1.5 Depressions and storms contribute substantially to the northeast monsoon rainfall. It has been found that in the case of Tamil Nadu, large excesses of rainfall occurred during years when depressions and cyclonic storms in the south Bay struck Tamil Nadu coast or moved within 2 degrees of the coast, while large defects in rainfall occurred during years when such depressions and storms were absent or when they did not move to within 2 degrees of longitude of the Tamil Nadu coast. Rainfall was also in moderate defect in some years when the depressions or storms crossed coast to the north of 13°N, as the area of rainfall extends mostly to the north of the centre. The nearer the storm centre to the coast the greater is its influence. The dependence of rainfall on cyclonic storms and depressions is more pronounced in coastal districts than in the interior. If such depressions strike the coast in the five week period. 15 October to 20 November, rainfall in Tamil Nadu is considered to be timely.

12.1.6 It is seen that Tamil Nadu gets significant rainfall activity only when the storm/depression is to the south of 14°N. Active to vigorous monsoon conditions prevail when the centre is within 2 degrees of the Tamil Nadu coast, or over Tamil Nadu or Sri Lanka. If the depression is further to the east, rainfall is only normal. Depressions to east of 86°E do not produce any significant rainfall. Thus, so far as Tamil Nadu is concerned, depressions and storms produce normal rainfall when they are a little out at sea and cause vigorous monsoon when they come close, within about 2 degrees of the coast.

12.2 Low pressure areas and Low pressure waves

12.2.1 During the northeast monsoon season, storms and depressions develop out of low pressure areas in the south Bay or southeast Arabian Sea. They (i.e. storms and depressions) also weaken into low pressure areas after they cross coast and move across the Peninsula. However, there are cases when the low pressure areas which form in the west central or southwest Bay move in a westerly direction without developing further and affect weather over south Peninsula. On an average, during October and November there may be 2 such low pressure areas in a month which do not develop further and in many years even 3. In December, they are slightly less – only 1 or 2.

12.2.2 While some low pressure areas may be traced from across the Andaman Sea, they often form, in situ, in west central Bay and southwest Bay.

12.2.3 Low pressure areas are delineated on the surface chart by a single closed isobar at 2 mb interval. At times, the closed isobar may only be an 'odd valued' isobar. When the area covered by the closed isobar is not wide and diffuse and the associated upper air circulation as far as could be judged from the coastal winds is also well-defined, the system is called a 'well-marked' low pressure area. When the satellite picture shows a heavy mass of clouding associated with the low, which can be categorised as Stage B, the system is always a well-marked low pressure area; at times it may be even a depression. About 40% of the low pressure areas are well-marked. When the closed isobar covers a wide area in the south and the adjoining central Bay of Bengal and the circulation is also seen in the lower troposphere, it is common practice to describe the situation only as "the seasonal low being well-marked". The seasonal low usually becomes well-marked as a prelude to the formation of a low or a depression.

12.2.4 Over land areas, the low pressure area may not be seen as a closed isobar; it may be seen as a moving isallobaric centre on the 24 hrs. pressure

change chart or as a region of negative pressure departure. Sometimes, it may be seen only in the lower tropospheric wind field.

12.2.5 In October, we can delineate the low pressure areas even over the sea area unambiguously as they usually form at a slightly northerly latitude and a few observations over Sri Lanka and the south Bay indicate a westerly wind. But later in the season, when the seasonal trough shifts to extreme south Bay, the central region of the low pressure systems may be to the south of 8°N or even further south. Under such circumstances, we may not be able to draw any closed isobar in our chart which is mainly due to the non-availability of observations in the equatorial region. In such cases, a trough may also extend from the low northwards to off Tamil Nadu coast and may appear to be more prominent on the charts than the main low to the south, which again is mainly on account of lack of observations in the south to define the low. However, satellite picture may help the analyst on such occasions to delineate the low in the south.

Figs. ~~12.A, 12.B and 12.C~~ 12.2(a), 12.2(b), 12.2(c) give the spatial distribution of centres of low pressure areas, monthwise, in the northeast monsoon season. The centres have been taken as the geometric centres of the closed isobar defining the low pressure areas. The low pressure areas are seen in the south Bay, Comorin and Laccadives area in October and November. Their higher frequency in Laccadives area is noteworthy. By December they are seen mainly to the east and south of Sri Lanka and in Maldives area.

12.2.6 Over land, the low pressure areas are much less in number and they also occur only in October. Many of the lows over the land are the remnants of depressions and storms. It is also noticed that whenever a well-marked system approaches Tamil Nadu coast from the east, it induces a low pressure area in the Laccadives region.

12.2.7 On an average, there are about 30 days in each year during the northeast monsoon with a low pressure area on the chart in the south Bay, south

Peninsula or south Arabian Sea. The number of days are considerably more in October and November than in December. Very often, particularly during the earlier part of the season, two low pressure areas may be seen simultaneously, one in the south Bay and the other in the south Arabian Sea.

12.2.8 The pressure departures associated with the low pressure areas are given in Table VI.

TABLE – VI

Pressure departures associated with Low Pressure Areas in the Bay of Bengal and Arabian Sea during the months October to December (based on data of 1967–71)

Pressure departures from normal (mb)	Percentage frequency
+ 2	5
+ 1	9
0	14
– 1	32
– 2	18
– 3	12
– 4	2
– 5	8

It will be seen that nearly 75% of the low pressure areas have a pressure departure ranging between 0 and –3 mb. Well-marked low pressure areas have a slightly more negative pressure departure which may be as low as –4 mb to –5 mb.

12.2.9 The upper air cyclonic circulation associated with a low pressure area generally does not extend beyond 850 mb. A large number of them is not seen even at 850 mb level. However, when the system is well-marked, the circulation invariably extends to 850 mb or even higher, about 25%–30% of them extending above 850 mb level. 60% to 70% of the low pressure areas (including well-marked systems) do not have any noticeable tilt with height. The rest of them have a

tilt usually towards a direction between south and west.
such low pressure systems or the intensification of the seasonal low, the northeasterlies along the Tamil Nadu coast may strengthen and weather may begin. This is sometimes called as the "strengthening of the northeast monsoon". (On a few occasions the strengthening of the winds over the south Bay could also be traced up-wind upto South China Sea, where the strengthening of the northeasterlies is initiated as a result of a pronounced intensification of the "high" over China.)

12.2.10 In a number of cases, the low pressure areas do not show any sequential movement. On a little over 50% of the occasions, they seem to be stationary or weaken in situ. Others move in some westerly direction (between west-southwest to northwest). A good number of low pressure areas weaken when they approach Tamil Nadu and Sri Lanka coasts. Of the remaining, many show a tendency to move towards a westsouthwesterly/southwesterly direction when they come close to the coast. It may be incidentally observed that even in the case of a few storms and depressions in this season, a westsouthwesterly to southwesterly movement has been observed as they approach the Tamil Nadu coast. It is not clear whether the peninsular land mass lying across the path of the low influences the direction of its movement. The number of low pressure areas that cross the Peninsula or Sri Lanka into the Arabian Sea is only a few. They are generally the well-marked ones or the remnants of depression/storms. In contrast to Bay, many of the low pressure areas in the Laccadives-Maldive area have a movement towards a northwesterly direction.

12.2.11 As in the case of depressions and storms, the rainfall belt extends northwards in the case of the low pressure areas also. Rainfall due to well-marked low pressure areas is fairly widespread over south Peninsula and heavy to very heavy rains may also occur, the coastal areas getting considerable rainfall.

12.2.12 The seasonal trough across south Bay, south Peninsula and south

Arabian Sea extends upto 700 mb. Higher up, a broad easterly current prevails which increases in speed with height. As the seasonal trough shifts to the south of Lat. 8°N or so during the second half of the season and also gradually becomes less marked, a nearly zonal easterly flow prevails over South Bay, south Peninsula and south Arabian Sea. In this zonal flow, wave like perturbations may form and move from east to west.

12.2.13 The main difference between a low pressure area and a low pressure wave is, that in the low pressure area there is a complete cyclonic circulation, with west winds in the south, while a wave is a sinusoidal perturbation without any west winds in the south. The low pressure area is embedded in the seasonal eastwest oriented trough, while the wave is a perturbation in a deep zonal current. With these differences, it should, therefore, be possible to clearly differentiate between a low pressure area and a low pressure wave and use the appropriate terminology.

12.2.14 Even during the earlier part of the northeast monsoon season, as the upper air pattern above 700 mb is a deep zonal flow, wave motion is possible in the mid- and upper tropospheric easterlies. Such waves may be expected to be associated with low pressure areas in the surface chart and in the lower troposphere (i.e.) a surface and lower tropospheric low pressure area may extend as a wave trough in the mid-tropospheric levels.

12.3 East-west oriented trough across the Peninsula

12.3.1 The seasonal trough (in surface and upper air) passes across the south Peninsula during the month of October. By November, the trough line shifts well to the south and is over the extreme south Peninsula and Sri Lanka. By December, the trough shifts still further south and the air over the south Peninsula, except along the Tamil Nadu coast and extreme south Peninsula is mainly of continental origin.

12.3.2 The seasonal southward progression of the trough line across the Peninsula (with low pressure systems forming and moving westwards along the trough) agrees well with the mean rainfall distribution. In contrast to the seasonal trough over the northern India during the southwest monsoon where the

rainfall is mostly along and to the south of trough, the area to the north getting relatively much less rainfall, in the case of the trough across the Peninsula during this season, rainfall extends on either side of the trough. The northern limit of the cloudiness and rainfall is upto the region of the dry air of continental origin. This northern limit between dry air and most air is quite marked over the country during this period; the limiting zone can be well delineated by the surface dew point temperatures and lower tropospheric mixing ratio values. This moisture discontinuity line is an useful aid in analysis and prognosis during this season (see para 18.6.5 and Fig. 18.1).

12.3.3 The seasonal trough extends from the surface upto about 600 mb in the mean charts with a southward slope with height, the average slope being about 1/100. The slope of the trough line can be seen clearly in October when the trough is near about 13°N in the surface and there are enough upper air observations to the south of the trough. However, later in the season when the trough shifts southwards, the slope cannot be fixed as there is hardly any upper air observation to the south of trough line.

12.3.4 The east-west trough becomes well-marked when the low pressure systems in the south Bay and southeast Arabian Sea become prominent. This east-west trough is occasionally seen on the synoptic chart, extending from south Arabian Sea in the west to as far east as southwest Pacific across the south Indian Peninsula and south Bay and we notice a series of low pressure systems embedded in the trough, spaced at nearly equal intervals (for instance see Fig. 18.2 of Section 18).

12.3.5 The east-west oriented trough, the seasonal trough over the south Bay and low pressure areas in the south Bay and southeast Arabian Sea are generally inter-related phenomena, so that when one of them is seen, the others may also be simultaneously present on the charts on many occasions.

12.3.6 The remaining sections of the report will deal with typical synoptic situations causing strong and weak northeast monsoon conditions in the various meteorological sub-divisions of the south Peninsula.

13. Severe cyclonic storm in the Bay of Bengal crossing Tamil Nadu coast and causing strong to vigorous monsoon- 2 to 6 November 1966.

13.1 Storms and depressions form a very important category of synoptic situations which cause active to vigorous northeast monsoon in the south Peninsula. The heaviest falls occur when they cross coast and the extension of rainfall to the north (discussed in para 12.1.4) is characteristic of these systems during this season.

13.2 Storms and depressions coming close to or crossing the coast of the Peninsula are mostly in October and November; their number decreases considerably in December. In November and December, cyclonic storms are more numerous than depressions. The entire Andhra Pradesh - Tamil Nadu coast is liable to be affected by the storms and depressions in October; later in the season south coastal Tamil Nadu is more vulnerable than the coastal line further north. The coastal area near about Pondicherry-Cuddalore-Nagapattinam is the place where the maximum number of storms and depressions cross coast in November and December. In this section, we will discuss a typical cyclonic storm which crossed Tamil Nadu coast and caused strong to vigorous monsoon conditions in the south Peninsula.

13.3 A depression which formed over the south Andaman Sea on 1 November 1966, moved westwards, intensified into cyclonic storm and was over southeast Bay with its centre near 9.5°N 88°E on the morning of 2 November (Fig. 13.1). 24 hour pressure change pattern became more organised by the evening and the maximum negative pressure changes were along Tamil Nadu coast and North Sri Lanka (about -3 mbs). Except for a feeble cyclonic circulation over Kerala in the very low levels, the upper air flow pattern (Fig. 13.2) was mainly one of northeasterlies over

south Peninsula. Rainfall was generally light in Tamil Nadu. The storm was too far away to produce any weather over the Peninsula and the east-west trough line was also present only over Kerala. The rainfall in south Kerala was due to the feeble cyclonic circulation over the area. Even by the evening (12 GMT) when the storm was near 10°N 85°E (i.e. 5° to the east of the coast), heavy rainfall had not commenced in Tamil Nadu.

13.4 By 3rd morning, the cyclonic storm which was severe by now, rapidly moved in a northwesterly direction and was close to coast near Madras (Figs.13.3 and 13.4). The movement was rather rapid. The maximum pressure fall along the coast was about 8 mbs (at Madras) and the maximum departure was also -8 mbs along the coast. Ships in the storm-field reported winds reaching 60 kts. The highest observed wind speed in the storm area was B.F. 15-17 (95-115 kts) and the lowest pressure 961.0 mb at 1440 IST of 3rd (52 mb below normal). As the cyclonic storm approached the coast, rainfall increased in Tamil Nadu and a few rather heavy to heavy falls were recorded along the coast.

13.5 By the evening, the severe cyclonic storm moved inland and weakened into a cyclonic storm. Heavy amounts were recorded along Tamil Nadu coast even by the evening.

13.6 Moving in a westsouthwesterly direction and weakening into a deep depression, it was over interior Tamil Nadu and adjoining area of South Interior Mysore on the 4th morning (Figs. 13.5 and 13.6). It had caused very heavy rainfall near the track and to the north of the track, the amounts being heavier along the coast. The heaviest fall was 22 cm at Nellore. South of the track (i.e. south of latitude 11°N) there was very little rain in the Peninsula. However, in the north, rainfall extended into coastal Andhra Pradesh and Rayalaseema, the northern limit of rainbelt being latitude 18°N.

13.7 During the next 24 hrs, the deep depression continued to move in a westsouthwesterly direction, it also further weakened as it travelled over land.

By 5th morning, it emerged into southeast Arabian Sea, and lay as a depression over Laccadives area(Fig. 13.7). As the depression moved into the Arabian Sea, pressures rose over the south Peninsula. Rainfall continued to be generally widespread over the whole of south Peninsula and extended into Kerala and Arabian Sea Islands. Though the rainfall decreased in Tamil Nadu as the depression moved west, still it was nearly widespread. Some heavy falls still continued in Coastal Andhra Pradesh and Tamil Nadu and the significant rainfall amounts were still in the coastal areas. The persistence of the rainfall (with a few heavy falls) in Coastal Andhra Pradesh even when the depression had moved into Laccadives is a significant feature to be noted.

13.8 By the next morning (6th), the depression moved further westwards (Fig. 13.8) and rainfall decreased considerably over the south Peninsula,though a few moderate falls were still reported from Coastal Andhra Pradesh (Fig. 13.9). The synoptic situation over the south Peninsula subsequently changed by the formation of a low pressure area in southwest Bay of Bengal.

13.9 The significant features to be noticed in this sequence are:-

i) While the cyclonic storm was far out at sea, in the Bay of Bengal,generally northeasterlies prevailed over the south Peninsula and the east-west oriented trough was also not prominent over the Peninsula. Hence there was no significant rainfall in the Peninsula except for a few showers in the extreme south Kerala. Even on 2nd evening when the cyclonic storm was near 10°N 85°E (only about 5 degrees away from the coast) no significant rainfall had commenced along Tamil Nadu coast. On 3rd morning also, when the storm was severe and was close to the coast, the significant amounts were only along the coastal areas; the interior of Tamil Nadu did not get much rain. Only when the system moved to interior Tamil Nadu and adjoining South Interior Mysore on 4th, ~~that~~ Tamil Nadu reported widespread heavy to very heavy falls. Thus, the extent of rain area ahead of the storm centre was quite limited, while in the rear, rainfall was extensive and persisted

even after the storm had moved into the Arabian Sea.

ii) The heaviest falls occurred along the coast at the time of crossing coast. The rainfall along the coast (Tamil Nadu and Coastal Andhra Pradesh) was generally more than in the interior, even after the storm moved to west coast

iii) The extension of rainfall in the north was upto 18°N, while to the south of the track, there was no significant rainfall. Corresponding to the northern limit of rainfall, a zone of anticyclonic vorticity (due to speed variation) was noticed in the lower tropospheric wind flow.

iv) The persistence of significant rainfall amounts in Coastal Andhra Pradesh (on 5th and 6th) even after the storm had moved far to the west and rainfall had decreased in Tamil Nadu, is a noteworthy feature. The several causes which have been adduced for this, have already been discussed in para 11.2.1.

v) The axis of the sub-tropical ridge line in the middle and upper troposphere was well to the north of the track of the storm (by about 8° of latitude or so). As the storm moved from the Bay to southeast Arabian Sea across the Peninsula, the anticyclonic cell to the north (in the middle and upper troposphere) also moved westwards. On account of the southerly/southwesterly flow at the western edge of the westward moving anticyclone, the tops of the cloud systems associated with the cyclonic storm were sheared off and they spread northwards to a considerable extent.

14. Cyclonic storm crossing Andhra Coast, causing active to vigorous monsoon in Coastal Andhra Pradesh – 4 to 9 November 1969.

14.1 A severe cyclonic storm lay over the east central Bay of Bengal on the morning of 5th November 1969, with its centre near 13°N 90°E (Fig. 14.1). Satellite picture showed that the cloud belt associated with the storm extended quite far to the north and northeast of the storm centre and the western edge of the main cloud mass was still about 300 km away from the Indian coast. The lower tropospheric flow pattern over the Indian Peninsula was one of north/northeasterly (Fig. 14.2). Except over the south Peninsula, the air over the

country was one of continental origin and consequently dry. There was very little clouding or weather over the Peninsula. Pressures were rising over the Bay Islands and Burma coast by 1 to 2 mb and they fell by about 1 mb in the eastern half of the Peninsula. Similar pressure change pattern, with more pronounced pressure rise over Bay Islands and Burma coast was noticed in the evening. This perhaps was one of the early indications that the storm may move in a direction towards the Indian coast. It should, however, be admitted that in all cases, a fall by about 1 mb along the east coast when the storm is so far off may not be significant and associated with a storm moving in a westerly direction. But, in the present case, the pattern of rise and fall was pronounced and persisted.

14.2 The storm moved northwestwards and became severe on 6th morning when it was centred near 14.5°N 87°E (Fig. 14.3). Pressures rose further by about 3 mb over Bay Islands and fell further over the eastern half of the Peninsula. The maximum fall was along Coastal Andhra Pradesh (about 4 mbs). This suggested a further movement of the storm in a northwesterly direction. Lower tropospheric winds along Andhra Pradesh and south Orissa coasts also strengthened during the past 24 hrs and a considerable incursion of moisture was noticed over these areas, the air becoming almost saturated, although the general flow over the Peninsula still continued to be north/northeasterly (Fig. 14.4).

14.3 The satellite pictures showed that the peripheral cloud bands in the northwest sector of the storm had reached Orissa and West Bengal and the main overcast area was close to Orissa coast. Fairly widespread rainfall occurred along Orissa coast. Over the rest of the Peninsula, weather was dry.

14.4 During the day (6th), pressures continued to fall over the Peninsula; in the evening chart, pressure falls were quite marked in Coastal Andhra Pradesh and adjoining areas, the maximum being about 4 to 5 mb (Fig. 14.5). Lower tropospheric winds further strengthened along north Andhra Pradesh and

south Orissa coasts where speeds reached 50 kts (Fig. 14.6).

14.5 Continuing to move in a northwesterly direction, the severe cyclonic storm was centred near 16°N 84°E on the morning of 7th, the nearest part of the coast being only about 200 km from the storm centre (Fig. 14.7). The winds over the Peninsula came well within the circulation of the storm (Fig. 14.8). The pressure falls were very much concentrated along the north Andhra coast, being over 8 mbs. Satellite pictures showed that the western edge of the main cloud mass associated with the cyclonic storm reached Telangana and southeast Madhya Pradesh.

14.6 As the severe cyclonic storm approached, rainfall increased in Coastal Andhra Pradesh and Orissa, with a few heavy falls. The characteristic distribution of rainfall associated with the post-monsoon storms was noticed in this case also. With the storm centre along 16°N, the northward extension of rainfall was upto coastal West Bengal (latitude 22°N) while to the south of 16°N, there was hardly any rain over the Peninsula.

14.7 By the same evening, the severe cyclonic storm crossed coast between Masulipatam and Kakinada. The highest negative departure was 36 mb at Nidadavole. The storm had travelled at an average speed of about 27 kmph during the preceeding 12 hrs (perhaps a little fast compared to the normal rate of travel of cyclones). On 8th morning, it lay as a cyclonic storm over Telangana and adjoining areas with its centre close to Hyderabad (Figs.14.9 and 14.10). As the storm moved west, rainfall extended into Telangana and Rayalaseema. Heavy to very heavy falls occurred in Coastal Andhra Pradesh, Kalingapatnam recording 15 cm. A number of state rainguage stations in Coastal Andhra Pradesh recorded rainfall varying from 14 cm to 19 cm.

14.8 With the track of the storm being roughly along 16°N, the rainbelt extended upto 22°N (on the northern side) i.e. 6° of latitude to the north, while on the southern side, it hardly extended 1° of latitude. There was no

rain over the Peninsula south of latitude 15°N.

14.9 The cyclonic storm continued to move in a northwesterly direction and gradually weakened. It lay as a depression over northeast Madhya Maharashtra and the adjoining Marathwada on 9th morning. As the system moved away westwards, pressure rose considerably over the eastern Peninsula, the maximum rise being about 5 mb in Andhra Pradesh. The rainfall also decreased considerably in Coastal Andhra Pradesh where monsoon became normal. With further northwest movement of the depression, rainfall decreased further in Andhra Pradesh.

14.10 The main points to be noted in the discussion are:-

i) In association with the severe cyclonic storm rainfall started on 6th in Orissa which is situated at a more easterly longitude than Coastal Andhra Pradesh or Tamil Nadu. There was a sudden increase in rainfall in Coastal Andhra Pradesh on 7th when the monsoon became strong. The increase in Coastal Andhra Pradesh was significant only after 6th evening when the severe storm was about 400 km from Coastal Andhra Pradesh. Monsoon became vigorous in Coastal Andhra Pradesh on the 8th by which time the severe storm had moved inland. Rainfall considerably decreased in this sub-division on 9th when the system had moved to north Madhya Maharashtra.

ii) The storm centre was roughly along Lat. 16°-17°N, as it moved from west central Bay to Telangana (between 7th and 9th). During this period, rainfall extended in the north upto about Lat. 22°N (i.e. 5 to 6 degrees of latitude to the north of the track), while in the south, rainfall did not extend south of latitude 15°N. Thus, Tamil Nadu was dry while the increase in rainfall in Rayalaseema and South Interior Mysore was just marginal. This rainfall distribution is typical of the post-monsoon storms and depressions crossing the east coast of the Peninsula. The heaviest falls occurred at the time of the storm crossing the coast.

iii) The 24 hrs. pressure changes and the strengthening of the lower tropospheric wind field along Orissa and Andhra Pradesh coasts were significant and gave

useful indications to prognosticate the storm track. As may be seen in the above para, since the rainfall distribution is closely related to the storm track, a good indication of the place where the storm is likely to cross coast is a vital factor on which heavy rainfall warnings are to be based.

iv) The satellite cloudiness associated with the storm and the rate of westward movement of the western edge of the cloudiness are good aids to anticipate the time of commencement of rainfall in the coastal areas and its westward extension.

v) Throughout the period 4–7 November, the storm was well to the south of the sub-tropical ridge line at 200 mb level, by nearly 5° or so. This was also another indication of the continued westnorthwest/northwest movement of the storm without any tendency to move north or recurve. The ridge line over the Bay and the Indian Peninsula was along 15–17°N in the beginning(4th) and progressively shifted northwards reaching 20°N by 7th.

vi) The lower tropospheric winds in the storm area were stronger in the northwestern sector than in the other sectors. These strong winds also extend over a larger area. The region of anti-cyclonic shear in the wind field where the winds decreased in speed, was well-marked in the northwestern sector. This sharp zone was found to be the limit of the westward extension of rainfall and cloud belts associated with the storm.

15. Severe cyclonic storm in the Bay of Bengal *recurving northeastwards – 10 to 14 Nov.'68*

15.1 A depression which formed in southwest Bay of Bengal moved northwestwards, intensified into a severe cyclonic storm by the morning of 10th when it was centred near Lat. 12.5°N 85.5°E (Fig. 15.1). With these developments, the lower tropospheric flow pattern over the eastern half of Peninsula became north/northeasterly; the coastal winds also strengthened to 20/30 kt (Fig. 15.2). The dew point changes and minimum temperature changes indicated a general decrease of moisture over the Peninsula and the air over the Peninsula was

becoming drier; this was confirmed by the considerable decrease in the rainfall over the south Peninsula in the next 24 hrs.

15.2 Continuing to move in a northwesterly to northnorthwesterly direction, the severe cyclonic storm was centred near 14°N 85°E on 11th morning (Fig. 15.3). Satellite cloud picture showed that the western edge of the main cloud mass associated with the storm had just reached Andhra – Orissa coasts. Although the lower tropospheric upper winds over the Peninsula had come into the circulation of the cyclonic storm, still they were perhaps mainly of continental origin (Fig. 15.4). At this stage, the storm has come almost under the upper tropospheric (150 mb) ridge line.

15.3 During the next 24 hrs the storm moved more or less in a northerly direction to 16.5°N 84°E (Figs. 15.5 and 15.6). It was within 200 km of the coastline. Rainfall was mainly along the Orissa coast. In Coastal Andhra Pradesh also only the northern districts received rainfall. There was no heavy fall .

15.4 After the 12th, the storm recurved northeastwards and moved towards Sundarbans and also gradually weakened. Between the mornings of 12th and 13th the storm came within about 100 km of Orissa and north Andhra coasts (Figs. 15.7 and 15.8). As the storm came near, rainfall increased considerably along the coastal areas, when amounts uptc 10 cm to 14 cm were recorded on 13th morning, compared to only 4 cm to 5 cm on the previous day. Even on this day, only the extreme northern districts of Coastal Andhra Pradesh had heavy rains and rest of Coastal Andhra Pradesh was mainly dry. The gradient of rainfall in the south was very pronounced (with 12 cm at Kalingapatam and hardly a few mm at Visakhapatnam, only one degree of latitude to the south.) As the cyclonic storm moved away northeastwards, rainfall decreased in Coastal Andhra Pradesh the next day (14th) (see inset on 13th chart – Fig. 15.7).

15.5 The main features in this sequence are:-

i) This case is illustrative of a cyclonic storm which did not cause strong monsoon in Tamil Nadu or Coastal Andhra Pradesh, in contrast to the earlier two cases discussed in Sections 13 and 14 when strong to vigorous monsoon conditions prevailed in association with a cyclonic storm. The storm did not cross the Tamil Nadu or Andhra coast. It practically moved parallel to Orissa and north Andhra coasts between 12th and 14th when it came within 100–150 km of the coast line.

ii) Even in Orissa and north Coastal Andhra Pradesh, heavy rainfall occurred only when the storm was within 100–150 km of the coast line. Between 11th and 12th when the storm was within 200–400 km of the coastline, the rainfall was only light to moderate. Thus heavy rainfall was confined on the western side of the storm to about 200 km of the storm centre.

iii) This storm also showed the characteristic extension of the rainbelt to the north of the storm centre and the abrupt decrease in rainfall in the south. In view of this type of rainfall distribution associated with the storm, there was practically no rain in the east coast to the south of 18°N. Significant rainfall amounts in Coastal Andhra Pradesh were only in the extreme northern districts.

iv) In this case also the satellite pictures were very helpful in delineating the extent of the weather that may be expected over the east coast of the Peninsula in association with the storm.

v) This case highlights the importance of prognosticating the storm movement in anticipating the extension of rainfall and issue of heavy rainfall warnings. Although an eastward moving trough in middle latitude westerlies has often been associated with recurving cyclonic storms, in the present case, no such trough moved across northern India.

vi) If we contrast the movements of the cyclonic storm of November 1969 which crossed near Kakinada (Sec. 14), the storm of November 1966, which moved almost west (Sec. 13) and the present storm which recurved off the Andhra-

Orissa coasts, a salient feature that emerges is the differences in the location of the sub-tropical ridge line at 150 mb level. Severe cyclonic storms extend well above 200-150 mb level. Extensive research with aircraft data has shown that they may extend in a feeble manner even upto 19 km. However, the dimensions of the cyclonic circulation and the perepheral anticyclones at 200-150 mb level are considerably smaller than the sub-tropical anticyclonic cells which predominate the flow pattern at these higher levels. A preliminary examination has shown that the 200-150 mb ridge line has a fairly good correlation with the track of the storm. The chief conclusions are:

a) when the storm is well to the south of the subtropical ridge line, the storm movement is in a westerly to westnorthwesterly direction. The further south the storm is from the ridge line, the more it is likely to take west/westnorthwesterly track. The storm should at least be 3-4° of lat. south of the ridge line;

b) if the storm is within 3 degree of the ridge line, the storm is likely to take a generally northerly track than a westerly track; the storm may move slowly and may even remain stationary; and

c) when the storm crosses to the north of the ridge line, the movement gets an easterly component. The three storms discussed in Secs. 13-15 clearly illustrate the above conclusions. Satellite-derived upper winds are useful in delineating the 200-150 mb level flow patterns over the sea areas and fixing the location of the sub-tropical ridge line in an objective fashion.

16. Well-marked low pressure area moving westwards across south Peninsula (9 to 11 October 1970)

16.1 A well-marked low pressure area moved westwards across the south Peninsula between 9 and 11 October 1970, giving rise to a spell of rainfall activity there. The low pressure area could be traced from the south Andaman Sea; it moved across the Bay Islands between 6th and 7th. The passage across the Bay Islands was clearly noticed by the changes in the upper winds at

Port Blair and also in the pressure field.

16.2 On the 7th morning, the well-marked low pressure area apparently lay over the east central and the adjoining west central Bay (Fig. 16.1) with its circulation extending upto 400 mb sloping with height towards a southerly direction, as could be judged from the changes in Port Blair winds from westerly in the lower levels to southeasterly in the mid-troposphere (Fig. 16.2). Due to lack of observations over the oceanic area, it is difficult to infer the direction of the slope with greater precision. On this day, there was also a feeble trough of low pressure off Coastal Mysore; an east-west oriented trough across the south Peninsula joined the two low pressure systems in Arabian Sea and Bay of Bengal. The trough line was passing across the Peninsula from Coastal Mysore to coastal Tamil Nadu, with moderate to strong westerlies to the south and generally light northerlies to the north. The trough line could be noticed upto 4.5 km with a slope towards the south (cold air side). On this day (7th), there was well-distributed light to moderate rainfall in the south Peninsula, which was mainly due to the trough line across the area. Rainfall occurred both in the westerly stream to the south of the trough line as well as in the northerlies to the north of the trough line. Rainfall was generally accompanied by thunder.

16.3 By 8th morning, the well-marked low moved into west central Bay and the trough line persisted across the south Peninsula (Figs. 16.3 and 16.4). The more significant amounts of rainfall (ranging between 3 cm and 6 cm) were close to the trough line. By 9th, the well-marked low pressure area moved nearer to Tamil Nadu coast (Fig. 16.5). The maximum pressure departures were about -5 mb in Tamil Nadu, although pressures over the Peninsula were, in general, more than 2 mb below normal. The APT picture showed heavy overcast clouding associated with the low covering the eastern half of south Peninsula, extending in the north to Coastal Andhra Pradesh.

16.4 By 10th, the well-marked low pressure area moved into interior Tamil Nadu and one closed isobar could be drawn delineating the low (Fig. 16.6). Very often, when such low pressure systems move over land, it is difficult to delineate them in the isobaric field; they are seen mainly as an upper air circulation. The circulation in this case extended upto 400 mb sloping southwest with height, particularly above 700 mb (Fig. 16.7). As the low moved into the Peninsula, winds became easterlies over the entire Peninsula north of the low. In contrast to the wind pattern on 7th and 8th when the low was out at sea, the wind pattern over the Peninsula on 10th showed the following changes:

i) the westerlies over extreme south Peninsula weakened considerably on 10th and

ii) the easterlies strengthened to 20/30 knots in the lower troposphere.

16.5 As the well-marked low came near, rainfall considerably increased in the eastern portions of south Peninsula and monsoon became strong to vigorous in Rayalaseema and Coastal Andhra Pradesh, with some heavy falls. The main area of heavy rainfall was south Coastal Andhra Pradesh where a number of stations recorded 8 cm to 9 cm . The noteworthy feature of the rainfall distribution is the extension of rainfall to the north to a distances of about 6-8 degrees of latitude from the centre of the low. The higher amounts and heavy rains were in the immediate neighbourhood of the low as well as to the north of the low. The area of rainfall to the north was in the region of cyclonic shear in the easterlies in the lower troposphere; rainfall practically ceased to the north of the axis of the lower tropospheric wind maxima where the shear changed sign. In the easterlies to the north of the low pressure area, a north-south oriented trough line was also present extending from the centre of the low towards northeast Madhya Pradesh. The southeasterlies to the east of the trough line were more moist than the northeasterlies to the west of the trough. Rainfall was confined to the east of the trough line. The contrast in the temperature field between the east and west of the trough line was insignificant whereas it was quite

marked in the moisture field. The wind and the humidity fields tied well with the realised rainfall. The pressure changes as well as the deep easterly field in which the low was embedded indicated a continued westerly movement.

16.6 By 11th morning, the low moved to central and adjoining southeast Arabian Sea, off Coastal Mysore and continued to be well-marked (Fig. 16.8). The associated north-south trough also moved westwards into the Arabian Sea off south Maharashtra and Mysore coasts (Fig. 16.9). However, the east-west trough persisted across south Peninsula. With the westward movement of the low, pressures rose over the whole Peninsula, the maximum rise being about 3 mb in the eastern half. As the low and the associated north-south trough moved west, moist southeasterlies spread over the whole Peninsula and rainfall extended into western portion of the Peninsula; it generally decreased in the eastern half, though isolated heavy falls occurred in Coastal Andhra Pradesh where monsoon continued vigorous.

6.7 Subsequently the well-marked low moved away further westwards in the Arabian Sea and rainfall also decreased further in the Peninsula, being mostly confined to the western half.

16.8 This sequence brings out the following chief features:

i) The low pressure area was marked, being seen in the surface and in the upper air, with a well-defined cyclonic circulation; it could be traced from South Andaman Sea to East Arabian Sea. In the upper air, the associated cyclonic circulation was well-marked extending upto the mid-troposphere (400 mb) with a southwestward slope with height. The seasonal east-west trough across the south Peninsula was also well-marked extending to mid-tropospheric level, with a general tilt towards the south.

ii) There was also a north-south oriented trough extending from the low northwards, which also sequentially moved westwards along with the well-marked low. When the north-south trough moved across the Peninsula, radiosonde

data showed that though there was no temperature discontinuity across the trough line, the southeasterlies to the east of the trough line, were considerably moist and the northeasterlies to the west of the trough were dry. Rainfall was confined to the moist southeasterlies on the eastern side of the trough line.

iii) Though initially when the low pressure area was out at sea in the Bay, the westerlies over the Peninsula were moderate to strong, subsequently when the system moved inland, the easterlies to the north of the low became quite strong (reaching upto 35 kts) in the lower troposphere while the westerlies were relatively weak.

iv) Rainfall extended far to the north of the low in the field of the moist easterlies and the significant amounts were close to the low or to the north of it, in the field of the southeasterlies. Coastal Andhra Pradesh which was well to the north of the low got vigorous monsoon on two consecutive days and heavy falls upto 12 cms were recorded there. The rainfall to the north of the low was confined to the area of cyclonic shear in the easterlies.

v) The contrast in the rainfall and wind patterns on 7th and 8th when compared to 10th and 11th show the differences between the two situations:

a) When the low was out at sea with only a east-west oriented trough line across the south Peninsula and

b) when the well-marked low moved across the Peninsula.

vi) Rainfall was generally accompanied by thunder.

vii) The vertical time sections of Port Blair (Fig. 16.10) and Madras (Fig. 16.11) showed the passage of the low. The forward slope of the axis of the low with height, in both the sections, may be noted. Similarly, the strengthening of the southeasterlies after the low passed over the station is also noteworthy.

viii) The isobaric field, 24 hr. pressure changes and the changes in the upper winds gave good indications of the movement of the low; similarly the

cloud configuration in the APT pictures confirmed the existence of the well-marked low out at sea and also gave useful information regarding the extent to which the cloud system associated with the low has extended in the north. Based on this information one can predict the spread of rainfall in the north.

ix) During this period, there was also an upper westerly trough moving across Uttar Pradesh and Bihar and on some charts the rainfall and clouding associated with the well-marked low in the south and the westerly trough in the north, appeared ~~to be~~ as a single belt covering the eastern half of the country.

x) The wind changes along the coast (for instance at Madras) at 850 mb and above with the approach and passage of the low pressure area were more ~~consistent~~ regular and progressive than the wind changes below 850 mb.

xi) In the present case, the low pressure area moved westwards across the south Peninsula. There ~~was~~ were also cases where the low pressure area weakens off as it approaches the Tamil Nadu coast. In a few other cases, while the low may weaken in the surface, it may be still traceable in the lower troposphere and move westwards across the Peninsula. On such occasions also, weather may persist over the south Peninsula and extend westwards along with the upper air low.

17. Low pressure area moving across Sri Lanka with a trough extending northwards to off Tamil Nadu coast - 6 to 9 December, 1971.

17.1 On the morning of 6th December, 1971, the seasonal trough was over south Bay extending from Sri Lanka to south Andaman Sea. By the evening, a low pressure area developed in the seasonal trough over the southwest Bay off Sri Lanka (Fig. 17.1). The 'low' could be delineated clearly in the isobaric field; it extended in the upper air upto about 1.0 km, above which there was probably only a north-south oriented trough (Fig. 17.2 a). To the north of the low, the pressure gradient was strong over west central Bay and along Tamil Nadu

coast where surface and upper winds were strong northerlies. At this stage, rainfall had not yet commenced along Tamil Nadu coast. Satellite pictures showed that while the main heavy cloud mass was in west central and southwest Bay, there was an extension of broken to overcast clouds in the western half of the Bay extending as far north as 20°N. This was apparently due to the strong southerlies over this area in the middle and upper troposphere which had advected these clouds northwards (Fig. 17.2 b).

17.2 By the next morning (7th), the low pressure area moved southwestwards and was off Sri Lanka coast (Fig. 17.3). On this day also it was seen only upto 1.0 km (Fig. 17.4). Pressure gradient continued strong along Tamil Nadu coast. The maximum negative pressure departure associated with the low was about 4 mb. With the 'low' moving towards the west, rainfall commenced along south Tamil Nadu coast. Satellite pictures showed that the heavy mass of cloud from west Bay had moved west and covered Tamil Nadu also. There was no extension of the cloud belt beyond 15°N (in contrast to the previous day) because of the changes in the middle and upper tropospheric flow patterns, where the southerlies were no longer present over the west Bay.

17.3 As the system approached Sri Lanka on 8th, it apparently weakened slightly (Fig. 17.5). In the upper air, the circulation could hardly be seen, as may be inferred from the winds over Hambantota which became northeast/east upto 1.5 km (Fig. 17.6). Pressure departures were maximum over Comorin and southwest Sri Lanka indicating that the central region of the low was over these areas on the surface chart. As the low moved over to Sri Lanka (in the surface chart) rainfall suddenly increased in south Tamil Nadu where falls upto 21 cm were recorded along the coast. Monsoon became vigorous in Tamil Nadu.

17.4 By 9th, the low moved into Maldives region as seen from the surface isobaric and pressure departure charts (Fig. 17.7). In the upper air, it could not be noticed at all. As the low moved west, rainfall decreased in Tamil Nadu

though it was still widespread (an isolated heavy fall was also reported) and monsoon was active in Tamil Nadu. Rainfall decreased further on 10th.

17.5 The following are the main points brought out by this case:

i) A low pressure area developed over the southwest Bay in the seasonal trough. It showed a southwestward movement as it approached Sri Lanka coast and weakened while crossing the island. A southerly component for the movement is sometimes seen in this season for the systems approaching the Tamil Nadu and Sri Lanka coasts. The low could be traced on the surface chart upto Comorin-Maldive areas as a feeble system. Satellite pictures also showed a progressive westward movement of a heavy mass of cloud associated with the system, from west central Bay to southeast Arabian Sea.

ii) The low pressure area extended only upto about 1.0 km in the upper air. The changes in the upper winds at Hambantota also suggested that the low moved in a southwesterly direction. While the low was over Sri Lanka and Comorin area on the 8th, Hambantota winds became easterly suggesting that either the low was to south of Lat. 5°N in the upper air or the system was not well-defined.

iii) Rainfall commenced along Tamil Nadu coast when the low came near the east coast of Sri Lanka. When it was moving across Sri Lanka, rainfall was maximum in Tamil Nadu, with a few heavy to very heavy falls. Strong to vigorous monsoon prevailed in Tamil Nadu on 9th and 10th when the low was moving across Sri Lanka and Comorin. As it moved further away, rainfall decreased. The only other sub-division affected by the low was Kerala. However, here rainfall was much less.

iv) During this period, the high over northwest India was prominent and with a low moving across Sri Lanka, the pressure gradient over south Peninsula was relatively steep for the low latitude. The pressure difference between Trincomalee and Madras was about 5 mb (compared to the normal value

2.5 to 3.0 mb for the season).

v) On the northern side of the low, there was considerable cross-isobaric flow and moderate to strong northerlies/northeasterlies prevailed. This feature makes it difficult to uniquely fix the central region of the moving low pressure system from the observations over south Peninsula.

vi) Although it was not a well-marked system, it caused considerable rainfall in Tamil Nadu, particularly in the southern districts. The gradient in rainfall was quite strong in the north; on 8th, when Cuddalore, Nagapattinam and Vedaranniyam received rainfall ranging from 6 cm to 21 cm, there was hardly any rain at Madras (about 150 km to the north). The rainfall extended well to the north of the low pressure system, in the region of the strong northerlies. In contrast to the well-marked low pressure area discussed in Sec. 16, in this case there was no good evidence of a north-south oriented trough to the north of the low, moving from east to west.

18. East-west oriented trough across the Peninsula - 25 to 26 October 1971

18.1 During the first half of the northeast monsoon season, particularly in October, a trough of low pressure extends from south Arabian Sea across the south Peninsula to south Bay and south Andaman Sea. The trough may also extend further east across Malaysia. The trough is seen on the surface chart and in the lower tropospheric levels. An east-west oriented dumb-bell shaped isobaric configuration over the Indian Peninsula and the Indian Sea areas, is the common feature of pressure distribution during this period, with a low pressure area over the west central Bay and another over southeast Arabian Sea. Low pressure areas may form in this extended trough over these sea areas, and move from east to west. Rainfall over the south Peninsula is generally light to moderate when such a trough system overlies the area. But, when a low pressure area (embedded in the trough) moves across, it causes localised heavy to very heavy rains. The movement of the low pressure areas may be traced better in the upper air charts (aided by vertical time sections of stations across the path of the low pressure

area) than in the surface isobaric analysis. In this section an instance of this type of synoptic situation will be discussed.

18.2 From 23rd October 1971 onwards, the seasonal trough was well-marked over south Arabian Sea, south Peninsula and south Bay of Bengal. A low pressure area (clearly seen in the upper air) moved westwards across the south Peninsula between 23 and 25 and reached Laccadives area on 25th. On this day, the trough line also ran roughly along 9°N on the surface (Fig. 18.1) and in the lower troposphere, from Laccadives to extreme south Vietnam coast (Fig. 18.2). Extended charts showed that the trough extended as far east as southwest Pacific with a number of embedded lows in it (Fig. 18.3). The trough was seen upto 3.6 km without any noticeable tilt with height. Both the easterlies and westerlies (on either side of the trough line) were moderate to strong, the strength being on an average about 15/20 kts. Even though the low pressure area had moved to Laccadives, still an elongated closed isobar could be drawn over south Bay and south Andaman Sea. The rainfall on this day was fairly widespread over the Peninsula south of Lat. 13°N. The significant amounts were close to the trough line and they were moderate to rather heavy. Monsoon was active in Tamil Nadu. This increased activity was partly due to the low pressure area moving westwards across the area in the preceding 24 hrs.

18.3 Cloudiness and light precipitation extended in the north upto about Lat. 20°N. The upper air charts showed that air was considerably dry at all levels to the north of Lat. 20°N. To the south of Lat. 20°N, the easterlies were more or less uniformly moist. This was also reflected in the surface dew point distribution. Thus, there was a pronounced moisture discontinuity across the country along Lat. 20°N, which was also the northern limit of weather and cloud belts.

18.4 On the 26th also the situation was nearly similar except that the trough extended upto 6.0 km. On this day also significant rainfall amounts were

near about the trough line. But the rainfall decreased compared to the previous day as the low pressure area had moved into the Laccadives area even by 25th morning. Subsequently cyclonic storms developed in the trough both in the Arabian Sea and the Bay.

18.5 The main features to be noted in this sequence are:-

i) The east-west oriented trough system extending from South Arabian Sea to Malaysia, with embedded lows in it, is a typical synoptic situation in the early part of the northeast monsoon season. The trough is seen on the surface chart and extends generally upto 700-600 mb levels. The westerlies to the south of the trough line are usually stronger than the winds to the north of the trough line. As is seen during the southwest monsoon season also, the trough may extend as far east as southwest Pacific.

ii) Such a well-marked trough, when once formed usually persists for a few days causing a spell of rainfall in the south Peninsula. It is also, often, a precursor of formation of depressions/storms in the South Arabian Sea and south Bay of Bengal.

iii) Unless there is a low pressure system embedded in the trough moving westwards across, the weather associated with the east-west trough is generally scattered light to moderate rainfall over south Peninsula, being slightly more in and near the trough line. There may be isolated heavy falls in the interior Peninsula where orography may produce enhancement of the weather.

iv) Cloudiness and isolated rainfall extended over the entire field of the moist easterlies to the north of the trough line. The demarcation

between the moist easterlies and the dry air mass further north over the northern and central India is clearly defined by dew points (surface and upper air). There is also a perceptible discontinuity in minimum temperatures corresponding to this moisture discontinuity.

v) Rainfall over south Peninsula is generally accompanied by thunder.

19. Weak northeast monsoon over south Peninsula with pronounced northerly upper wind flow - 10 November, 1971

19.1 We shall now discuss a typical synoptic situation when the northeast monsoon was weak and there was little or no rain over the Peninsula, with dry continental air prevailing over the area.

19.2 On the morning of 8th November 1971, an extended low pressure area lay over the south and the adjoining central Bay of Bengal, with another feeble "low" over the Laccadives (Fig. 19.1). There was no well-marked eastwest trough across the south Peninsula connecting the two systems; as a result, the wind flow over the Peninsula was generally northerly/northeasterly in the lower and middle troposphere and this stream was also quite dry (Fig. 19.2). Weather was, therefore, mainly dry over the south Peninsula except for isolated rain in Tamil Nadu. However, satellite pictures indicated good clouding in the south and central Bay of Bengal in association with the low pressure area there.

19.3 On the 9th also, the two low pressure systems in the sea areas persisted (Fig. 19.3). On account of the intensification of the high pressure cell over the western parts of central India, the northerly flow of dry continental air became well-marked over the south Peninsula (Fig. 19.4). At 300 mb the subtropical ridge was over Laccadives area and the south Peninsula, far to the south of the normal position.

19.4 A space cross-section for 9th along the mean meridian of 78°E is shown in Fig. 19.5. It may be seen from this that the air was very dry with very low dew points in the lower and middle tropospheres practically over the whole

country. Surface dew point temperatures were falling over the Peninsula where the 24 hour changes were about -2°C to -6°C. The minimum temperatures were generally below normal over the country, being 2°C-4°C below normal over south Peninsula. Pressures also rose over the whole country during the previous 24 hrs and the departures were of the order of +2 mb to +3 mb (refer to the auxiliary charts in Fig. 19.3). All these features indicated the prevalence of dry winter type circulation over the country.

19.5 On the 10th, the low pressure area persisted over the southwest Bay of Bengal with a somewhat westward movement, while the low over the Laccadives area was weakening. There was a further fall in the dew points over central and south India. The minimum temperatures also decreased further over the whole of the Peninsula and they were 4°C to 5°C below normal in Andhra Pradesh and 2°C to 4°C below normal over the rest of the Peninsula (Fig. 19.6). There was little change in the wind flow pattern over the Peninsula in the lower troposphere. Weather continued to be dry over the whole country.

19.6 The low pressure area over the Bay of Bengal moved further westwards and became well-marked on the 11th, when it was over the southwest Bay of Bengal off Sri Lanka (Fig. 19.7). Under the influence of this system, the upper air flow changed to easterly over the south Peninsula in the lower and middle troposphere (Fig. 19.8) and incursion of moisture took place into the south Peninsula; correspondingly the dew point and minimum temperatures rose over this area and the spell of dry weather was broken on the 12th.

19.7 The tephigrams of Bangalore and Visakhapatnam for 9th and Madras and Trivandrum for 10th are given in Figs. 19.9 and 19.10 respectively. These show very dry and stable air. Madras even shows an inversion between 900 mb and 800 mb and Visakhapatnam between 850 mb and 750 mb.

19.8 This sequence highlights the following points:

i) During this period, the anticyclonic circulation over the central parts of the country was well-marked as an anticyclonic cell moved progressively eastwards from northwest Arabian Sea to west Madhya Pradesh in the lower troposphere. There was also a well-marked low pressure area in the southwest Bay of Bengal. Under the influence of these two systems, the wind flow over the Peninsula became more or less northerly in the lower and middle troposphere. This feature was most pronounced on the 9th.

ii) Minimum and dew point temperatures fell and were below normal over the Peninsula on the 10th.

iii) During such occasions, early morning ground frost is a phenomenon in the highlands (like the Nilgiris), against which warnings are required to be issued.

iv) This pattern again underwent changes as the low pressure area moved close to Tamil Nadu - Sri Lanka coasts and moist easterlies replaced the dry northerlies.

v) Although the low pressure areas were present in the southwest Bay of Bengal and the Laccadives, there was no east-west trough across the south Peninsula, connecting the two systems. The absence of this trough appears to be the main reason for the pronounced dry weather over the south Peninsula.

vi) Though the weather was dry and there was little or no clouding over the Peninsula, satellite pictures indicated considerable amount of cloudiness in the southwest and west central Bay of Bengal, which progressively travelled towards the south Peninsula along with the low pressure area and revived the monsoon there.

ACKNOWLEDGEMENT

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

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 elsewhere. 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. 3·1 MEAN RAINFALL (Cm)

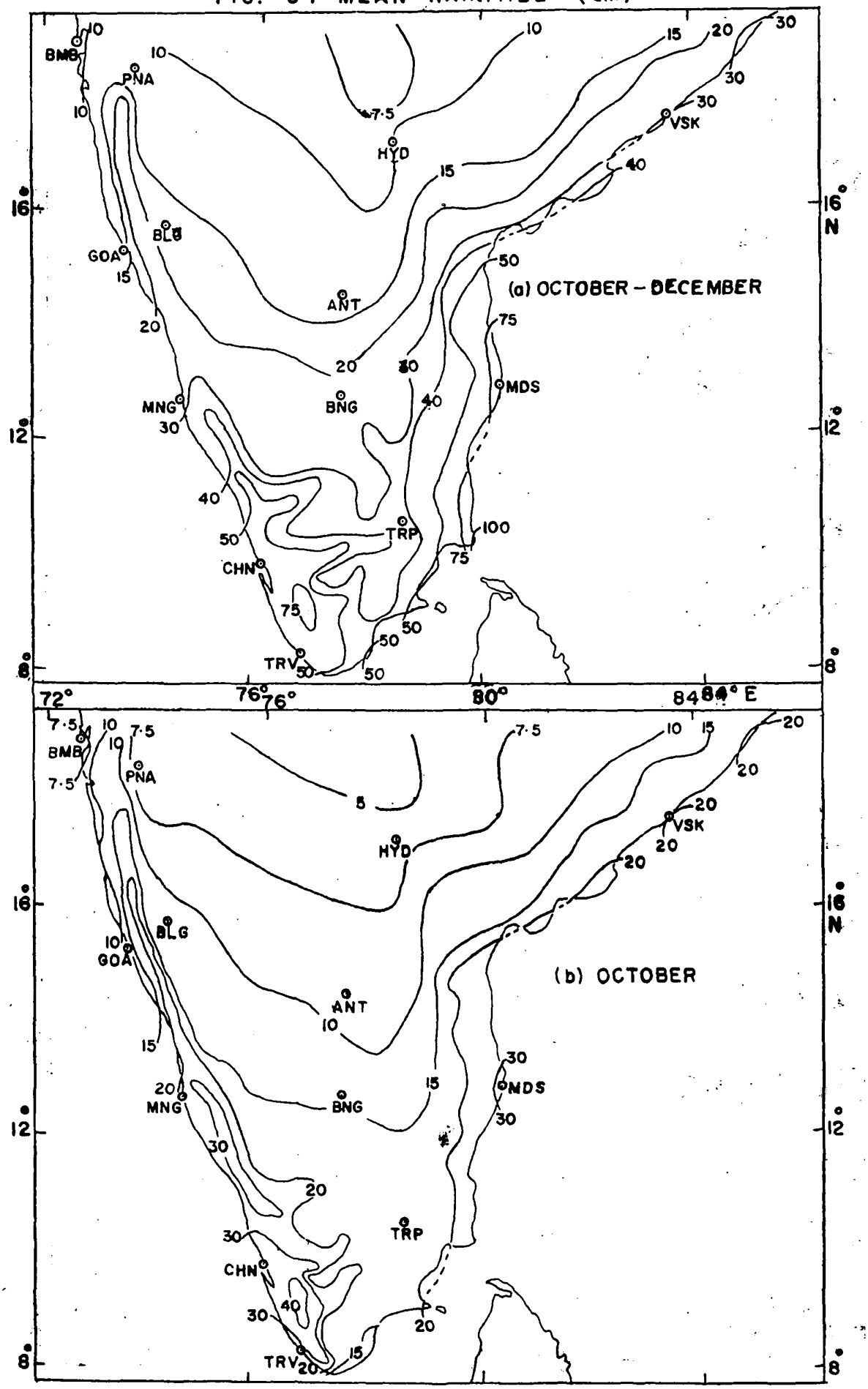


FIG. 3·1 MEAN RAINFALL (Cm)

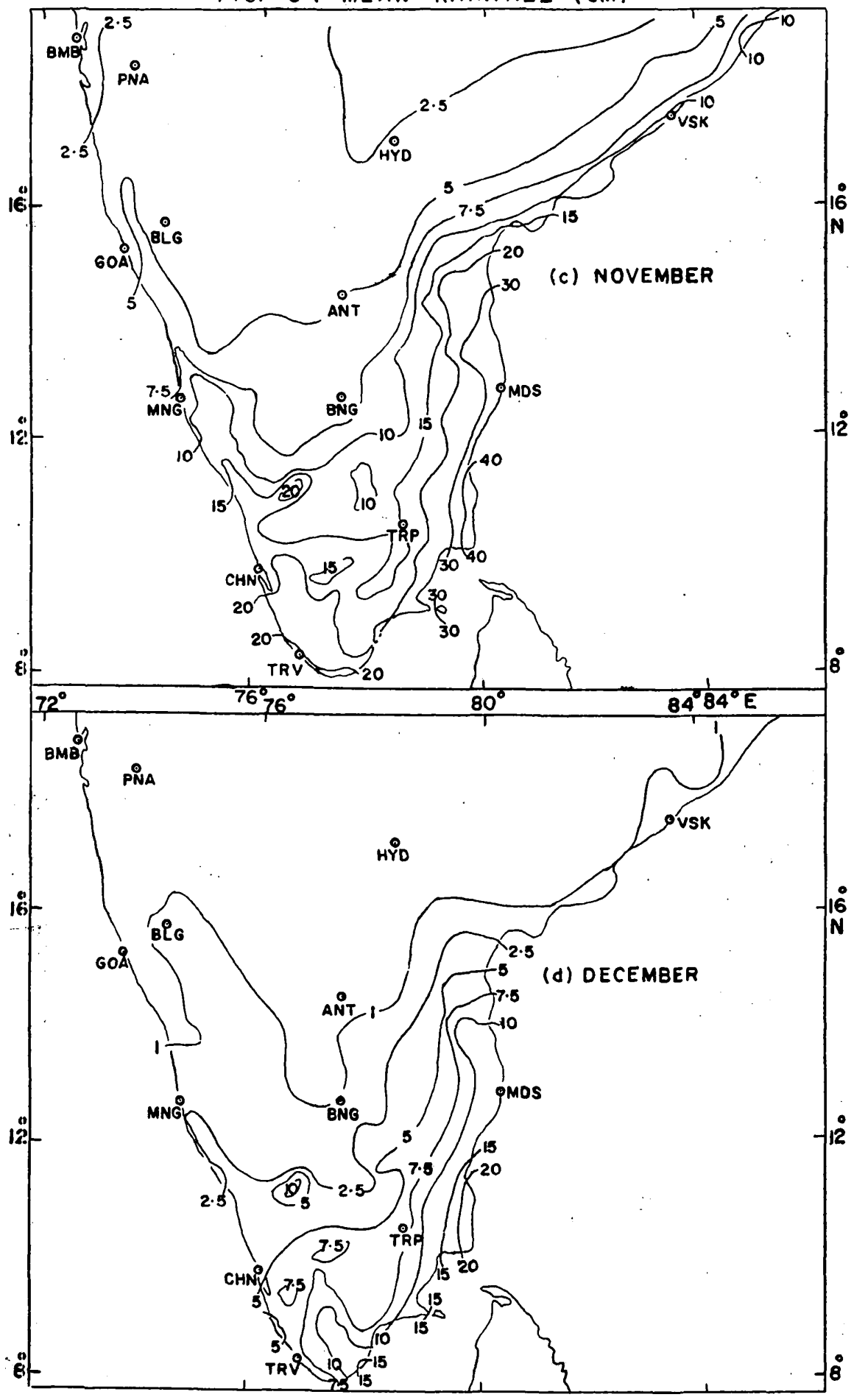


FIG. 9·1 VERTICAL PROFILE OF MONTHLY MEAN UPPER WINDS (00 GMT)

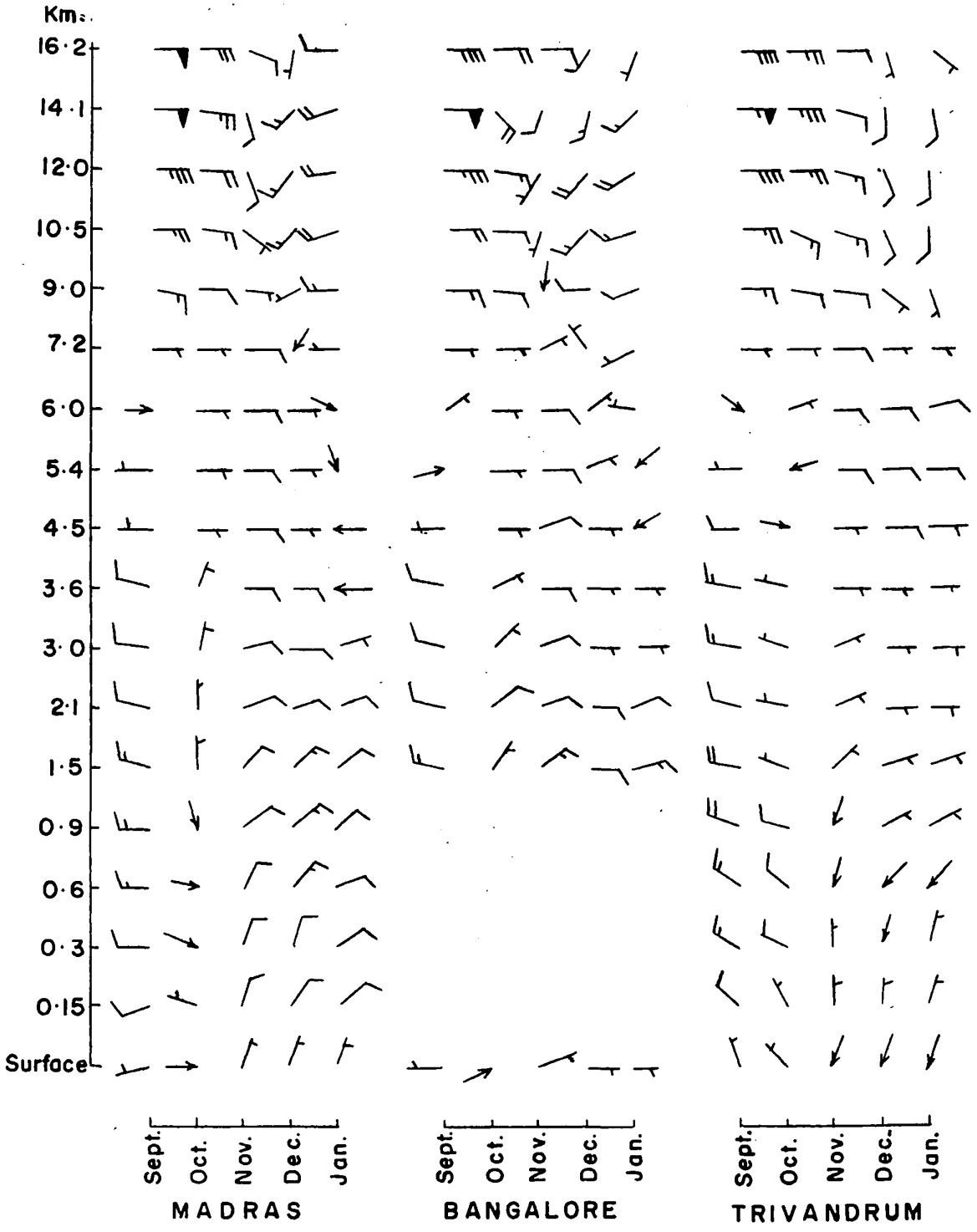


FIG. 10-1 MEAN TEPHIGRAMS OF MADRAS (00 GMT)

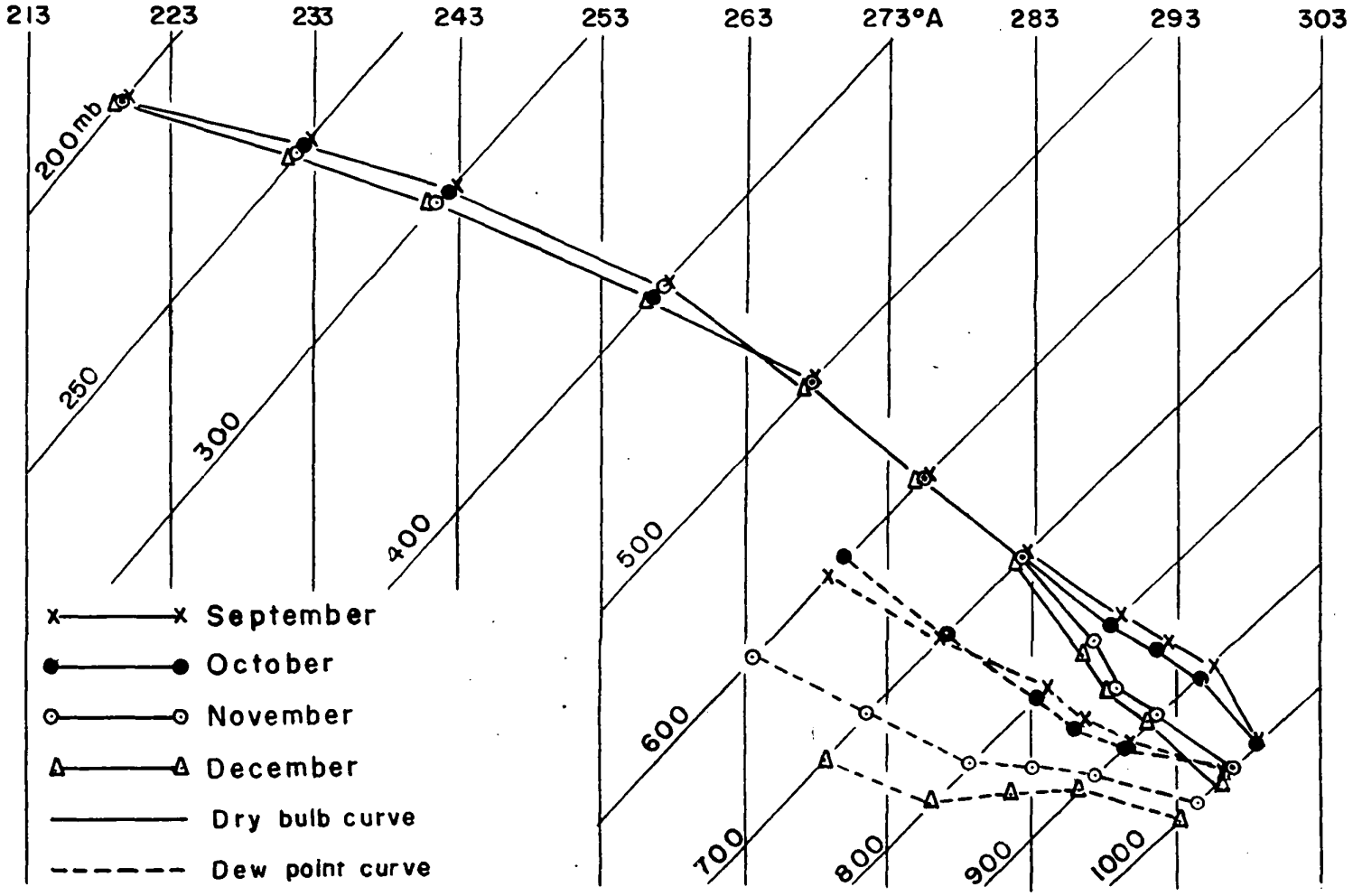


Fig. 10·2 Mean Tephigrams of Madras for Strong to Vigorous & Weak Monsoon (Based on data of Oct. & Nov., 70-71)

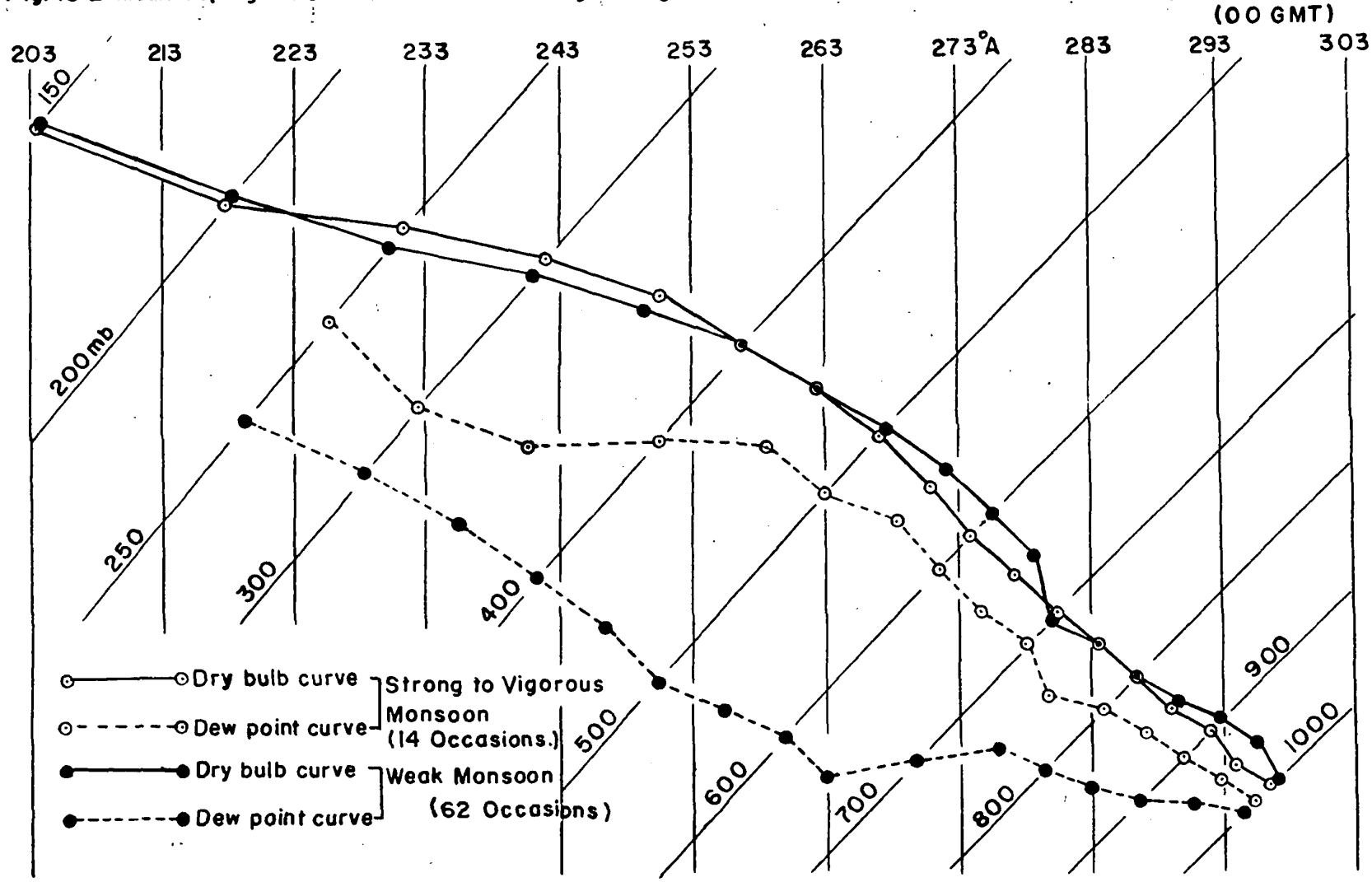


FIG. 10·3 TYPICAL TEPHIGRAMS OF MADRAS (00GMT)

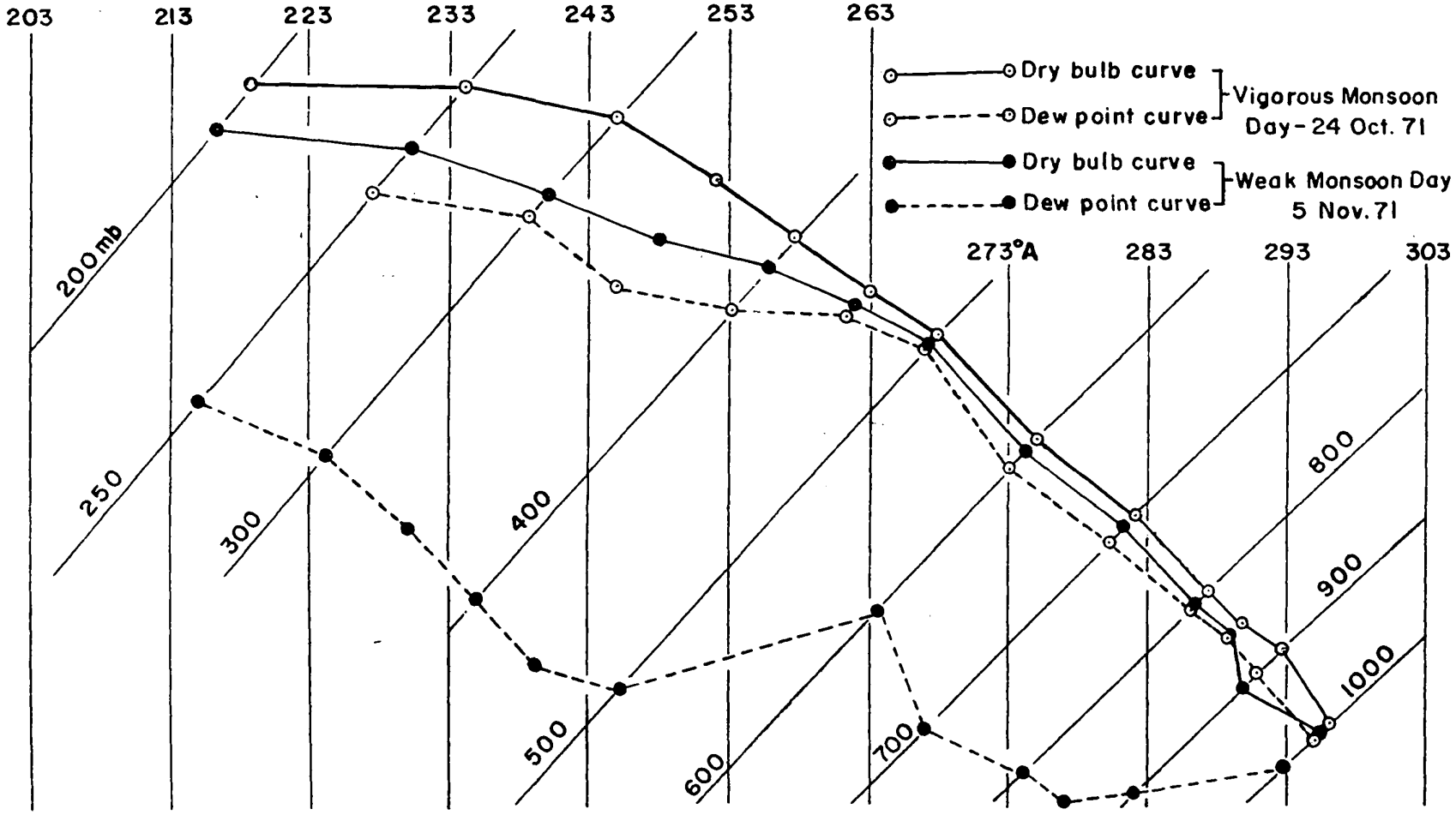
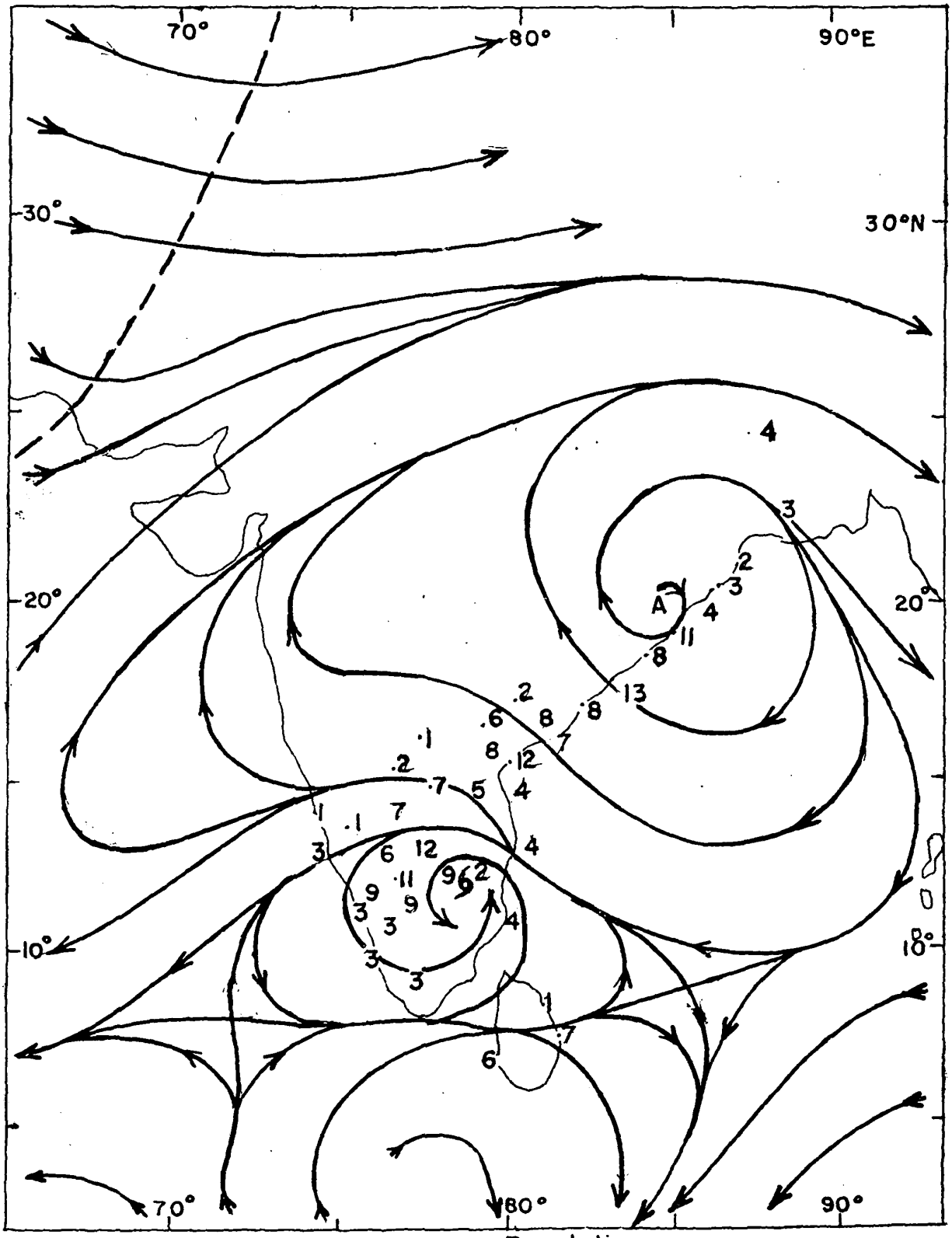


FIG. II·1 RAINFALL FOR 24 HRS. ENDING AT 0300 GMT OF 22 OCT. 63.
STREAMLINES AT 300mb. FOR 1200 GMT OF 21 OCT. 63.



From
"Some aspects of Bay of Bengal Cyclone of October 1963" by T. S. S. Anjaneyulu, D. R. Sikka and G. Gurunadham. (IJMG 1965, Vol. 16 No. 4. pp. 539-556. Fig. 16)

FIG. II·2 RECURVING CYCLONIC STORM IN THE BAY OF BENGAL & THE ASSOCIATED RAINFALL ALONG THE INDIAN COAST

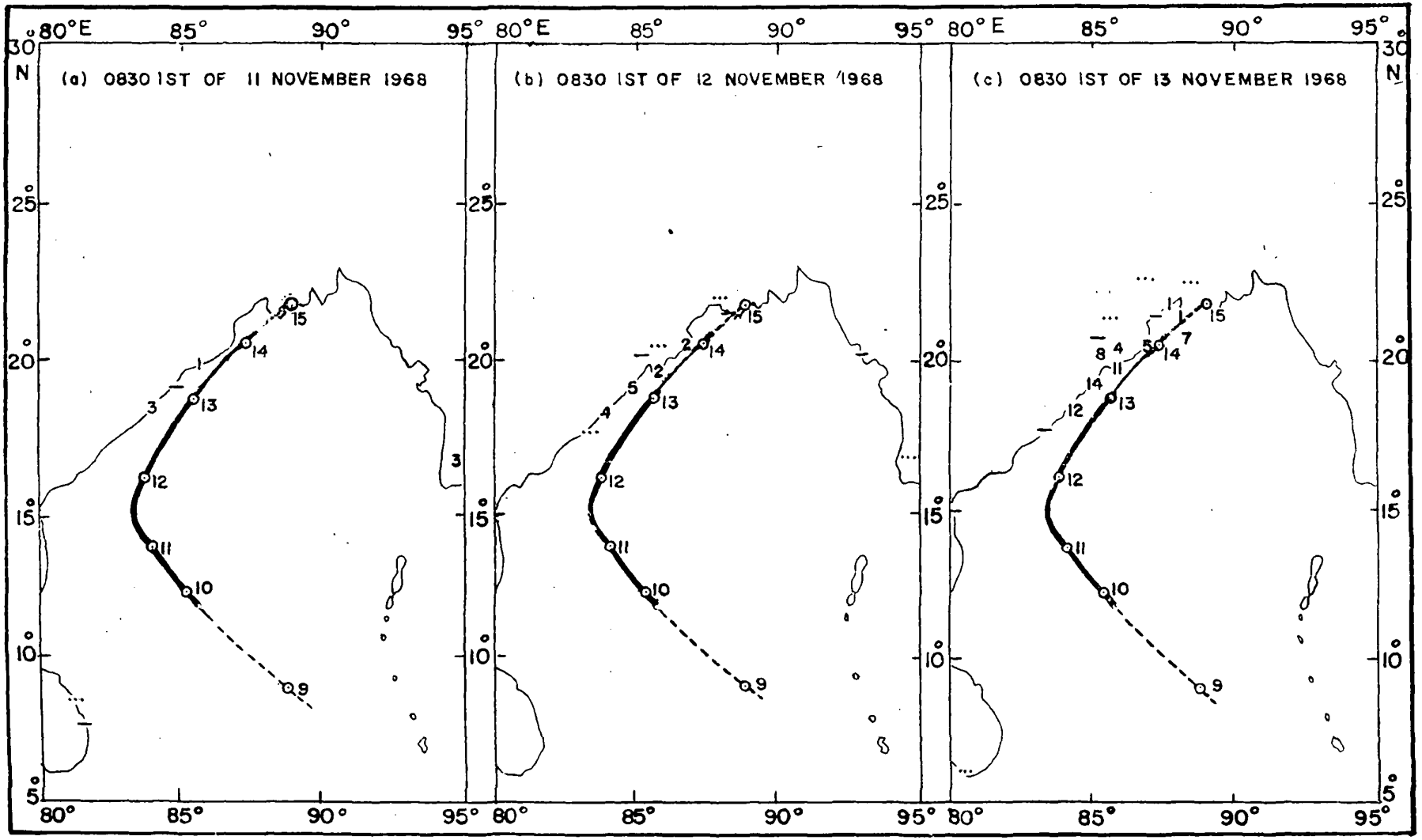


FIG. 12·1 TYPICAL DAY'S ISOHYETAL CHARTS SHOWING THE DISTRIBUTION OF RAINFALL IN ASSOCIATION WITH CYCLONIC STORMS IN THE POST-MONSOON SEASON

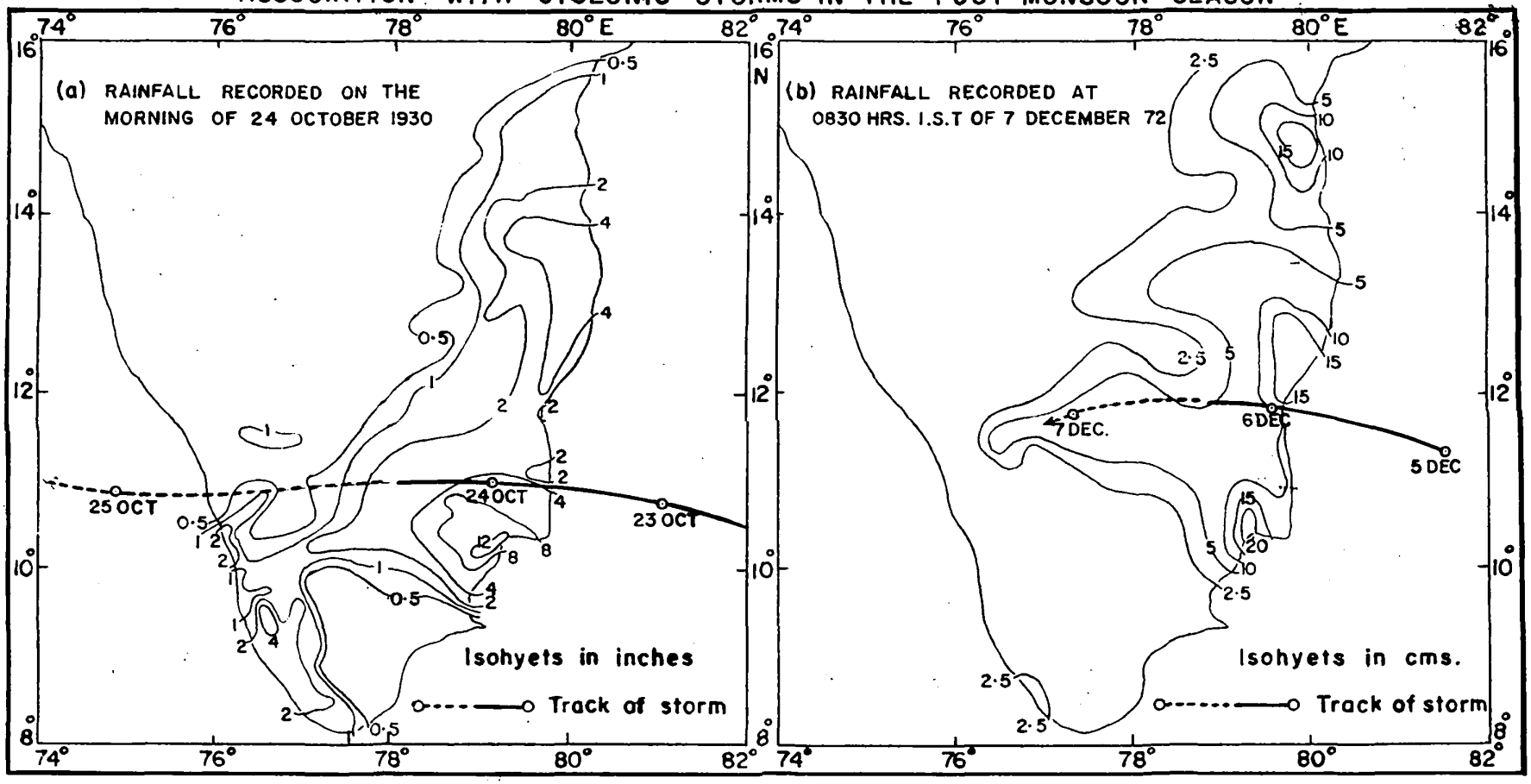
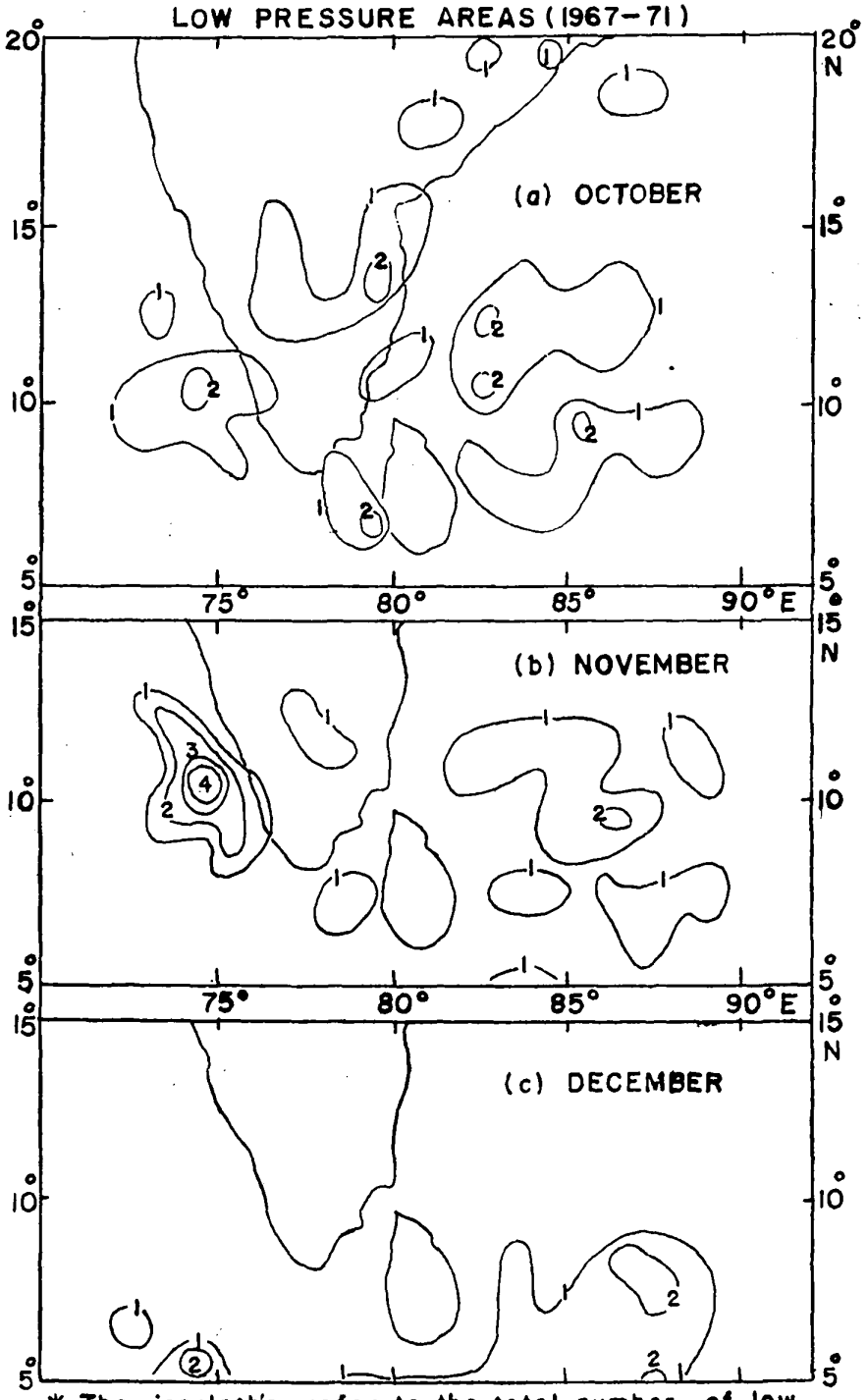


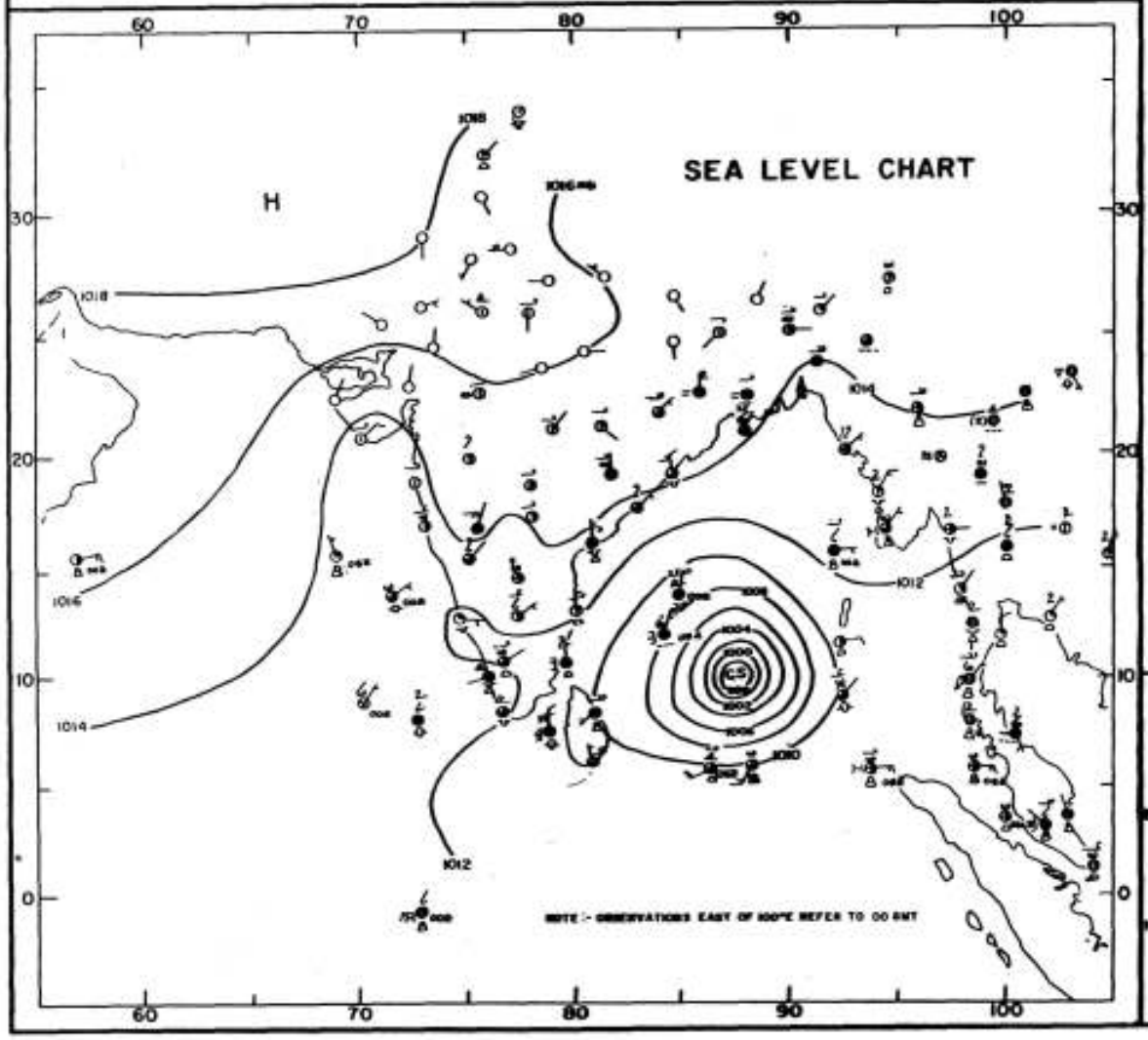
Fig.(a) :-
Reproduced from plate I of IMD Scientific Note
vol. VII No. 74 — K. P. Ramakrishnan

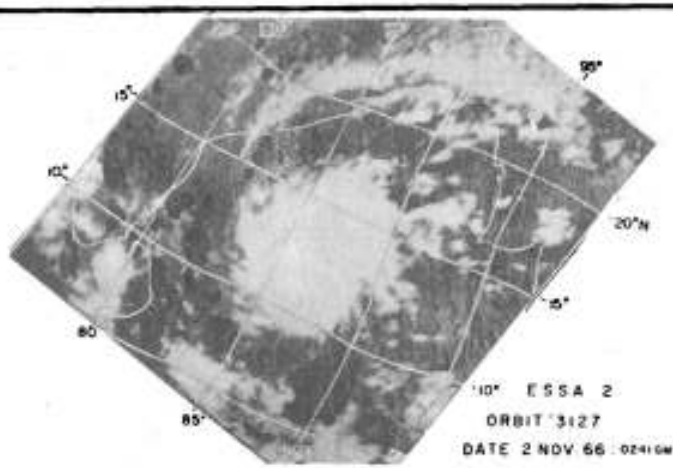
FIG. 12·2. SPATIAL DISTRIBUTION OF CENTRES* OF LOW PRESSURE AREAS (1967–71)

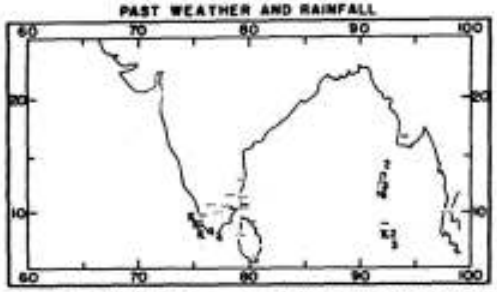


* The isopleth's refer to the total number of low pressure centres during the 5-year period (1967–71)

FIG. 13·1 SYNOPTIC CHARTS 0300 GMT 2 NOV. 66







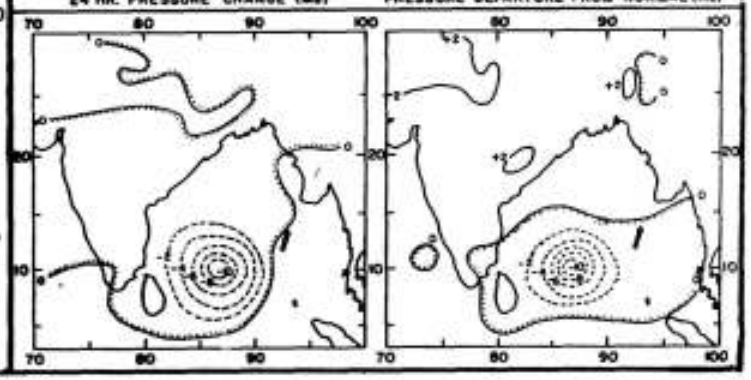


FIG 13·2 UPPER WINDS 00 GMT 2 NOV. 66

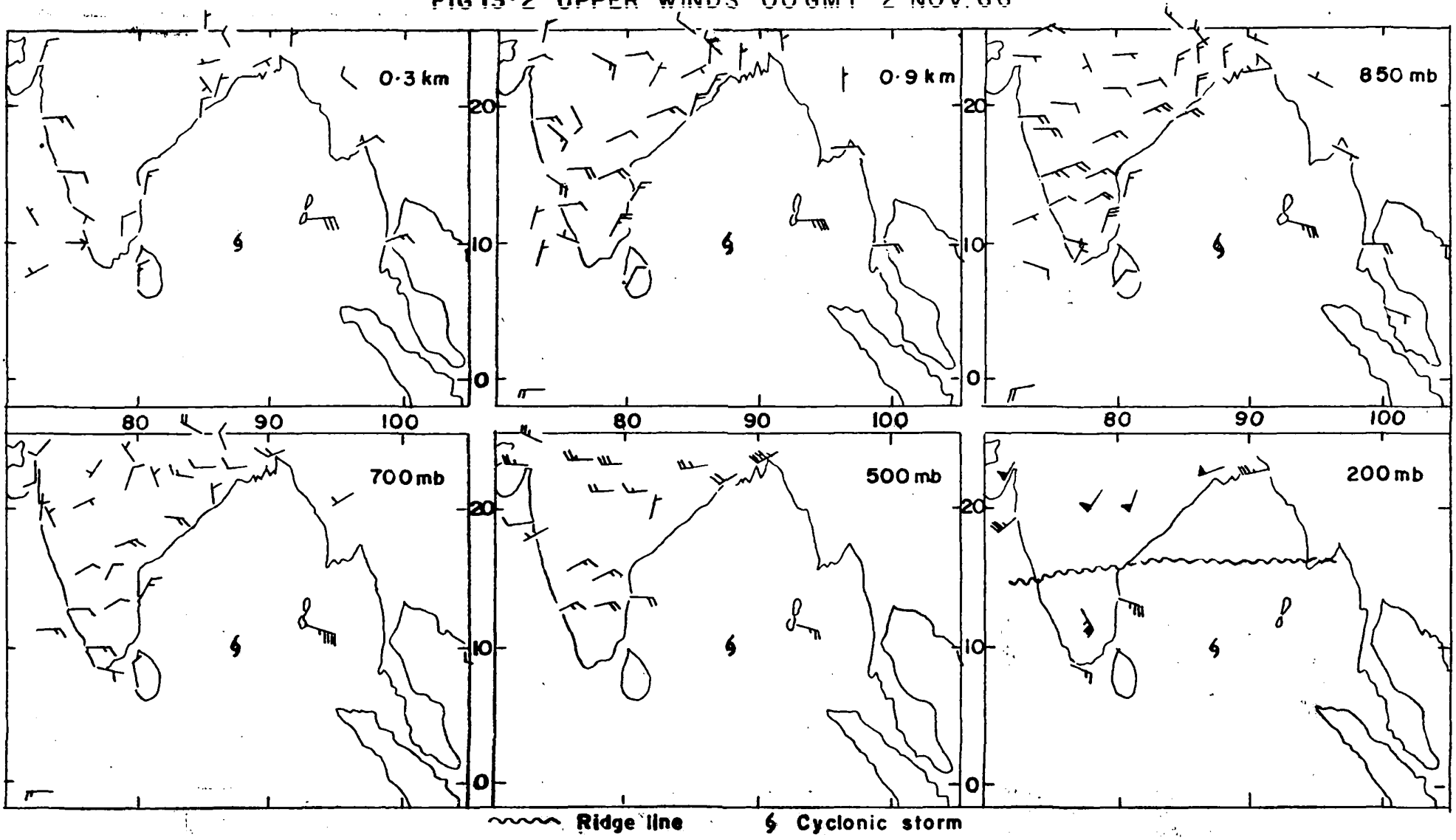
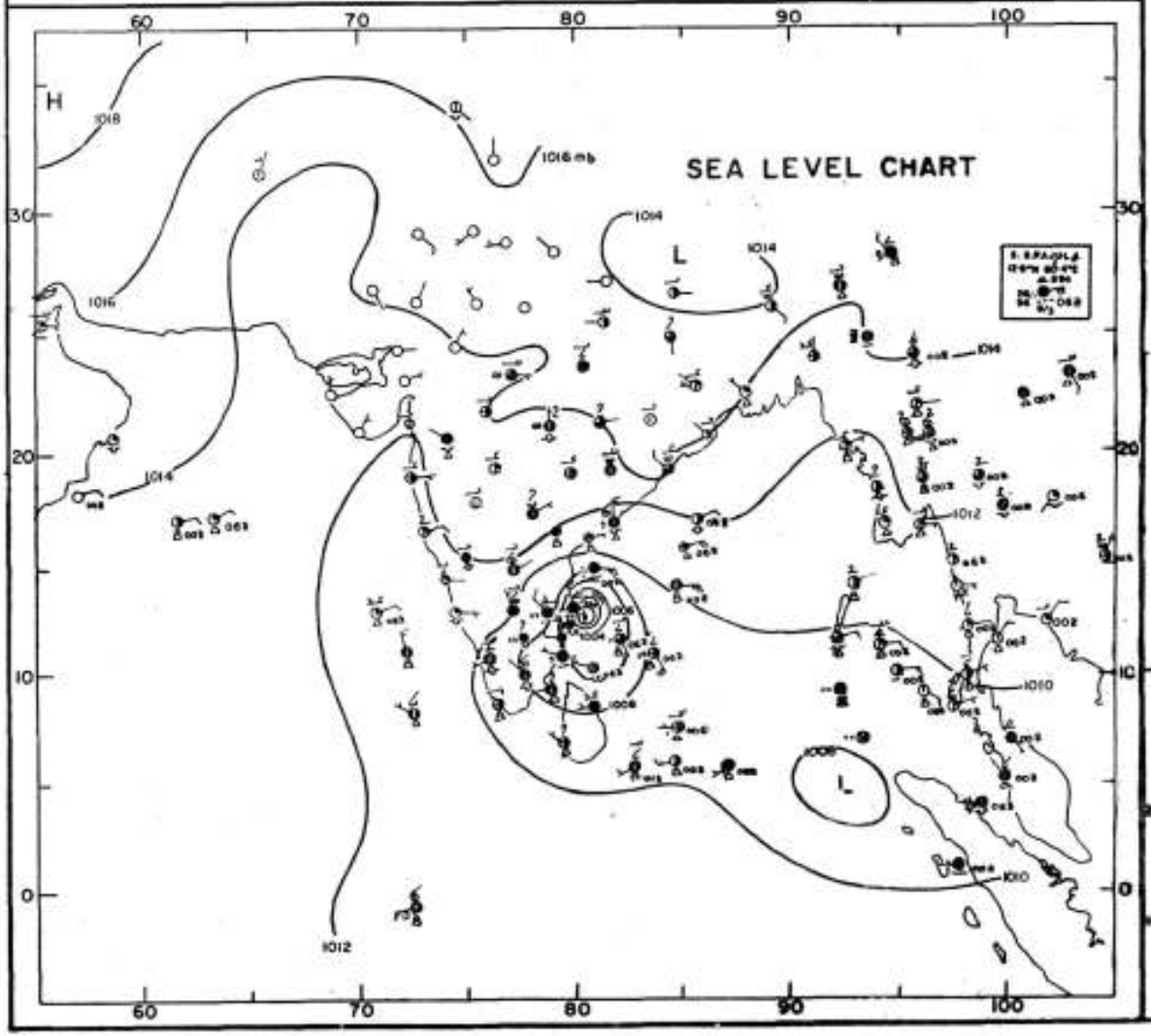
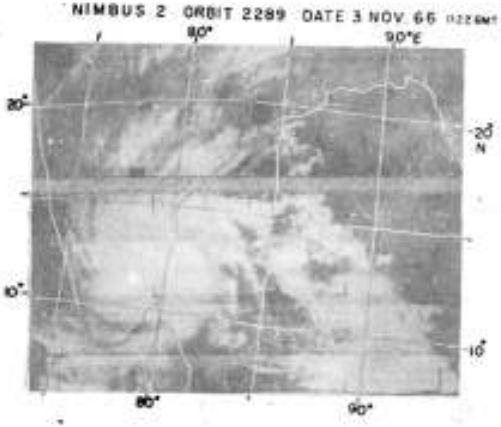
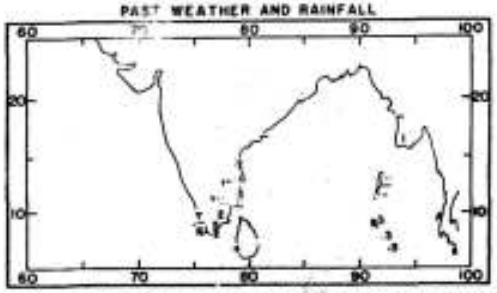


FIG. 13·3 SYNOPTIC CHARTS 0300 GMT 3 NOV. 66







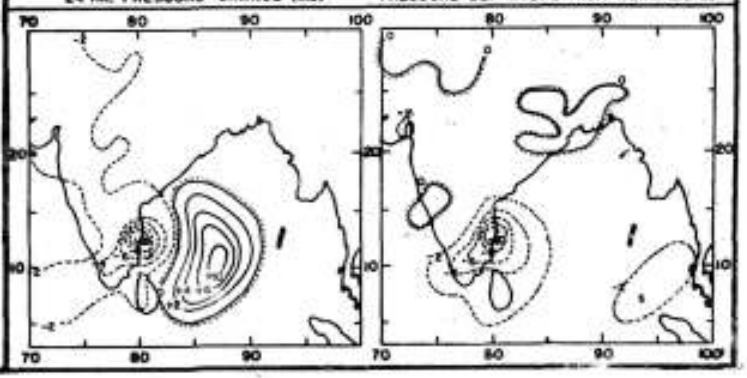


FIG. 13·4 UPPER WINDS 00 GMT 3 NOV. 66

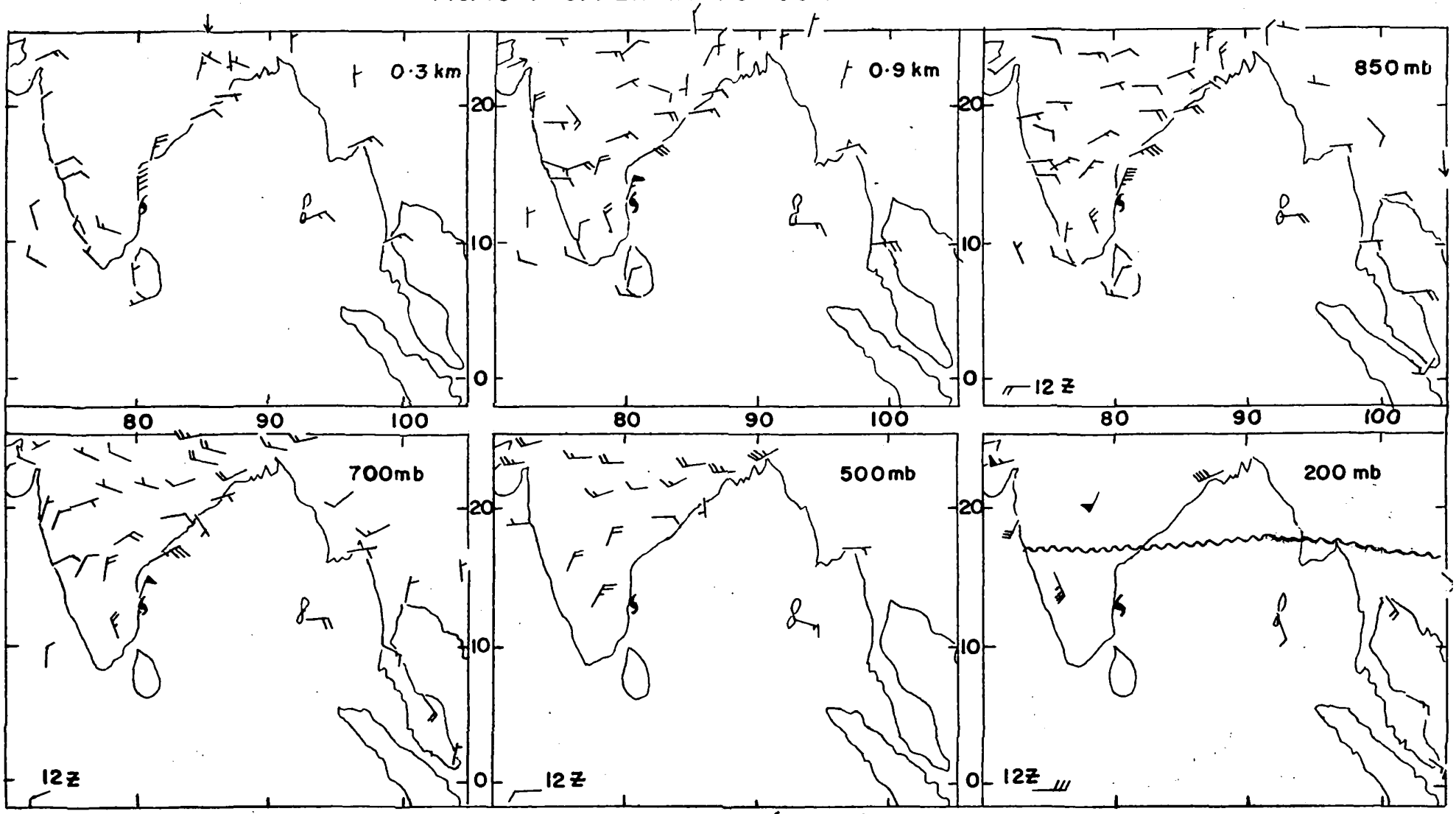
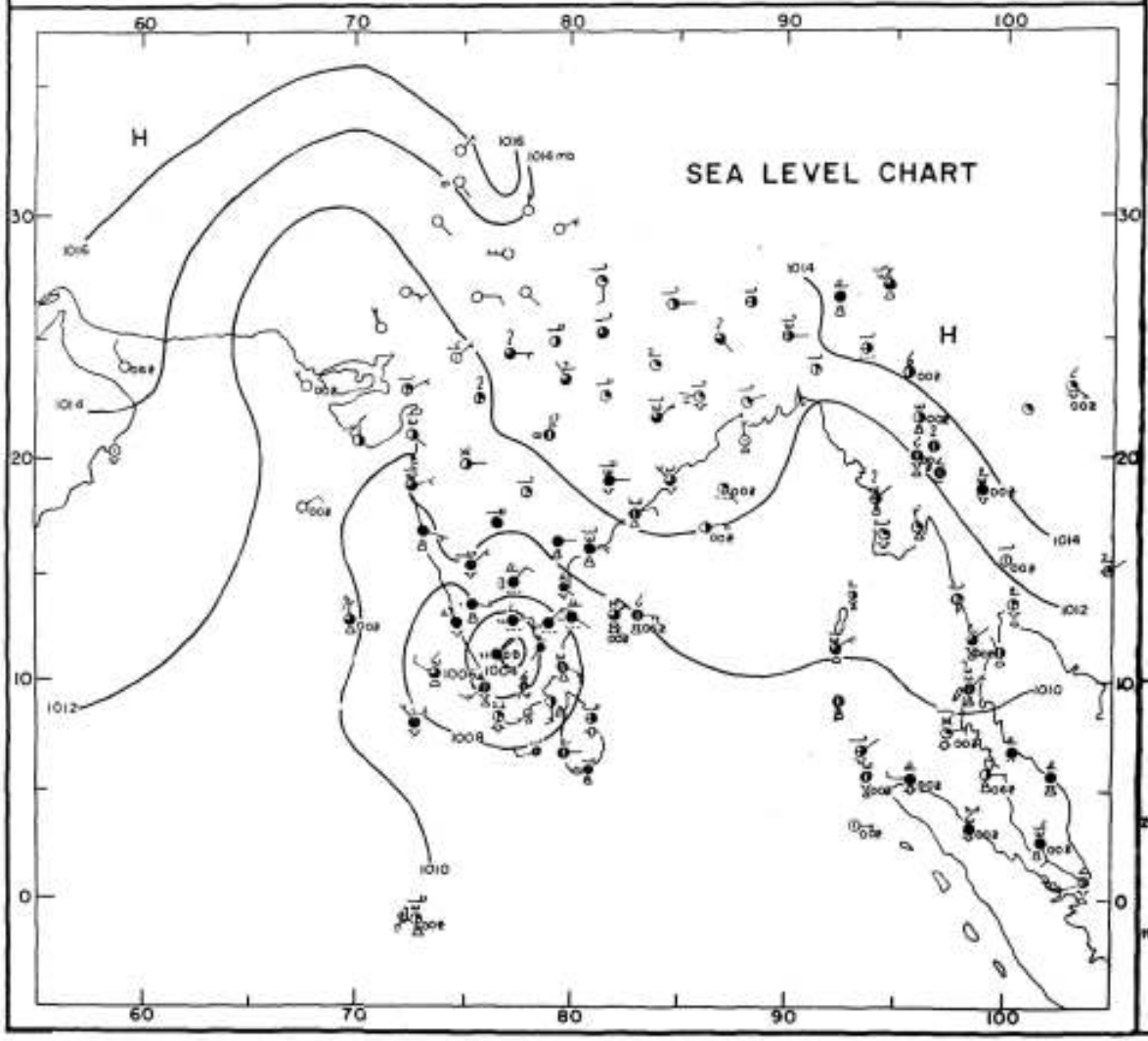
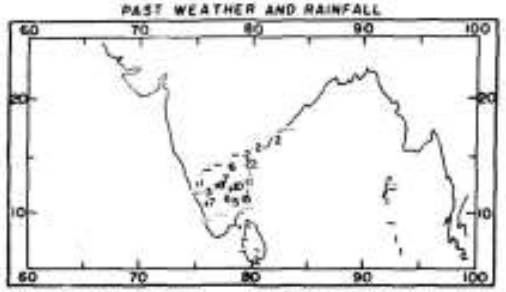


FIG. 13·5 SYNOPTIC CHARTS 0300 GMT 4 NOV. 66





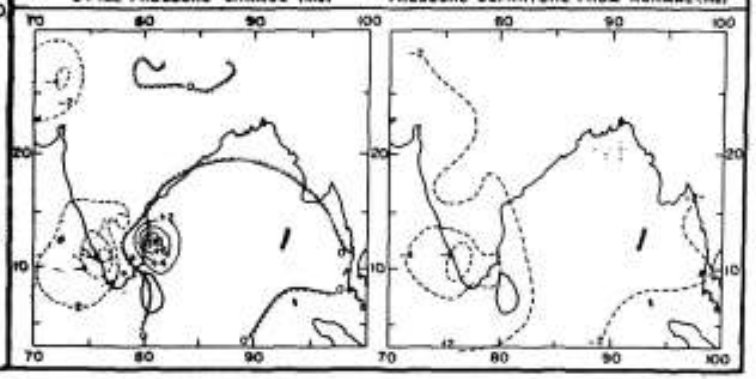
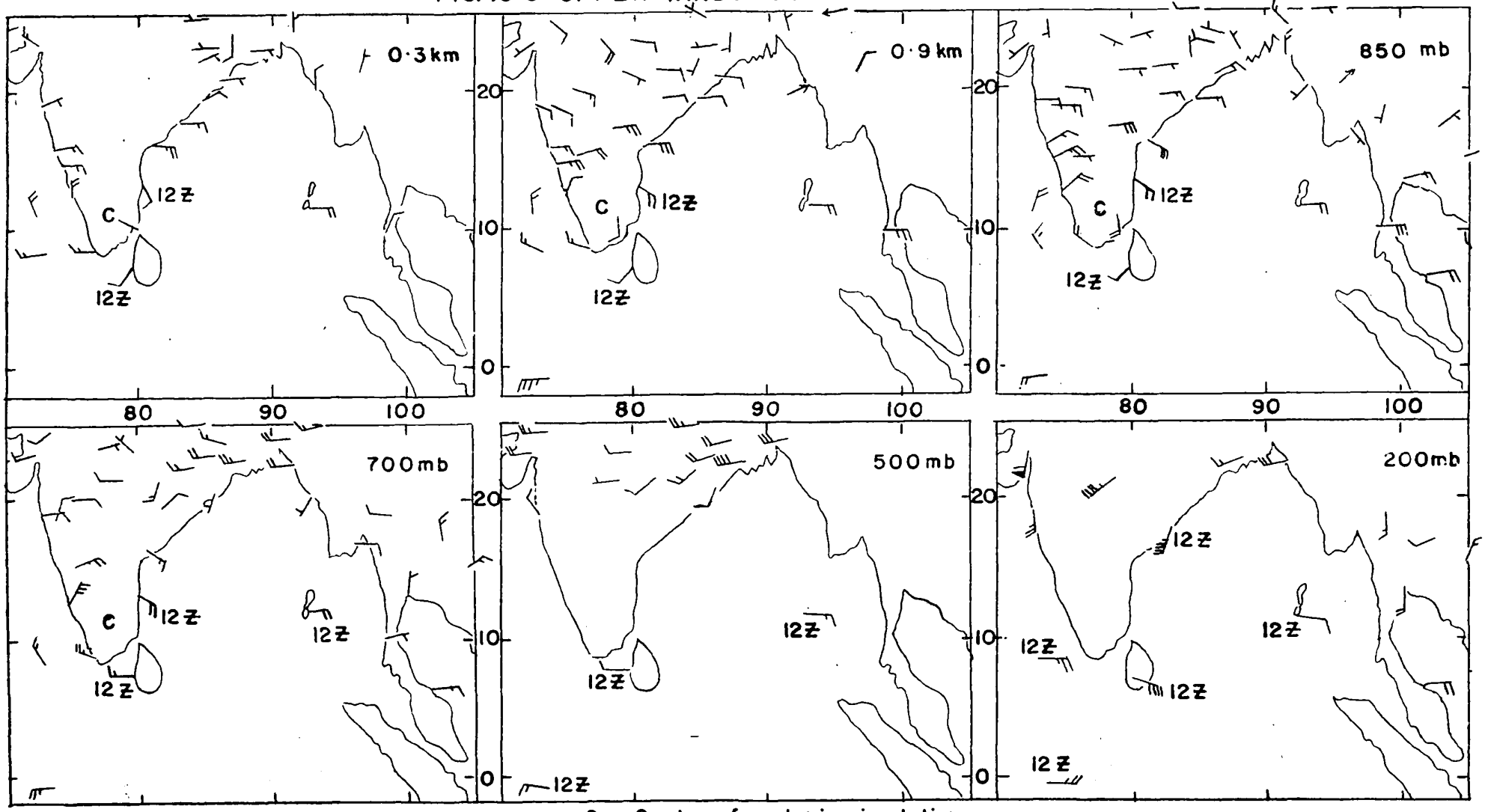
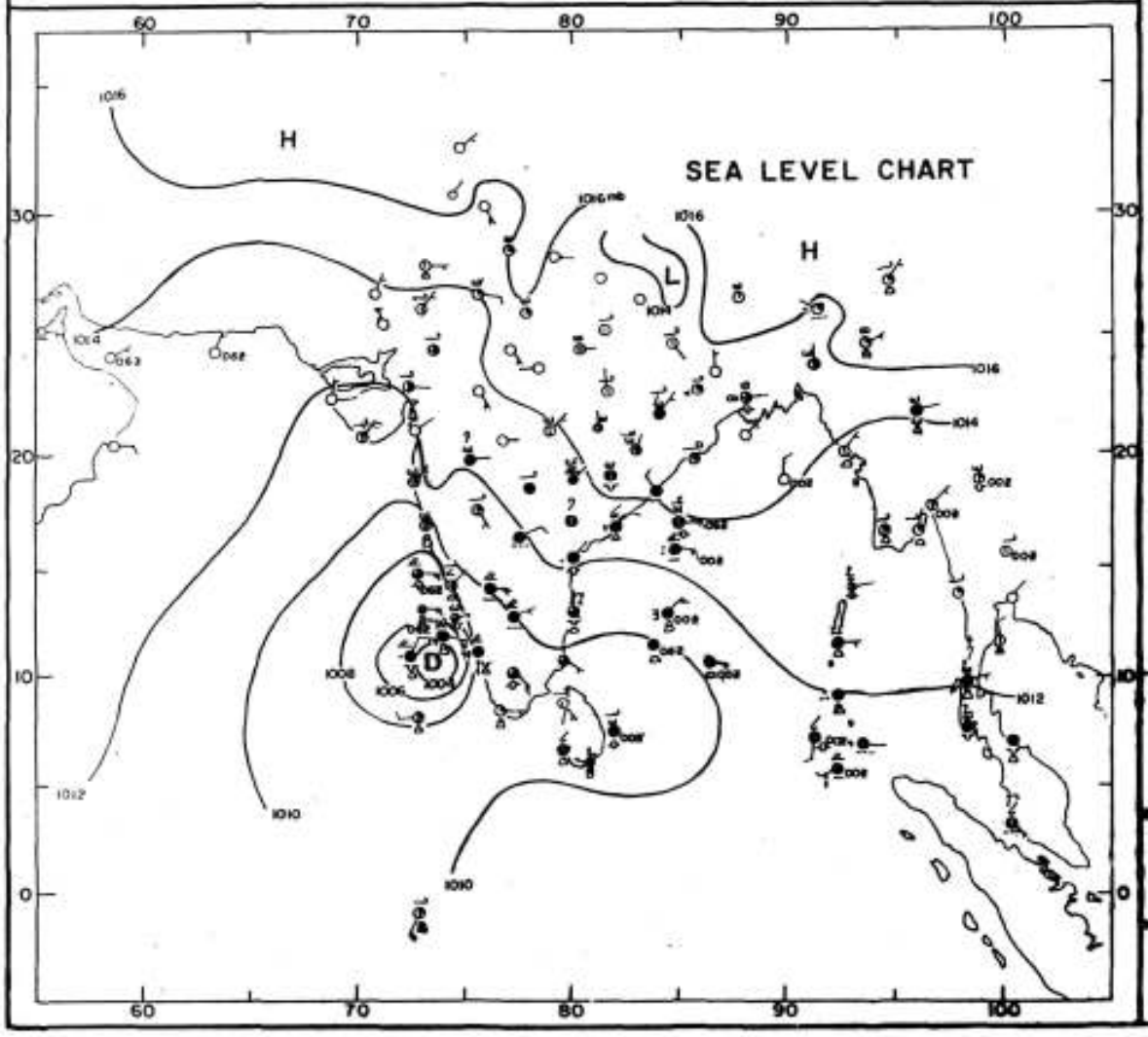


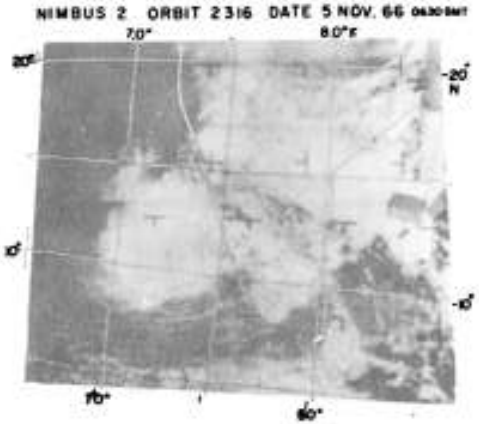
FIG. 13·6 UPPER WINDS 00 GMT 4 NOV. 66

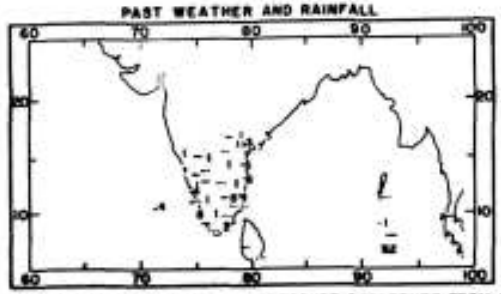


C – Centre of cyclonic circulation

FIG. 13·7 SYNOPTIC CHARTS 0300 GMT 5 NOV. 66







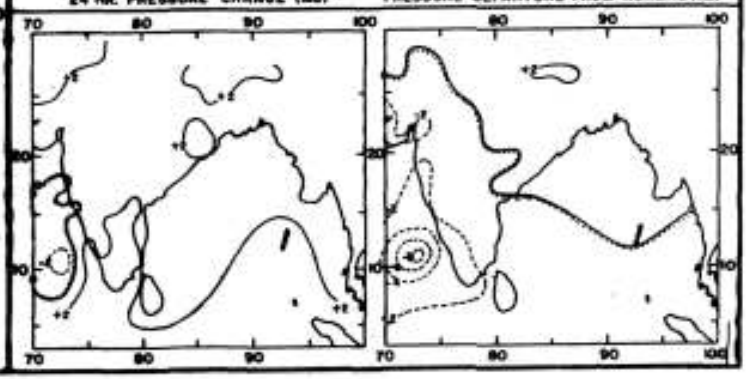


FIG. 13·8 SEA LEVEL CHART 0300 GMT 6 NOV. 1966

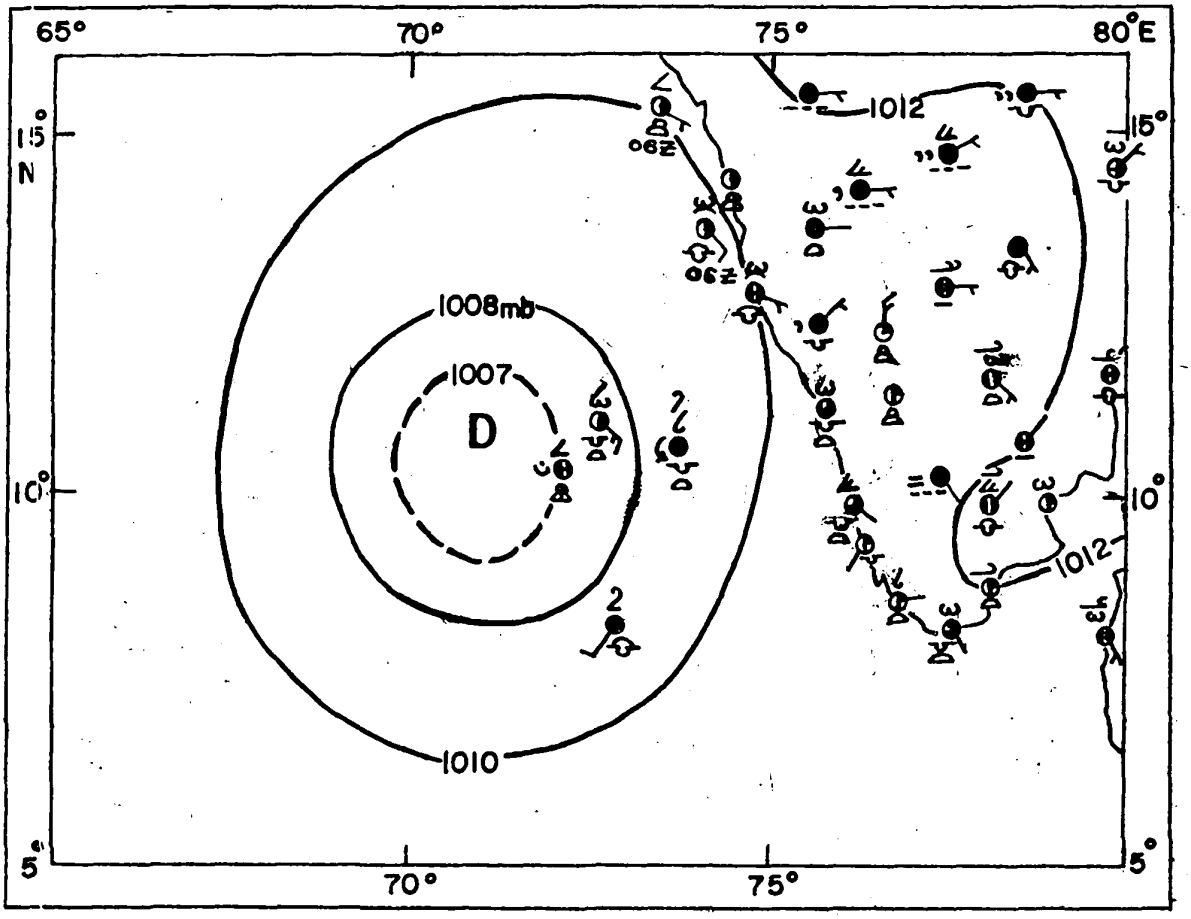


FIG. 13·9 RAINFALL & PAST WEATHER 0300 GMT 6 NOV. 1966

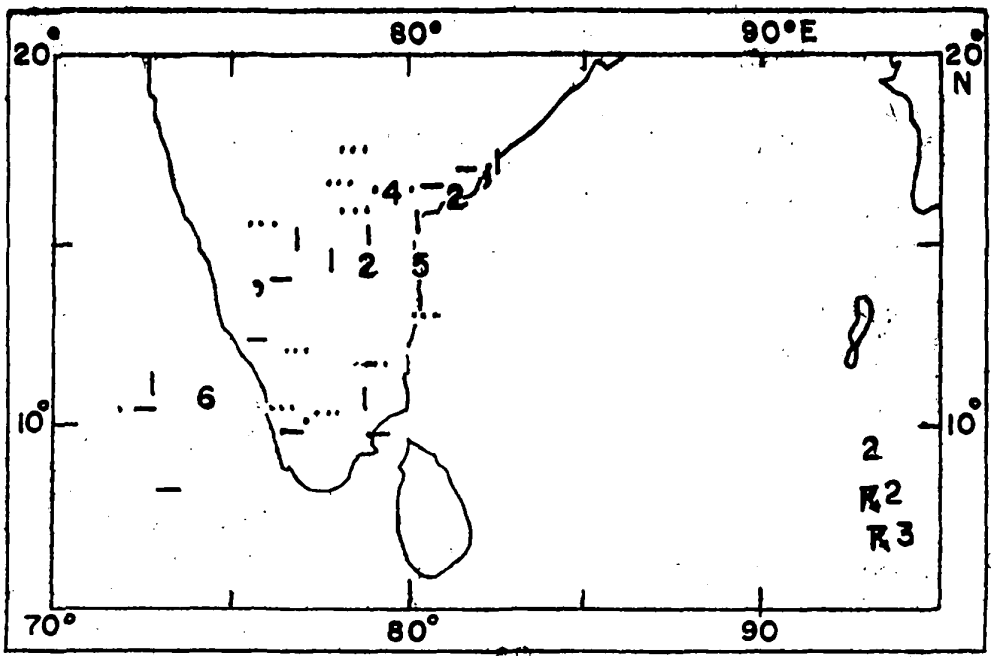
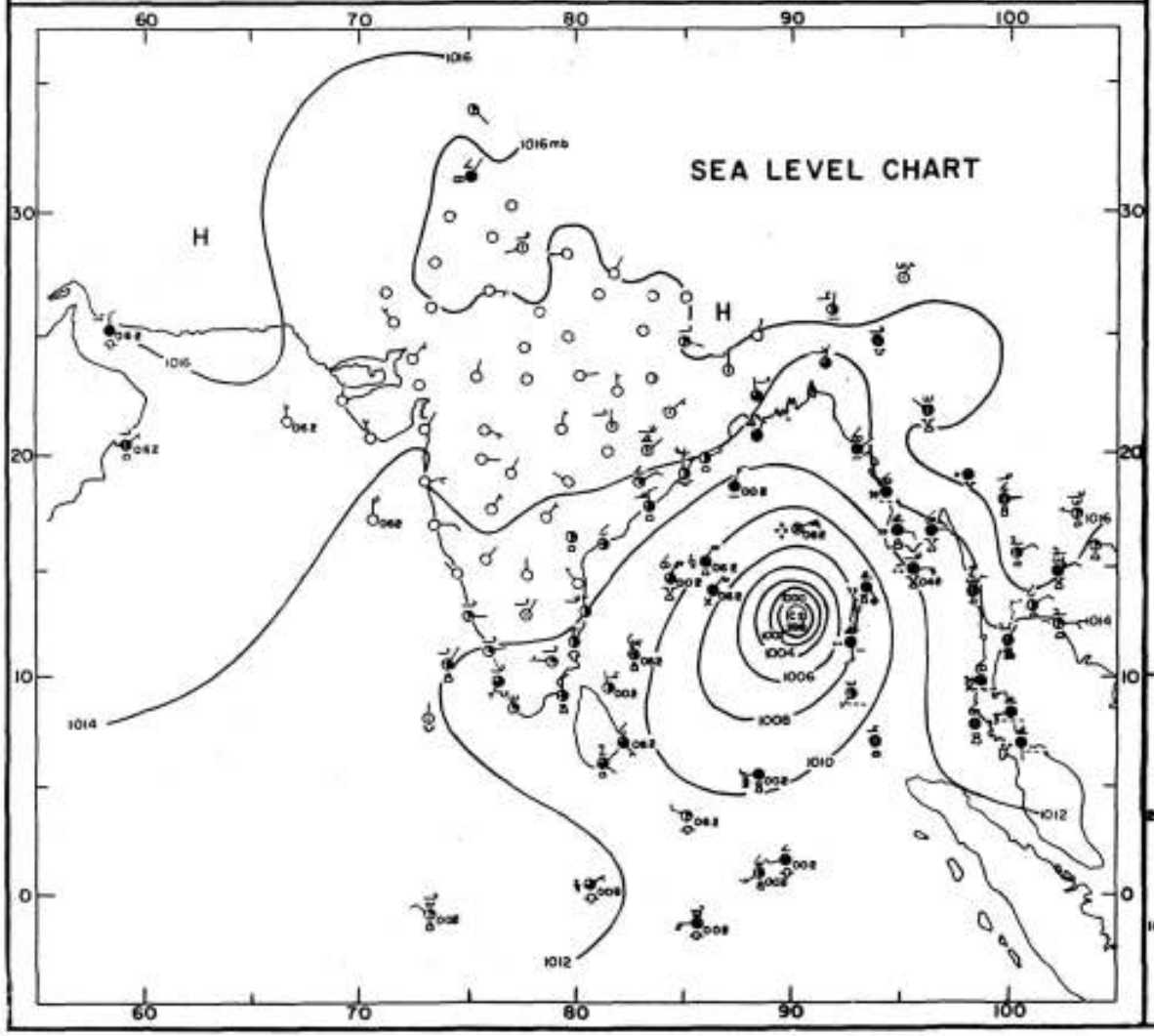


FIG. 14·1 SYNOPTIC CHARTS 0300 GMT 5 NOV. 69



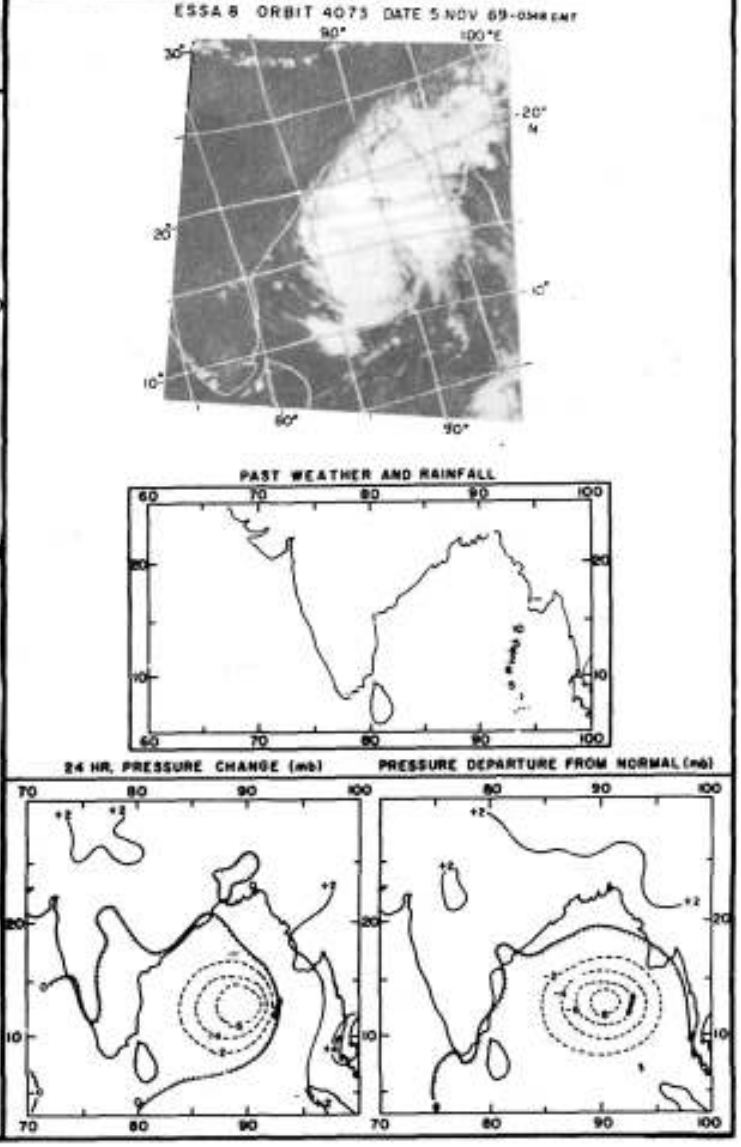
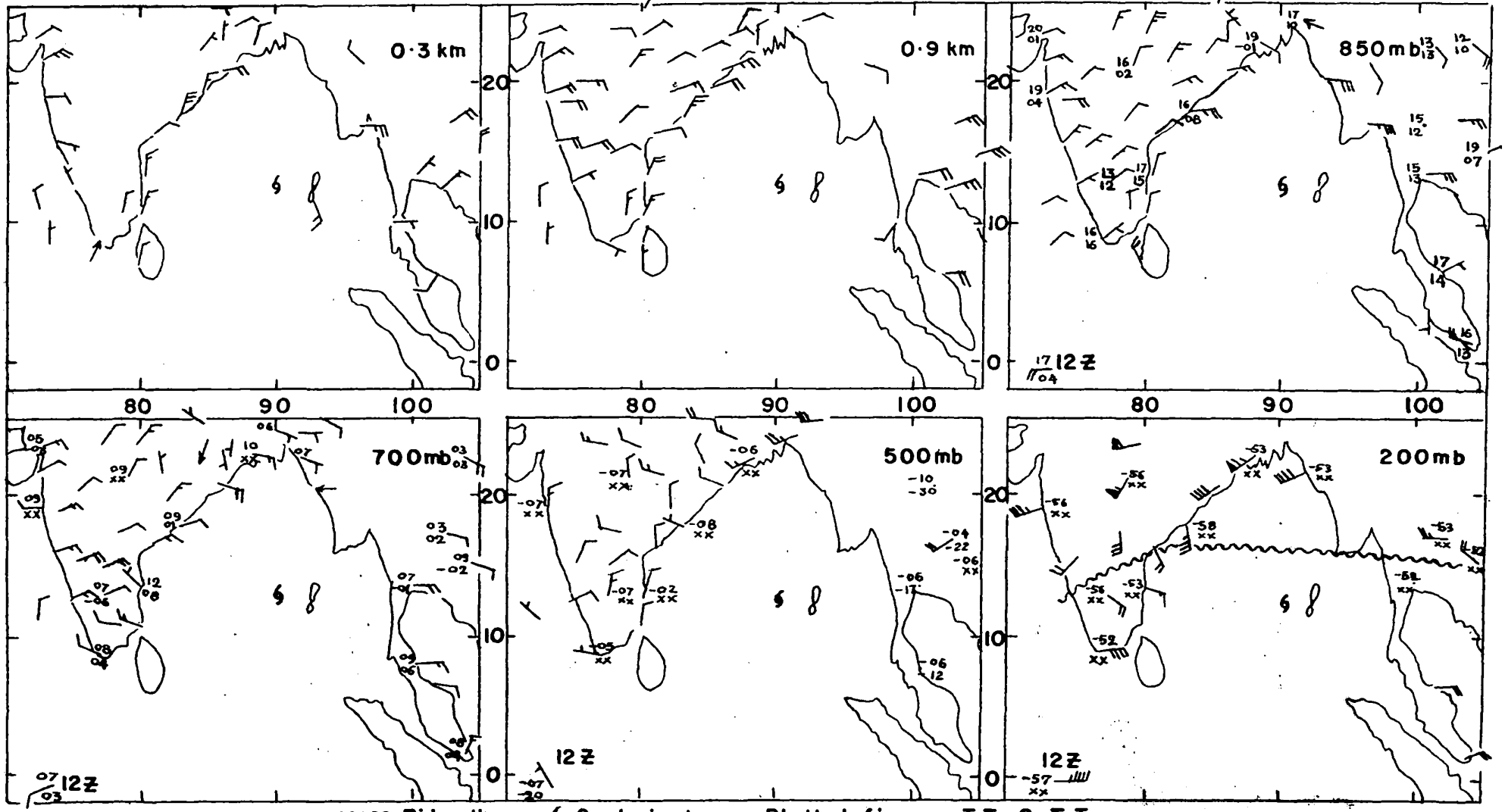
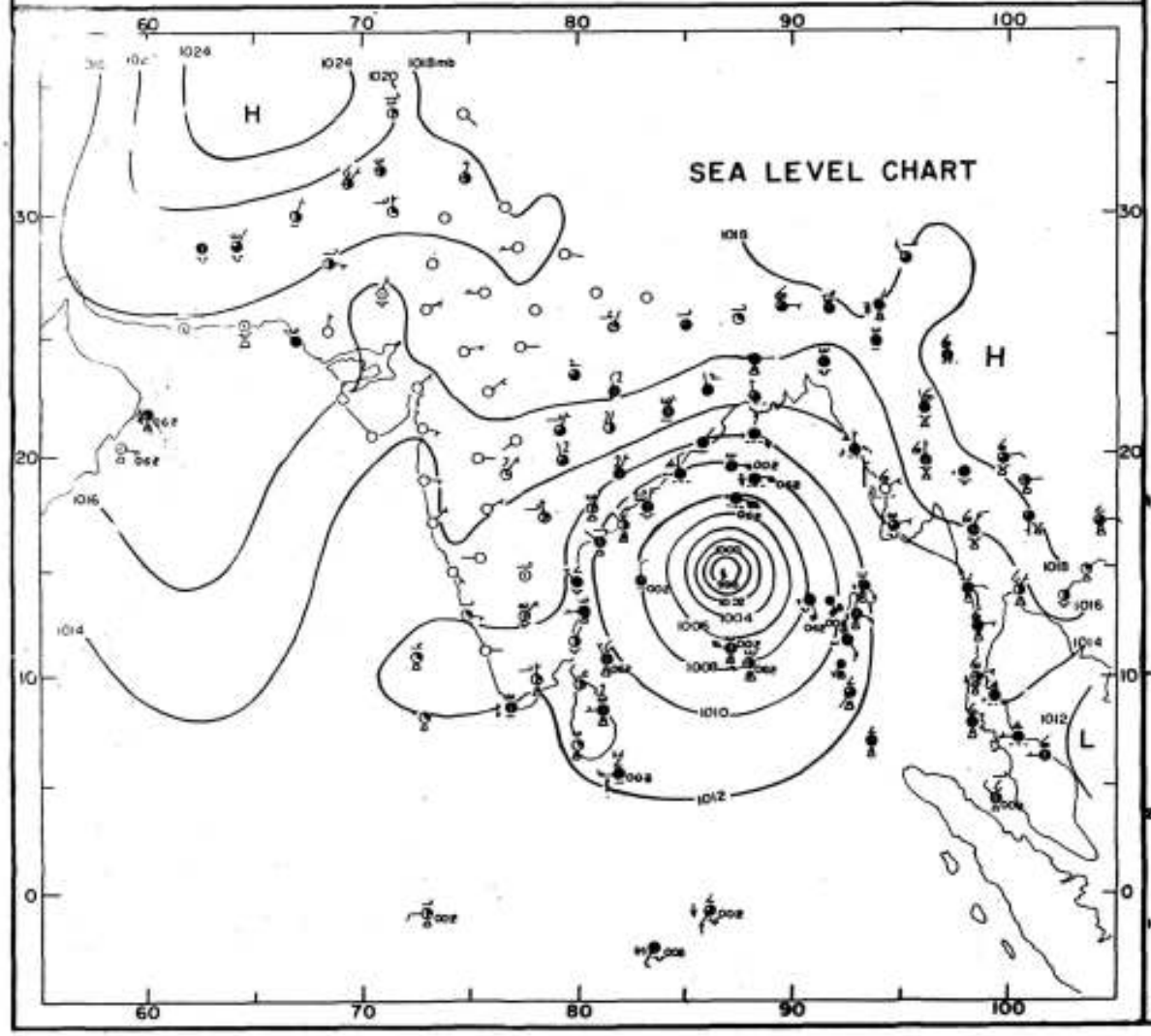


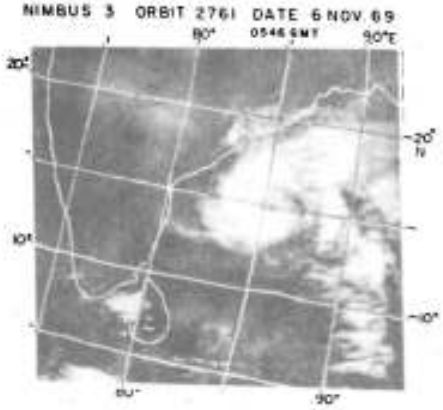
FIG. 14·2 UPPER WINDS 00 GMT 5 NOV. 69

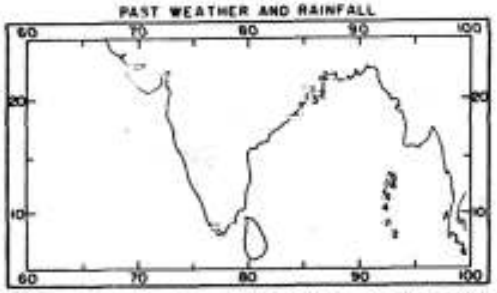


Ridge line. ϛ Cyclonic storm. Plotted figures T T & T_dT_d

FIG. 14·3 SYNOPTIC CHARTS 0300 GMT 6 NOV. 69







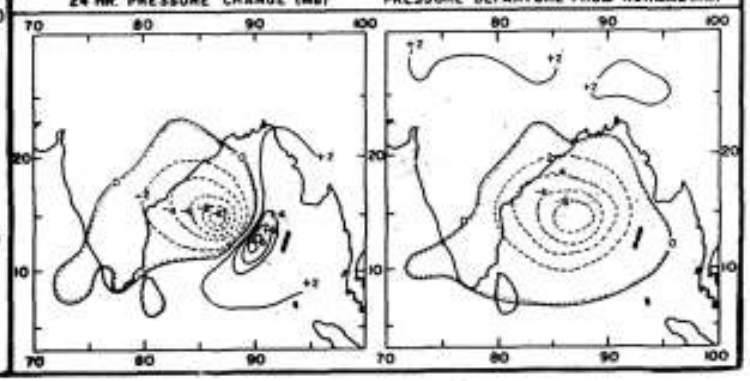
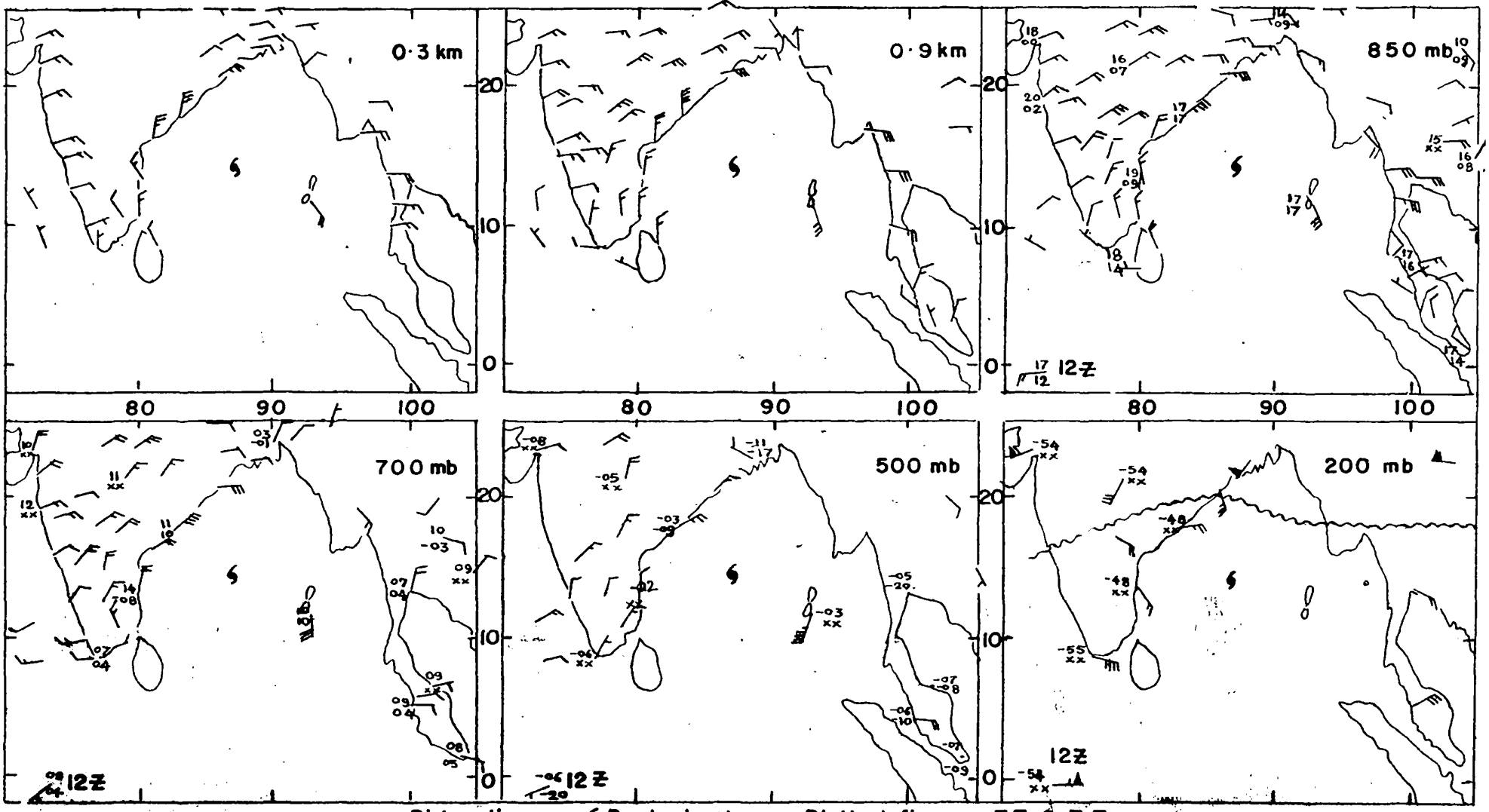


FIG. 14.4 UPPER WINDS 00GMT 6 NOV. 69



Ridge line. Cyclonic storm. Plotted figures TT & T_dT_d.

FIG. 14·5 1200 GMT 6 NOV. 69

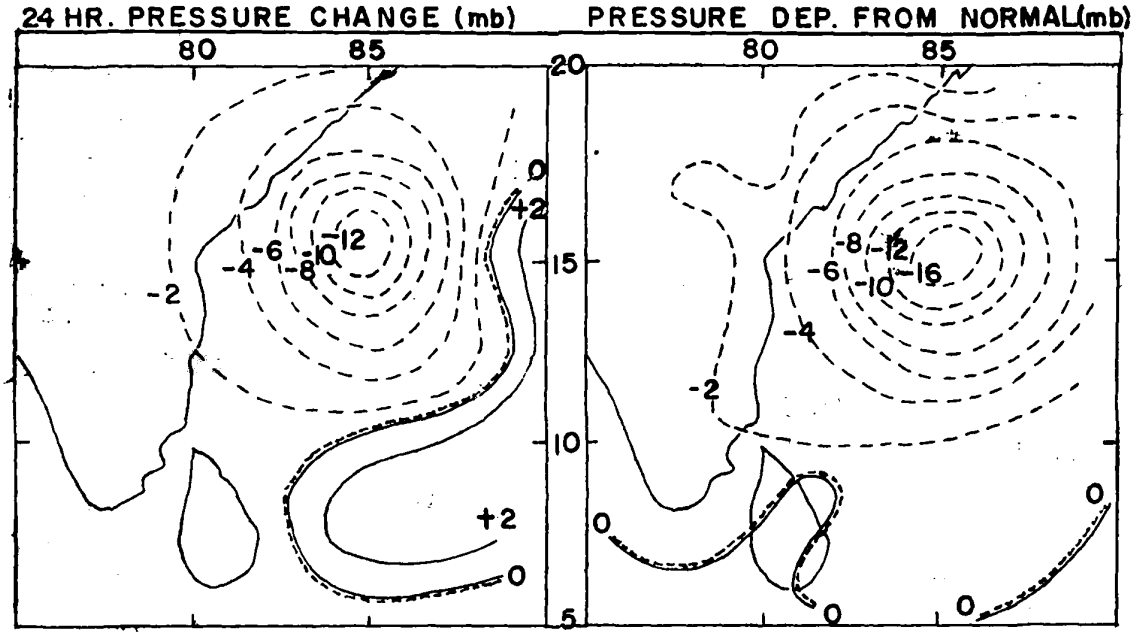
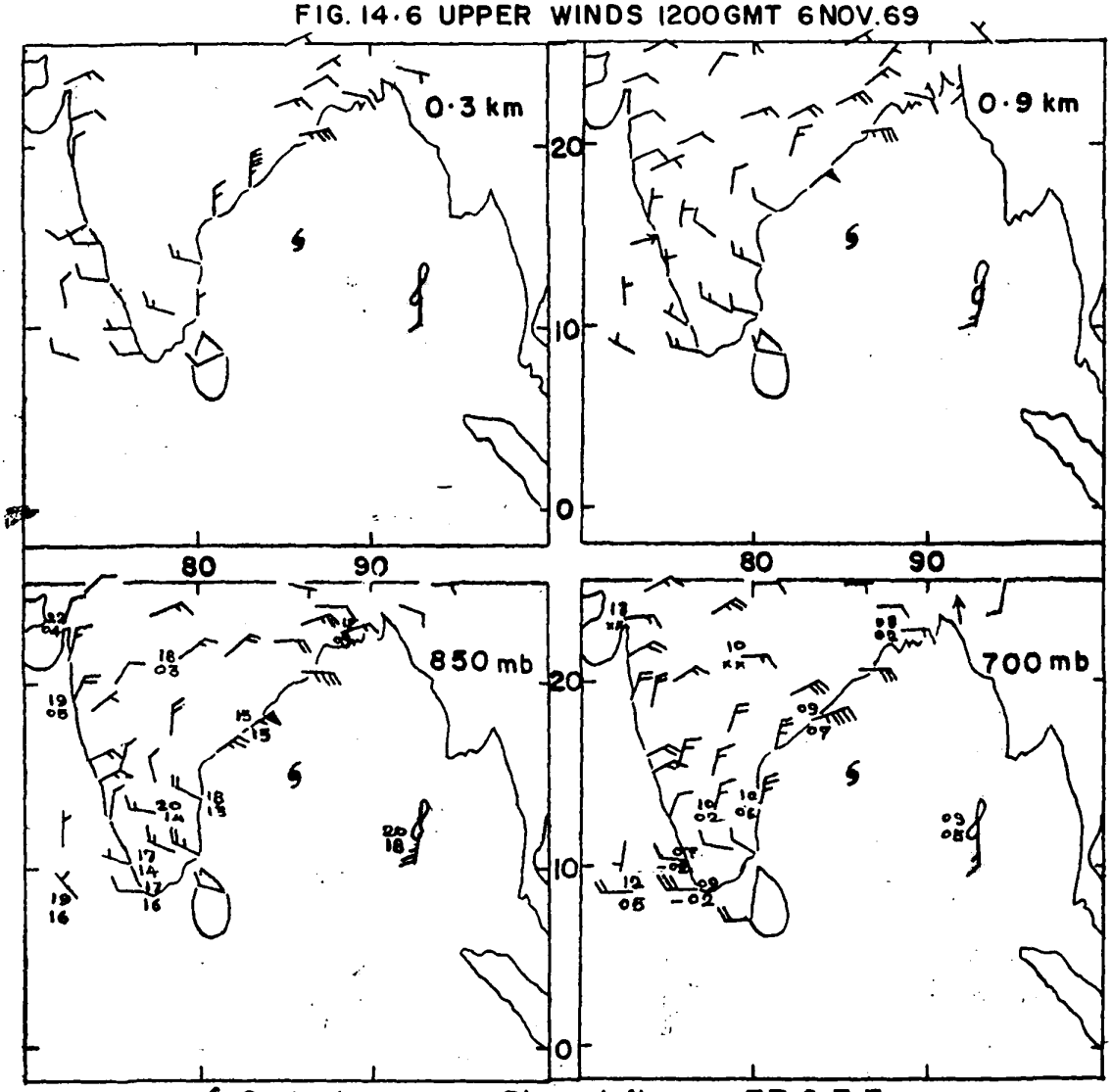
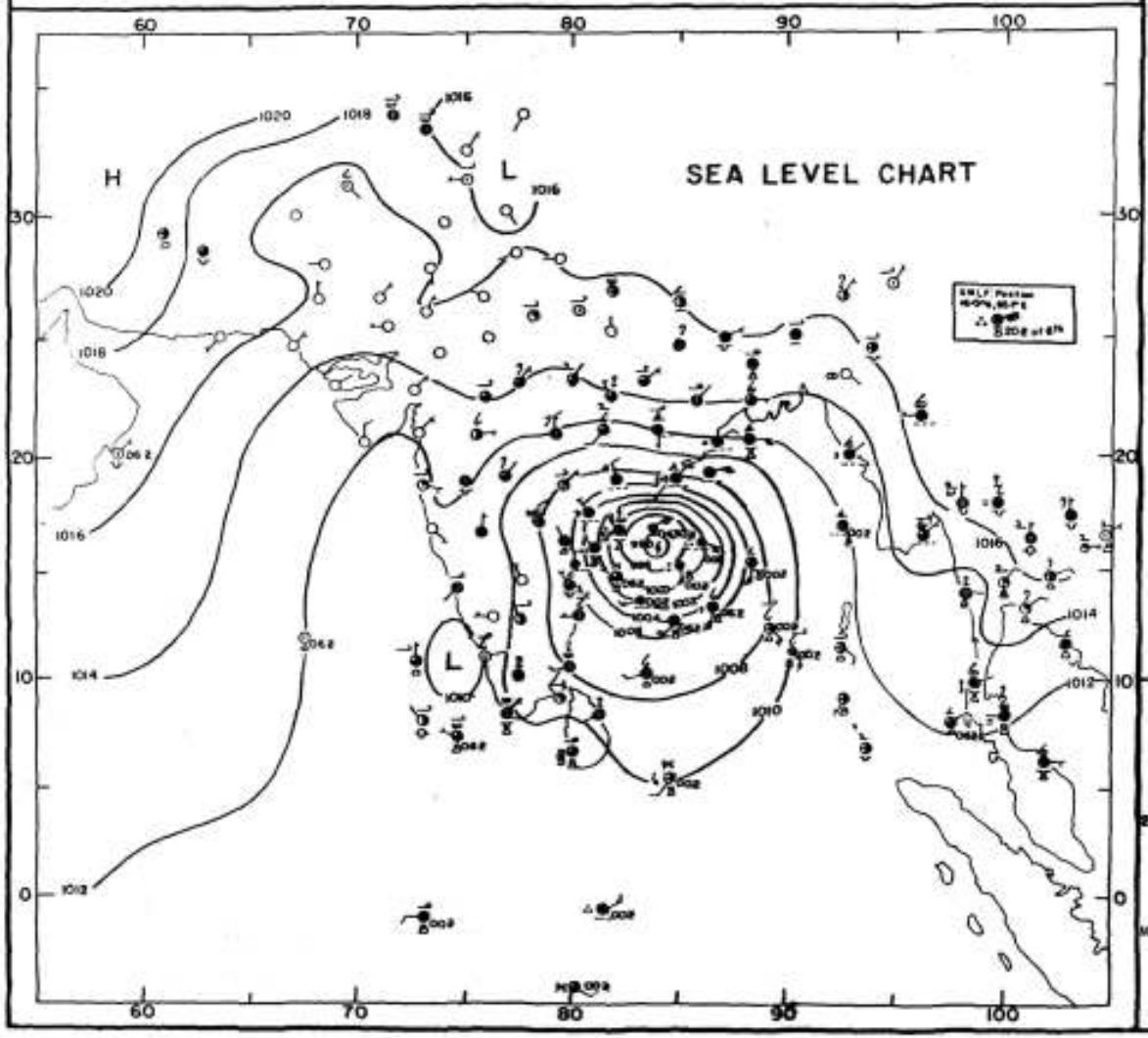


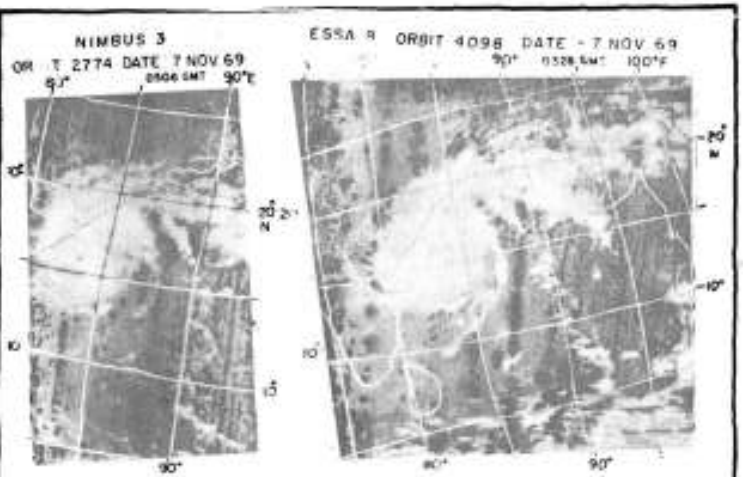
FIG. 14·6 UPPER WINDS 1200GMT 6NOV.69

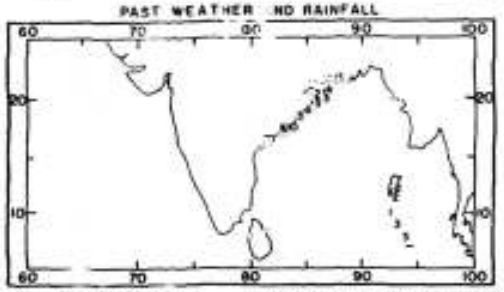


§ Cyclonic storm. Plotted figures TT & $T_d T_d$

FIG. 14·7 SYNOPTIC CHARTS 0300 GMT 7 NOV. 69







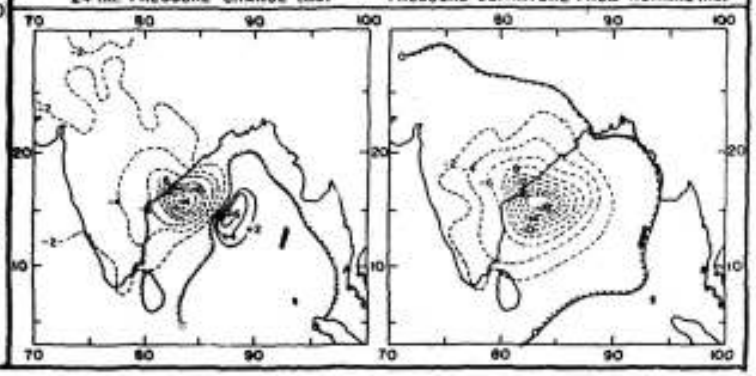


FIG. 14·8 UPPER WINDS 00 GMT 7 NOV. 69

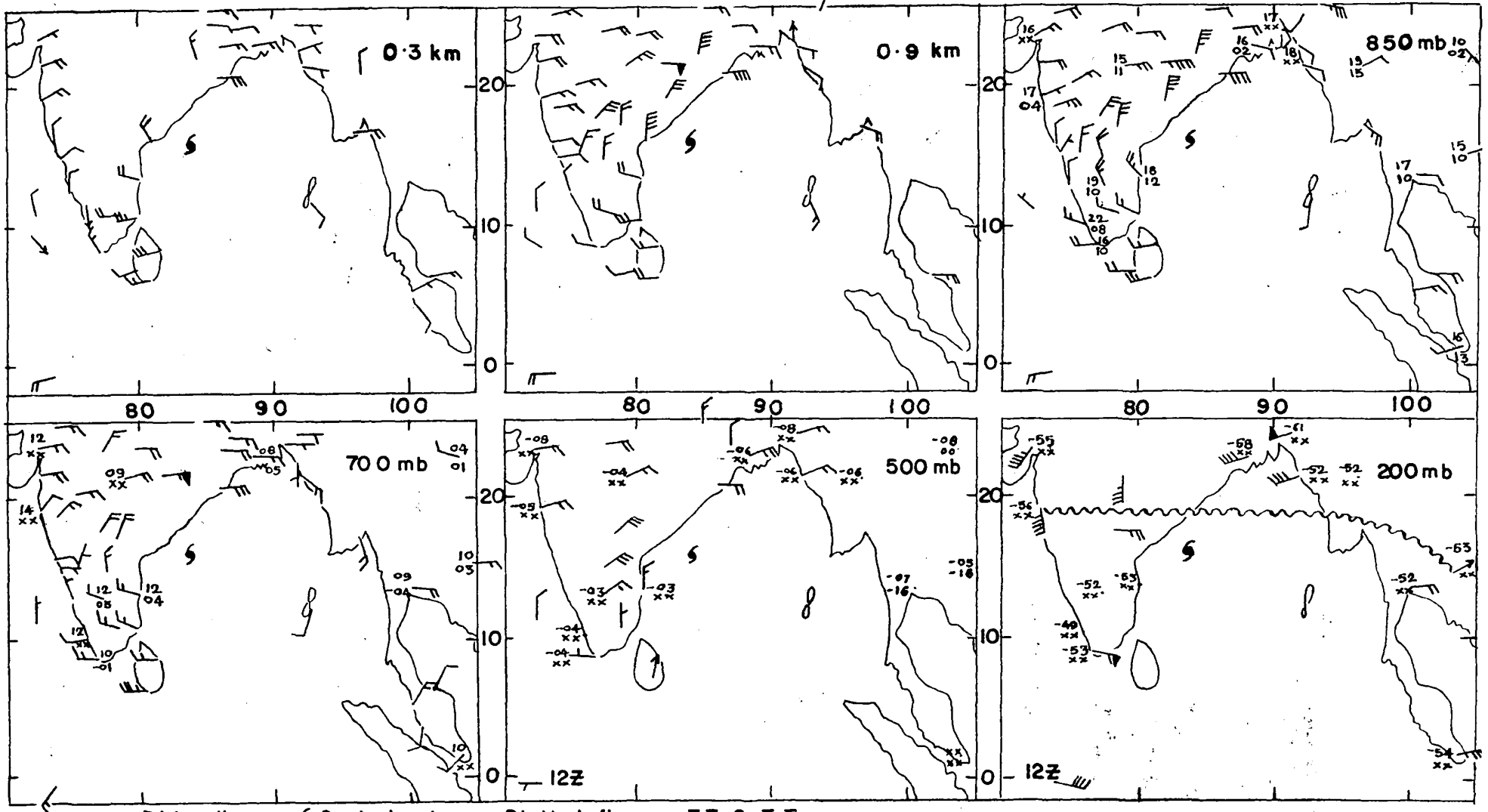
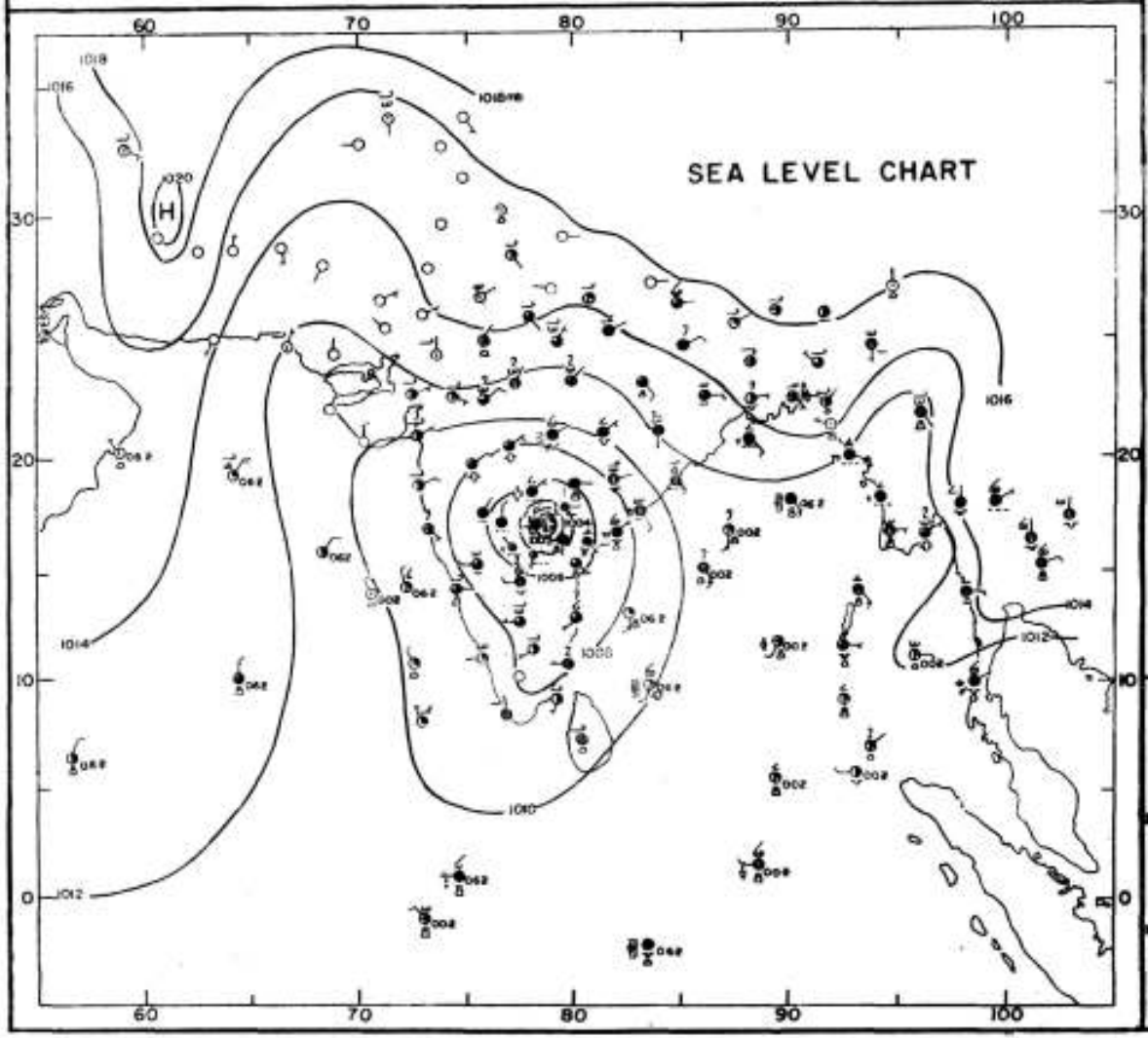
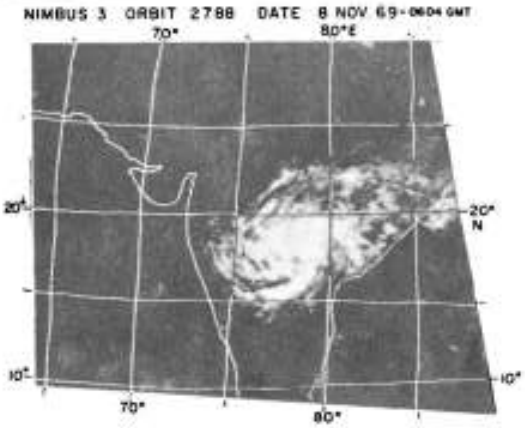
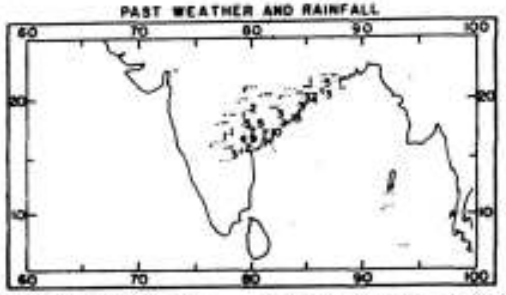


FIG. 14·9 SYNOPTIC CHARTS 0300 GMT 8 NOV. 69







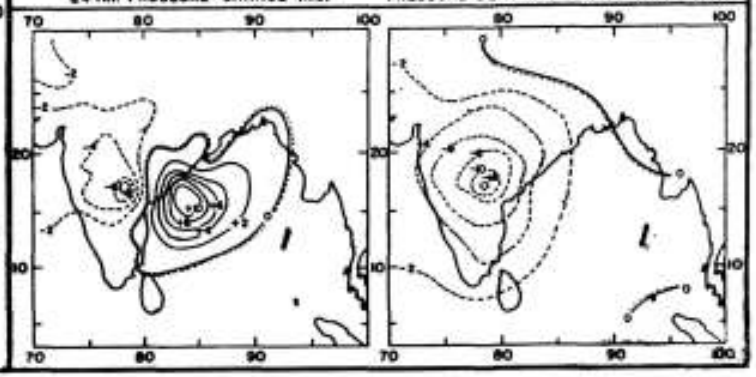
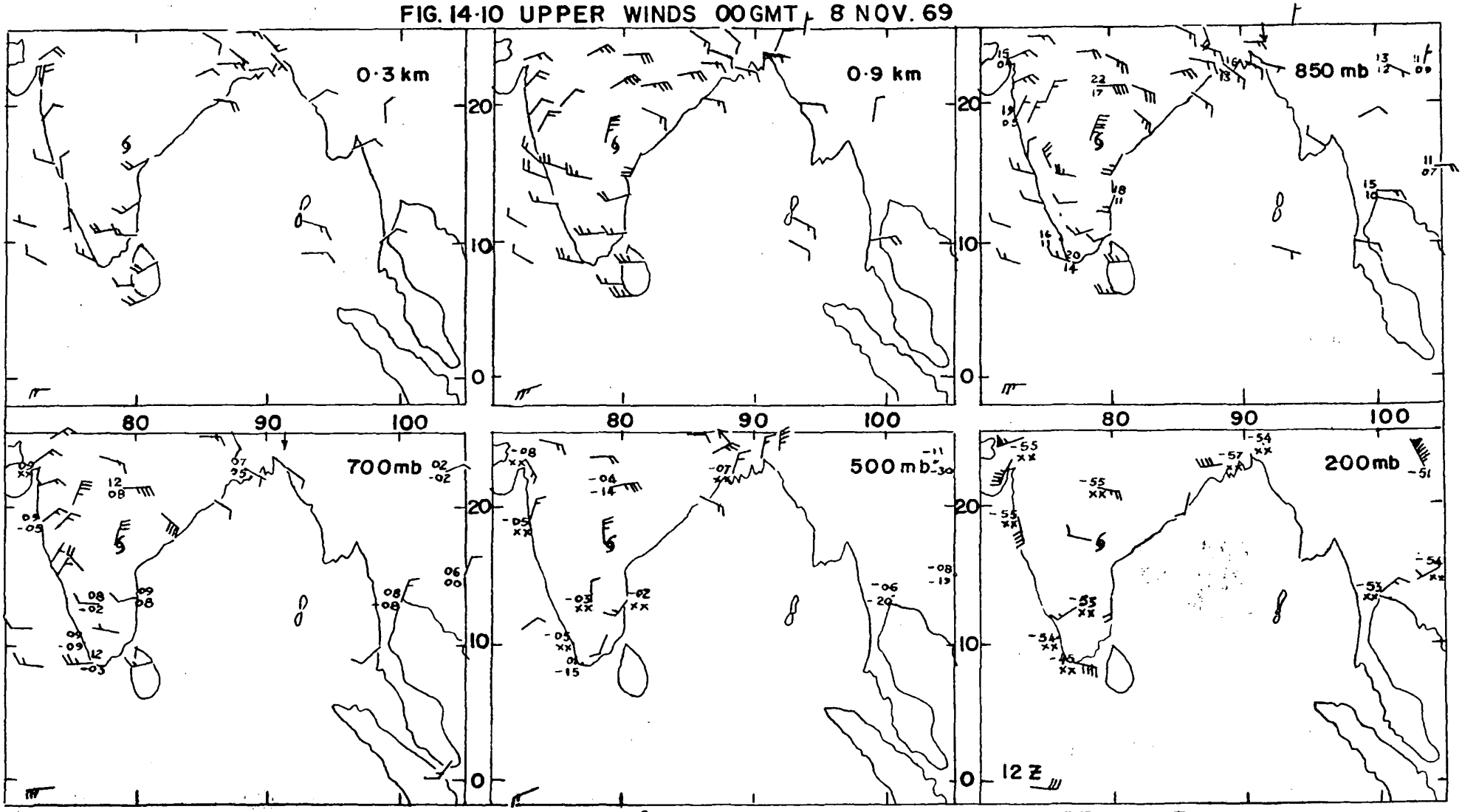
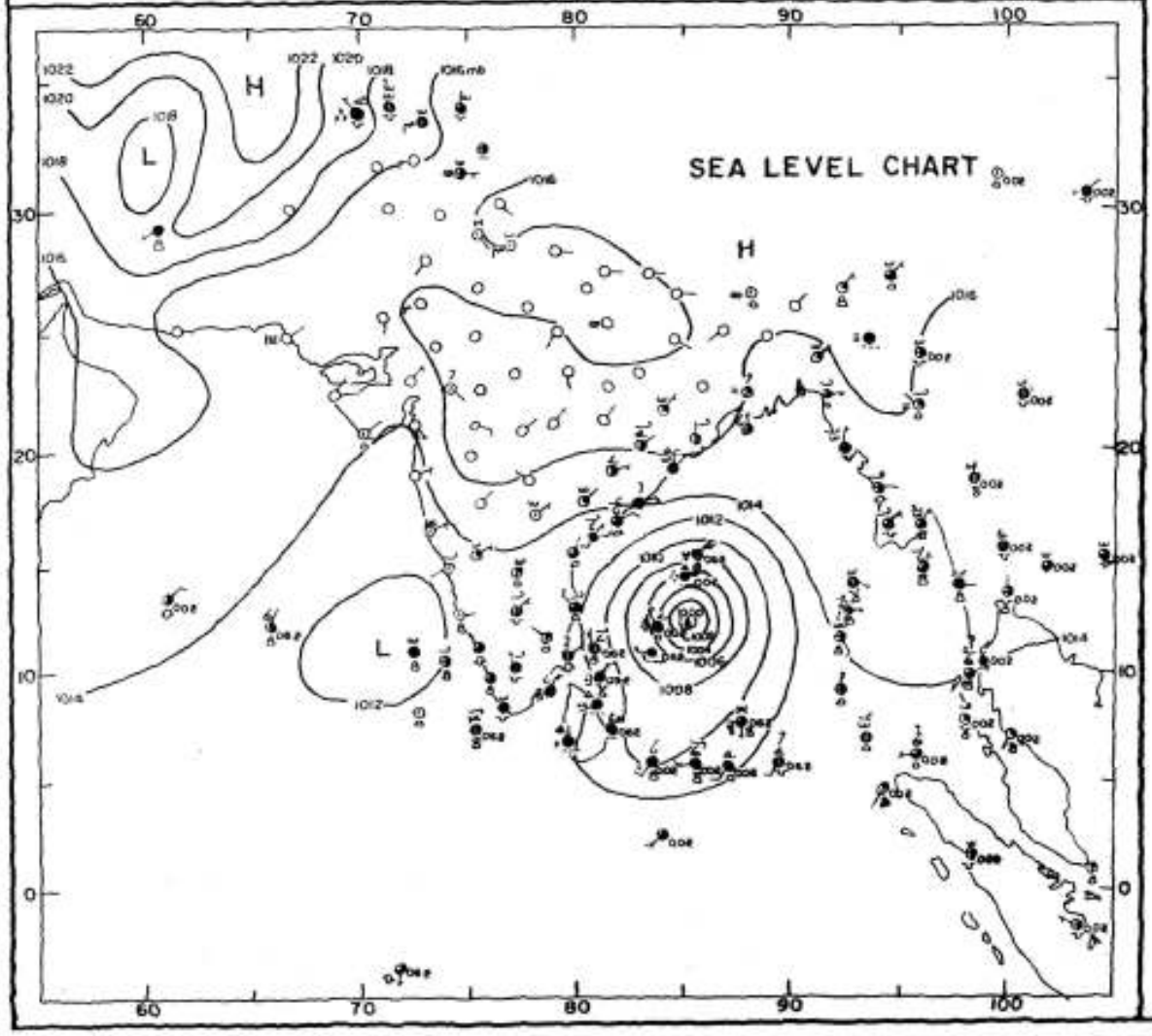


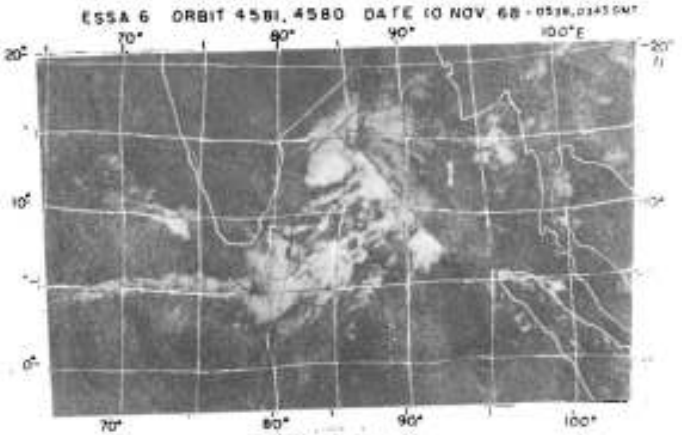
FIG. 14·10 UPPER WINDS 00GMT 8 NOV. 69

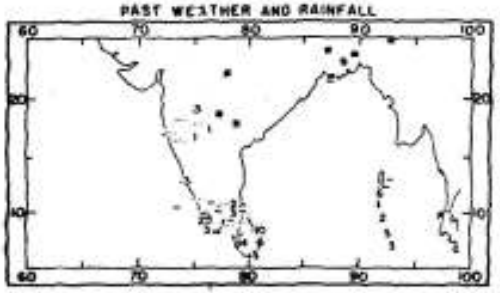


§ Cyclonic storm. Plotted figures T T & T_d T_d

FIG. 15·1 SYNOPTIC CHARTS 0300 GMT 10 NOV. 68







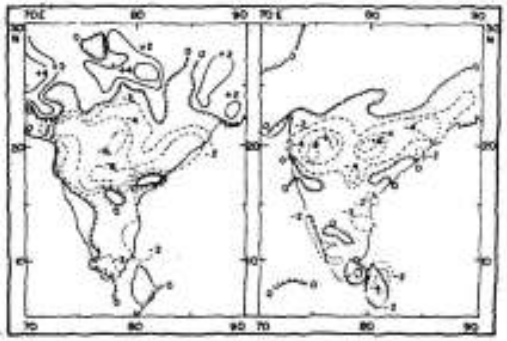


FIG. 15-2 UPPER WINDS 00 GMT 10 NOV. 68

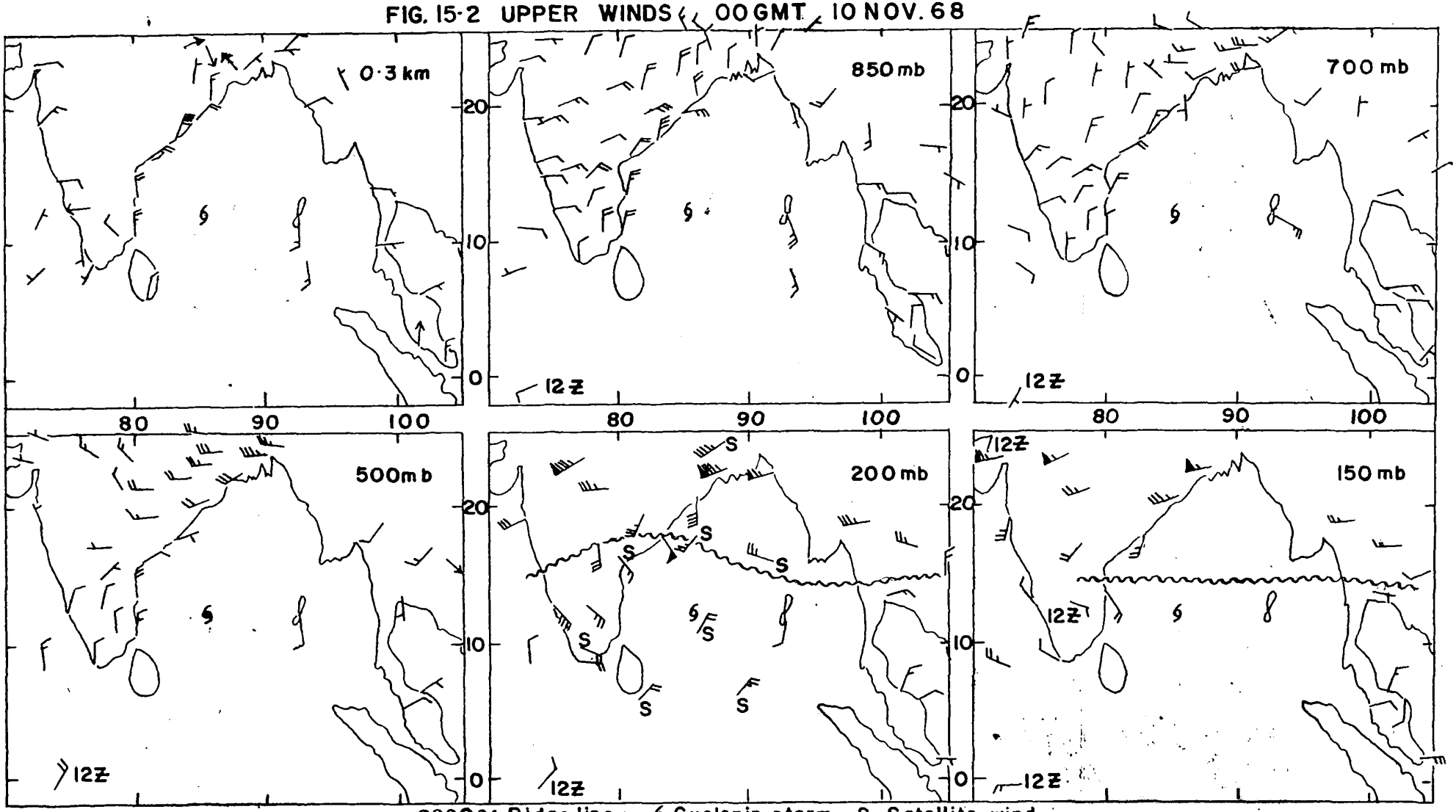
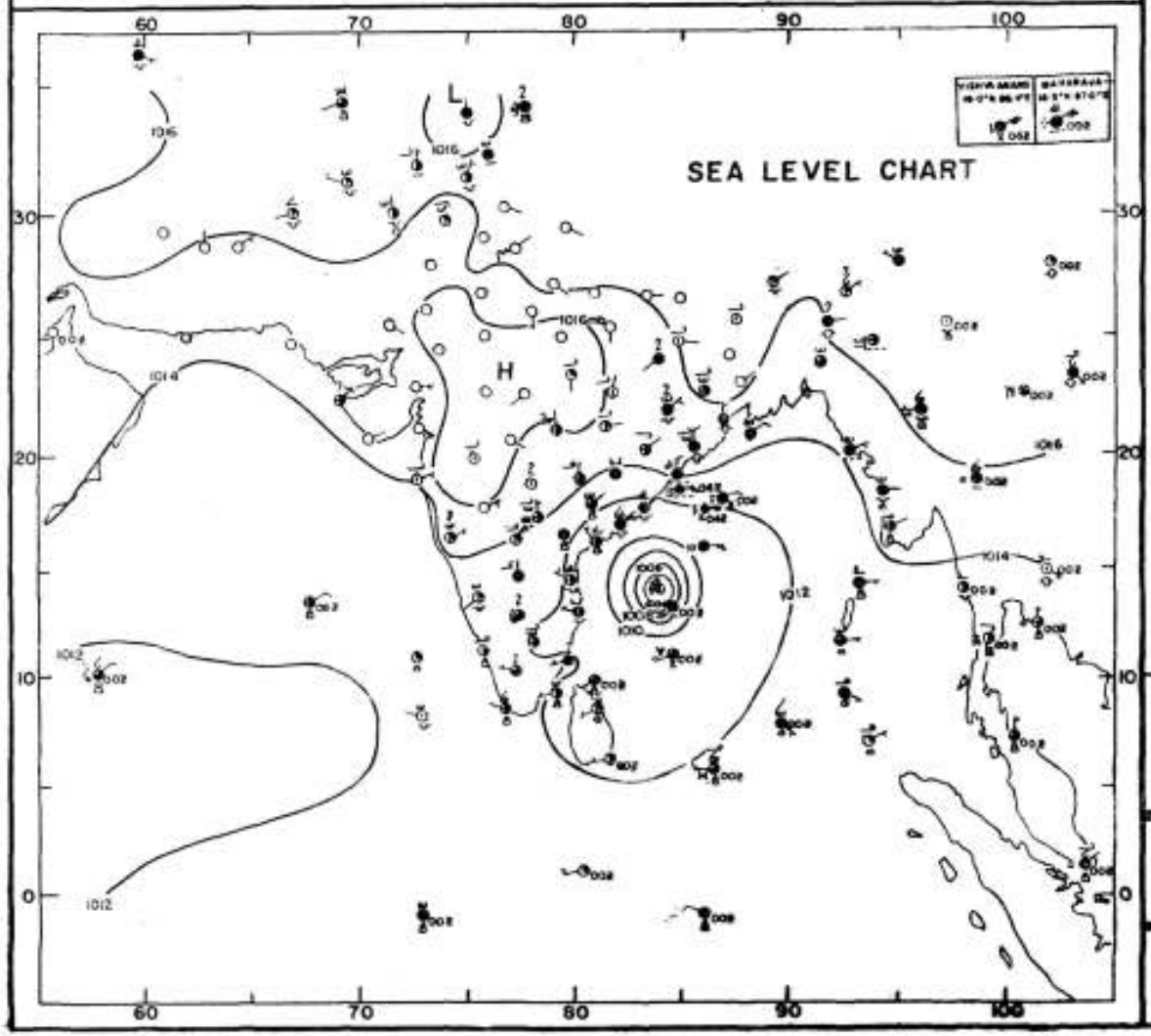
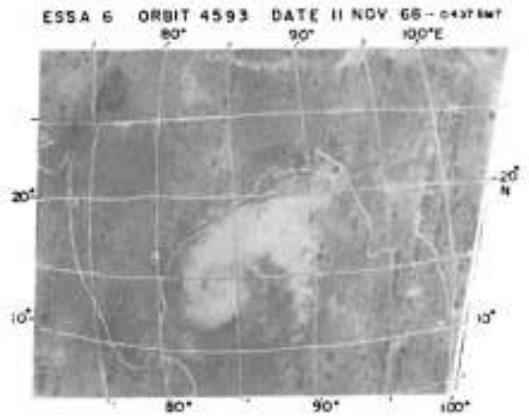
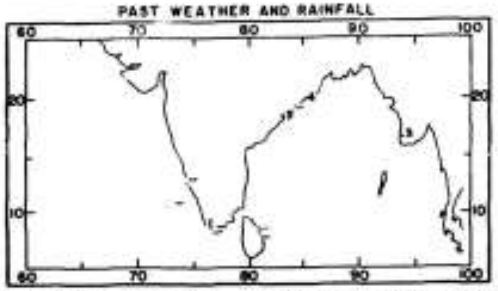


FIG. 15·3 SYNOPTIC CHARTS 0300 GMT 11 NOV. 68







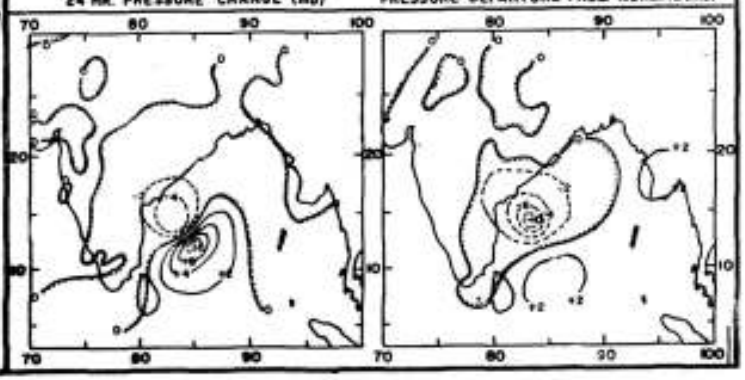


FIG. 15·4 UPPER WINDS 00 GMT 11 NOV. 68

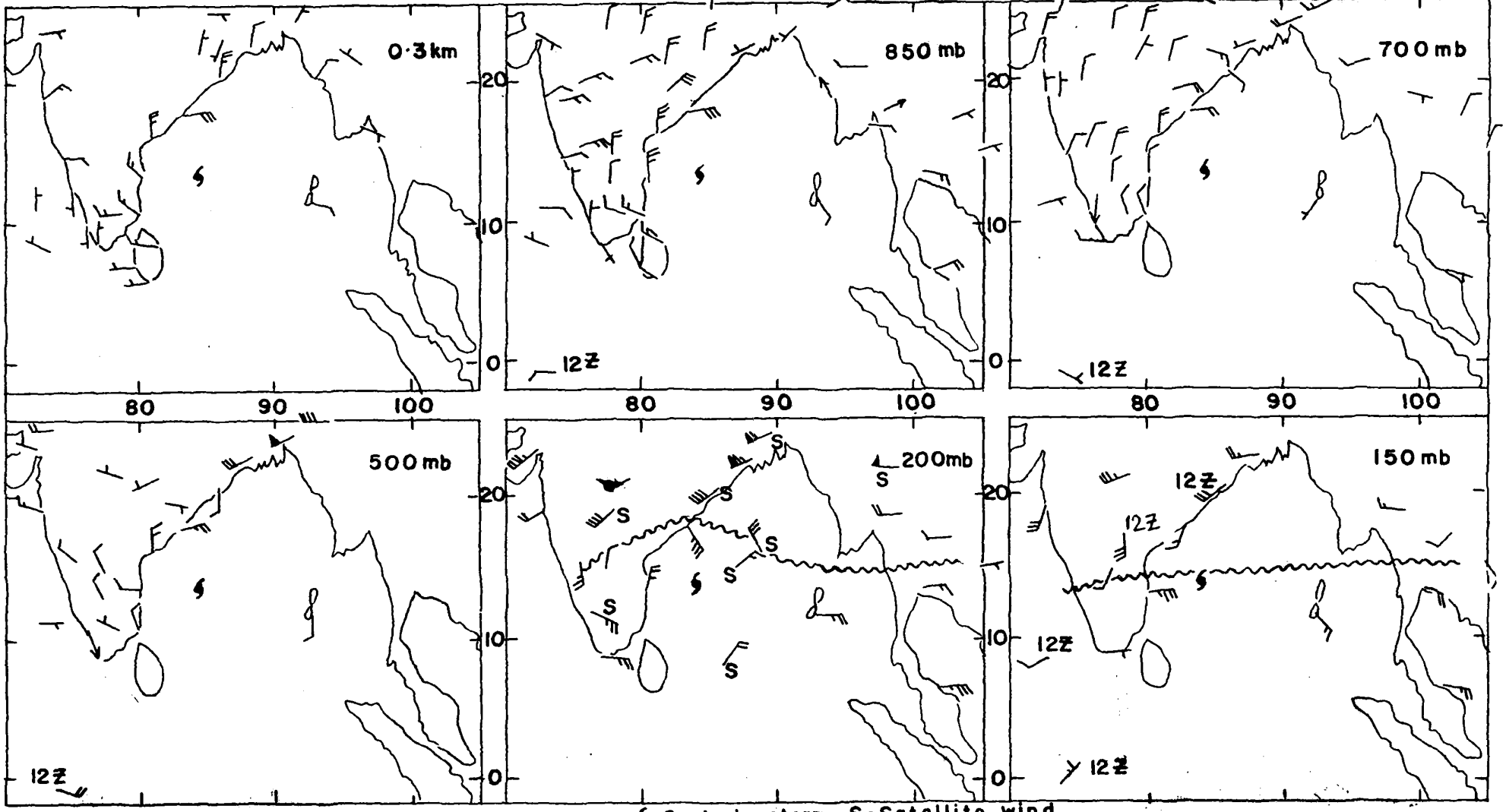
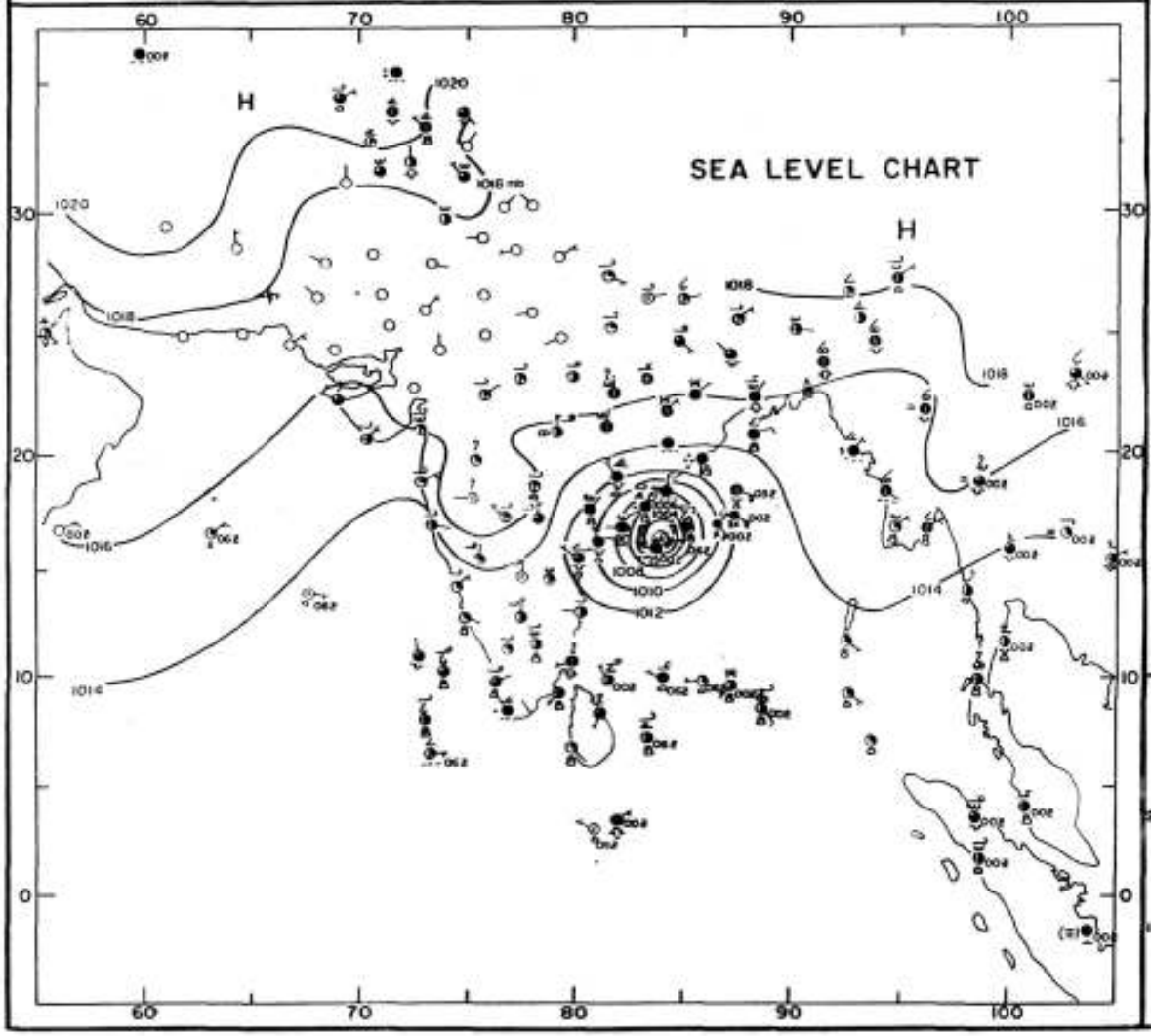


FIG. 15·5 SYNOPTIC CHARTS 0300 GMT 12 NOV. 68



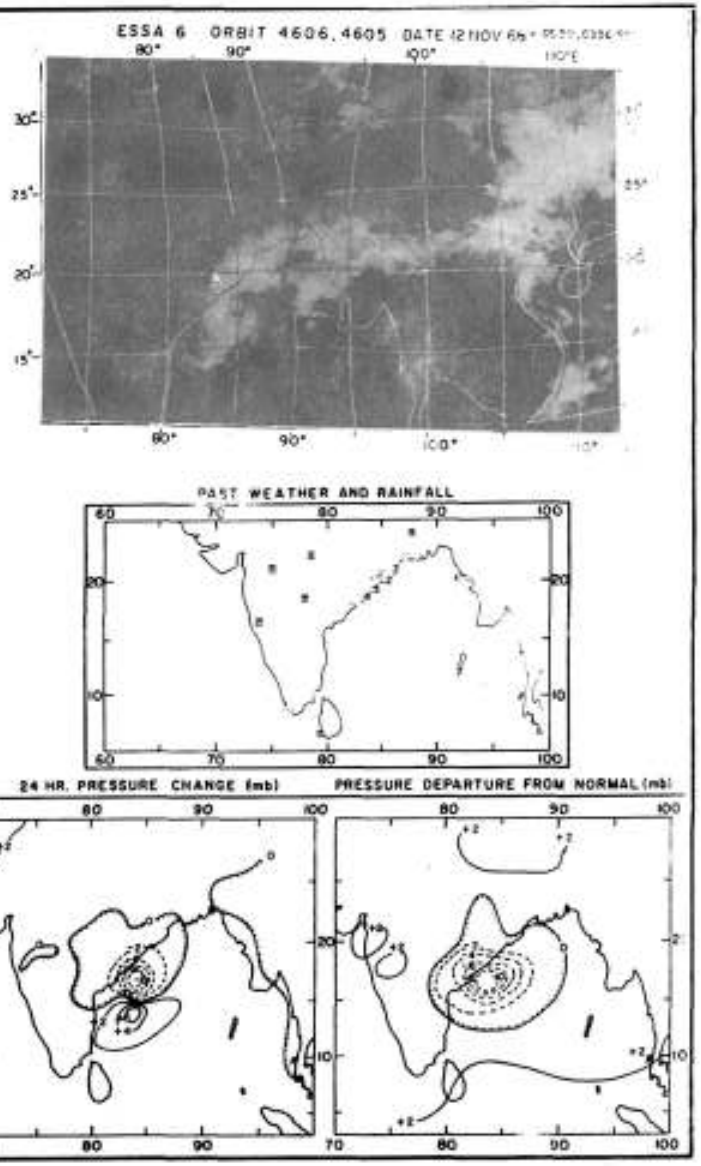


FIG. 15·6 UPPER WINDS 00 GMT 12 NOV. 68

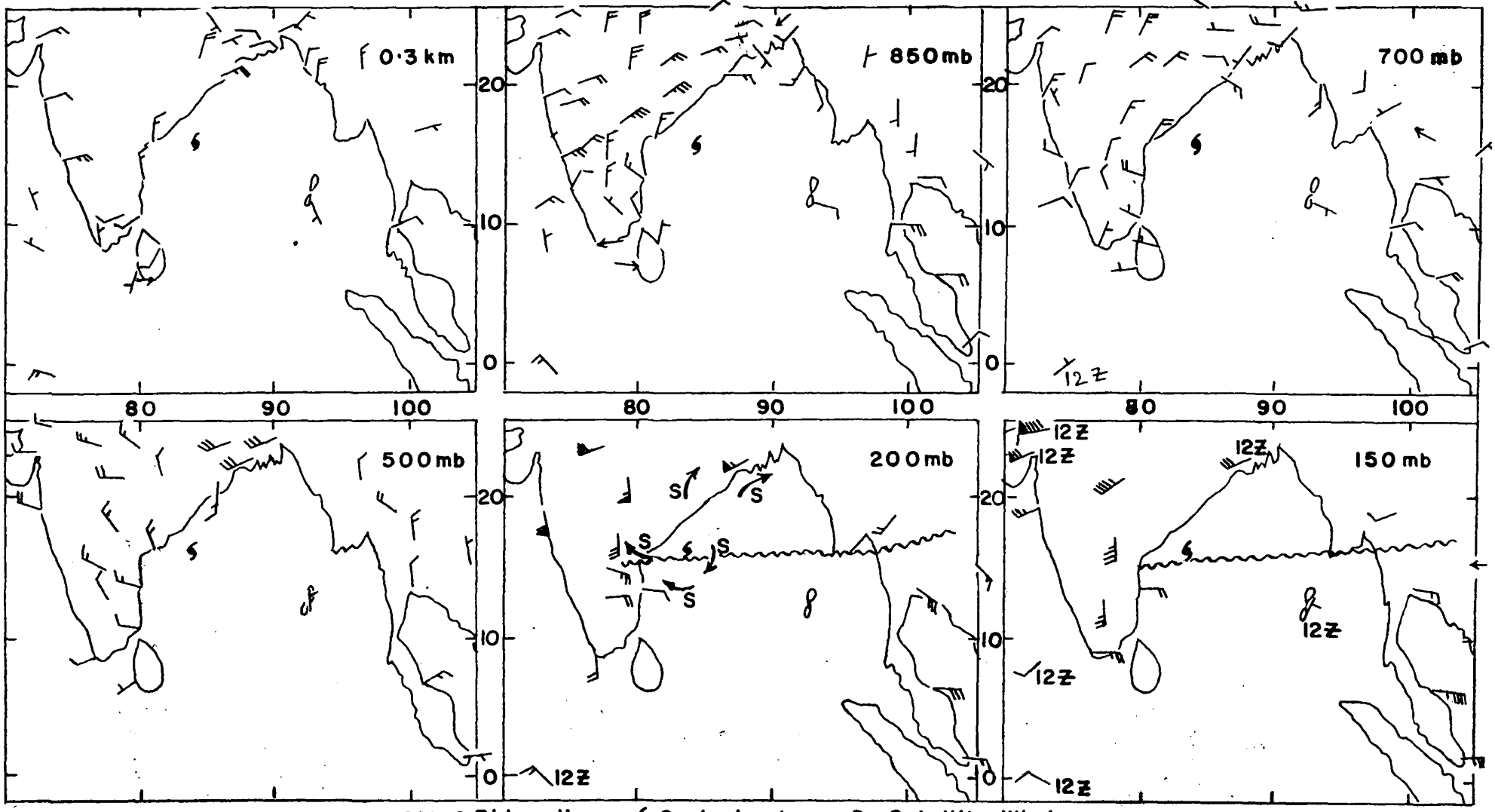
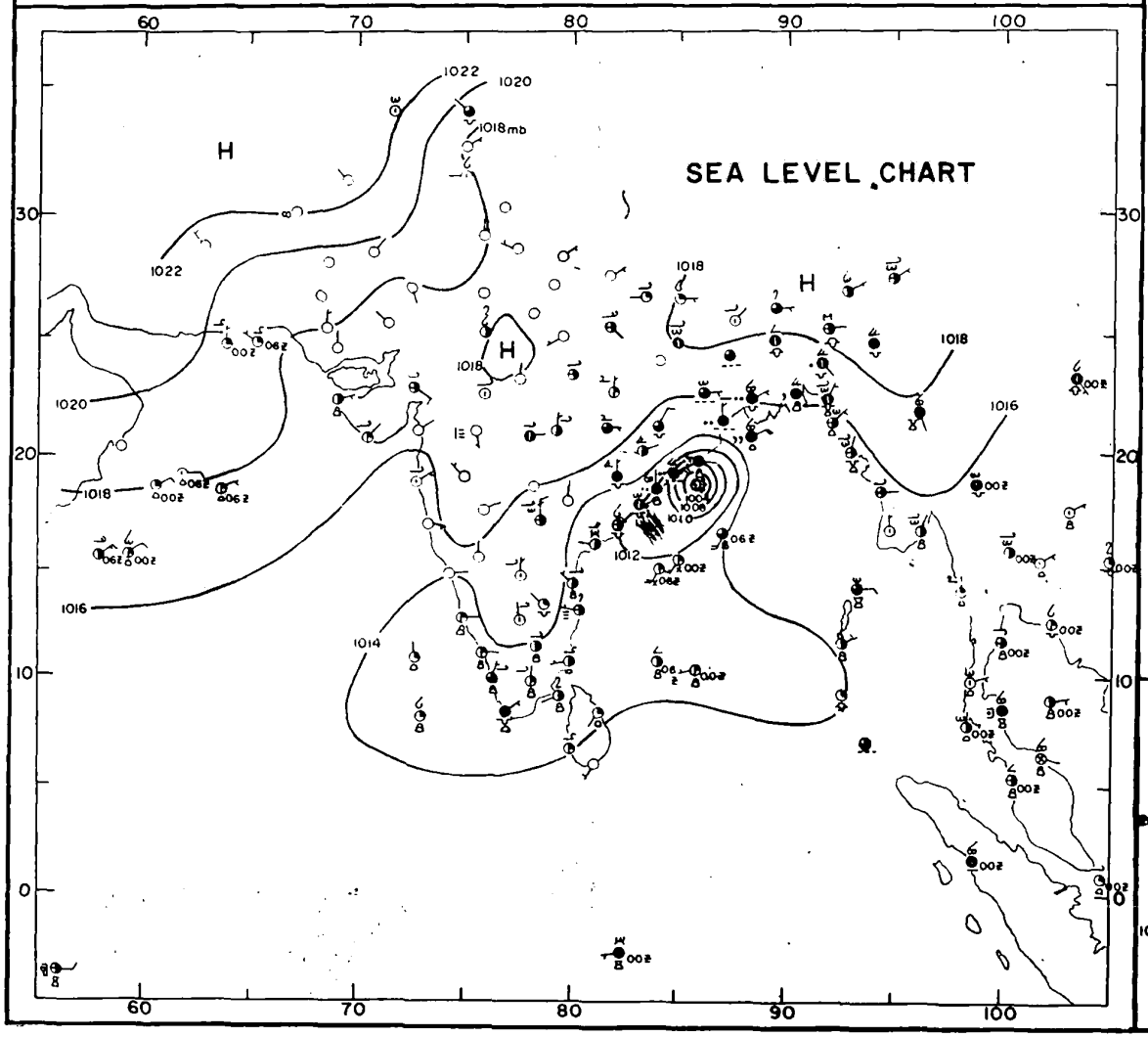
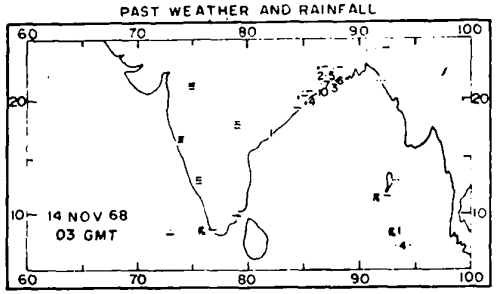


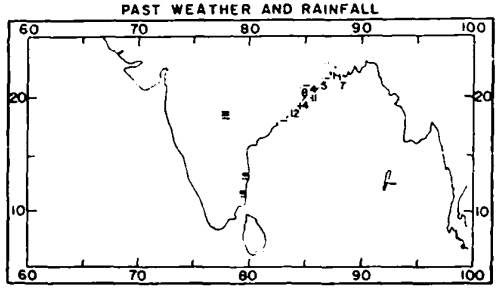
FIG. 15·7 SYNOPTIC CHARTS 0300 GMT 13 NOV. 68



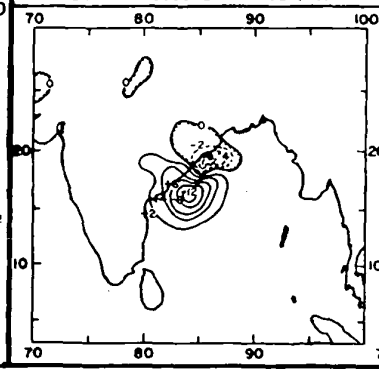
PAST WEATHER AND RAINFALL



PAST WEATHER AND RAINFALL



24 HR. PRESSURE CHANGE (mb)



PRESSURE DEPARTURE FROM NORMAL (mb)

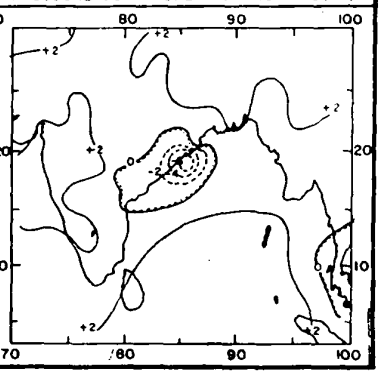
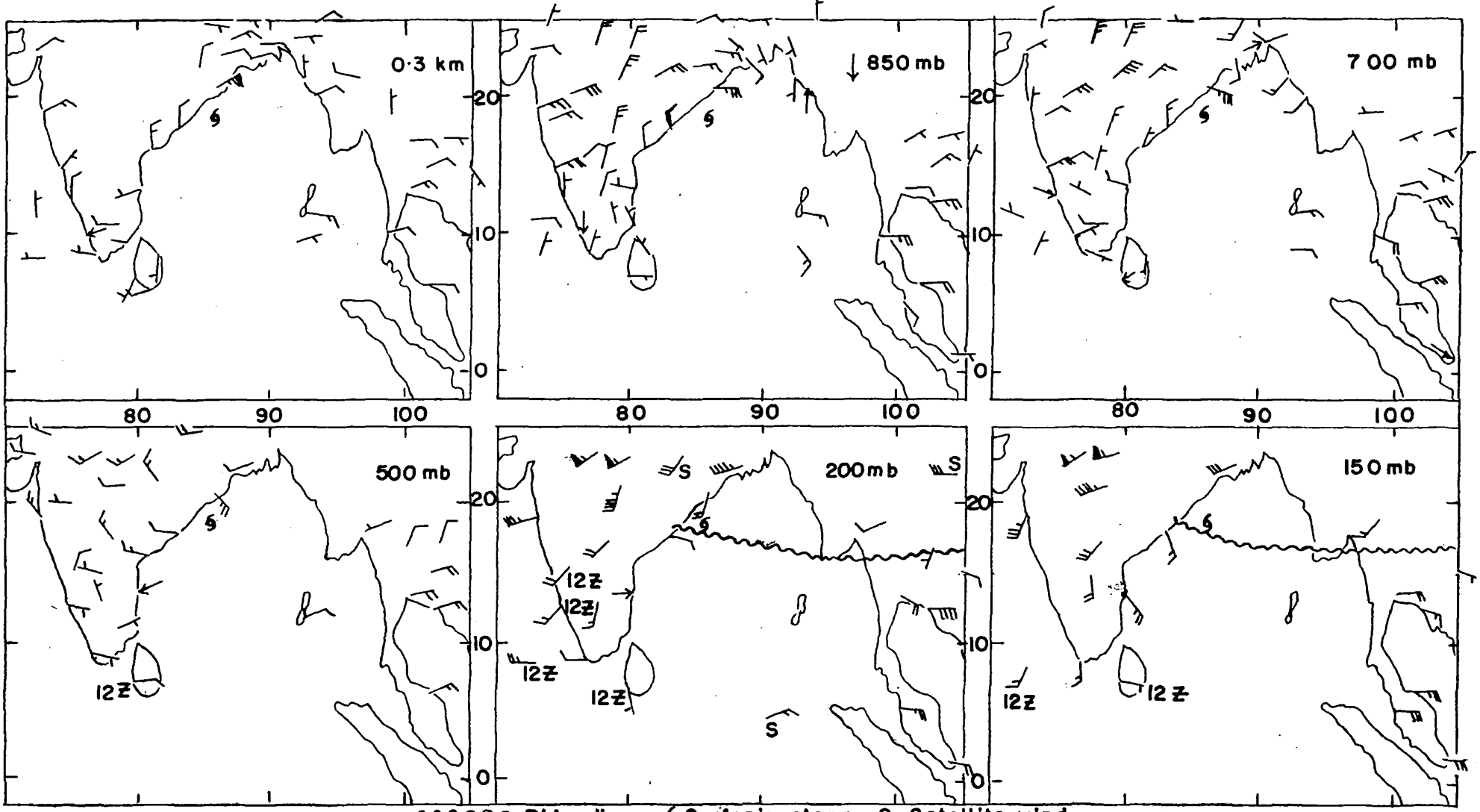
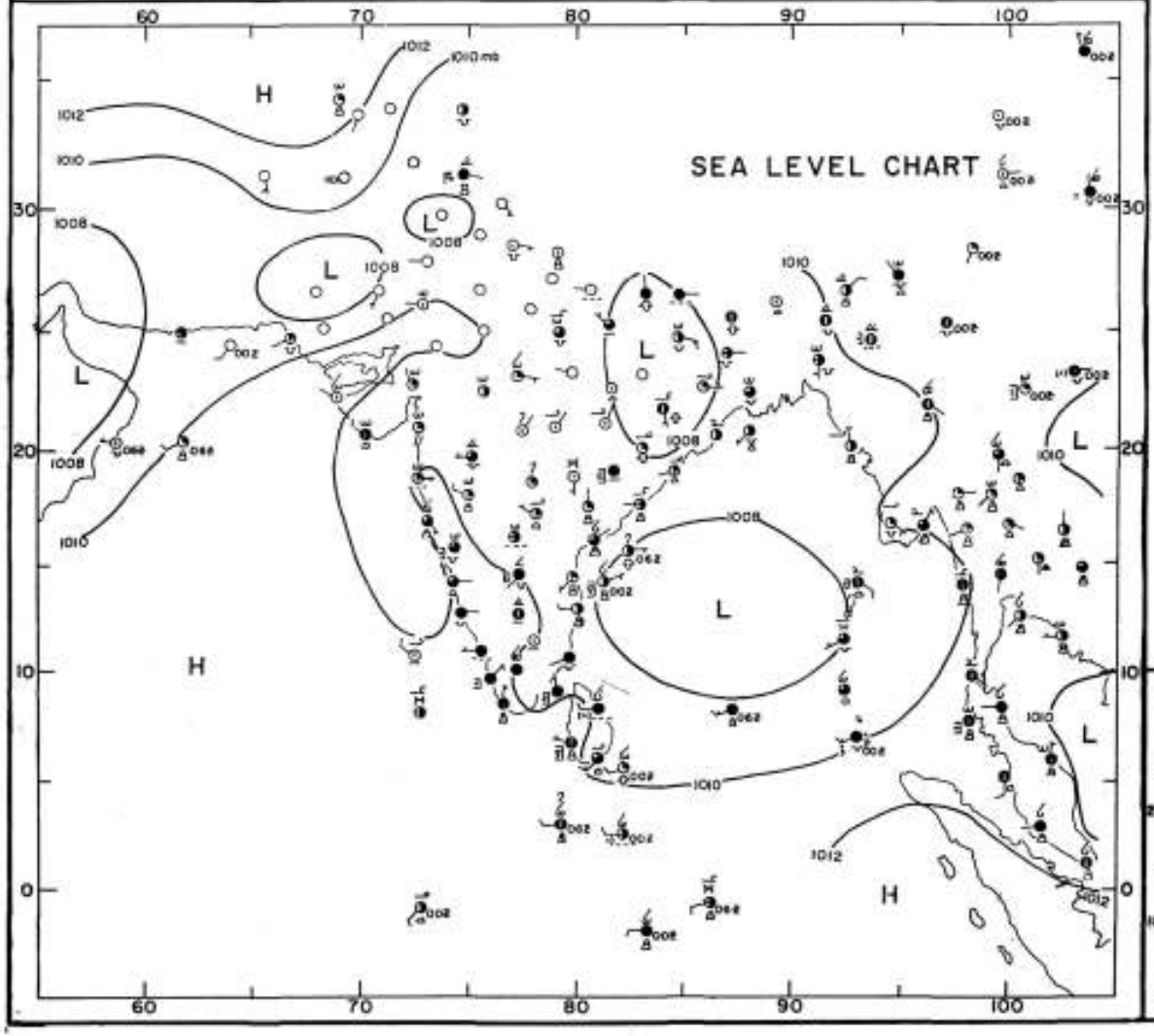


FIG. 15·8 UPPER WINDS 00GMT 13 NOV. 68



Ridge line. Cyclonic storm S-Satellite wind

FIG. 16-1 SYNOPTIC CHARTS 0300 GMT 7 OCT. 70



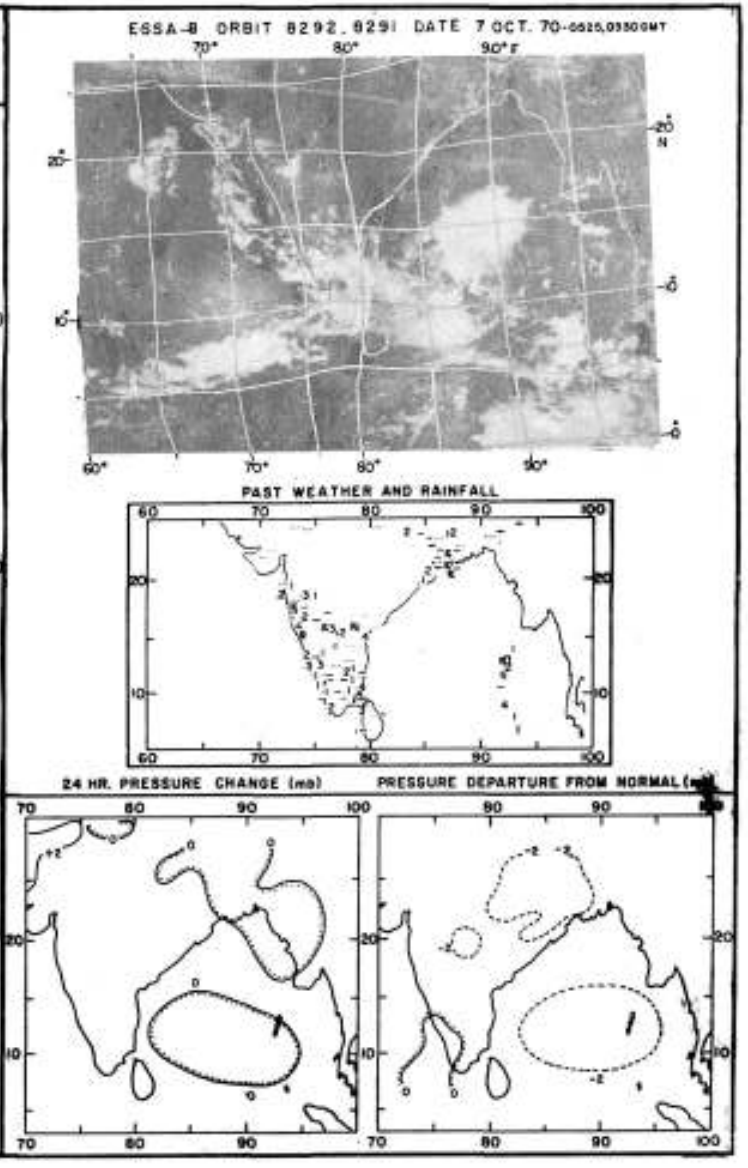


FIG. 16-2 UPPER WINDS 00GMT 7 OCT. 70

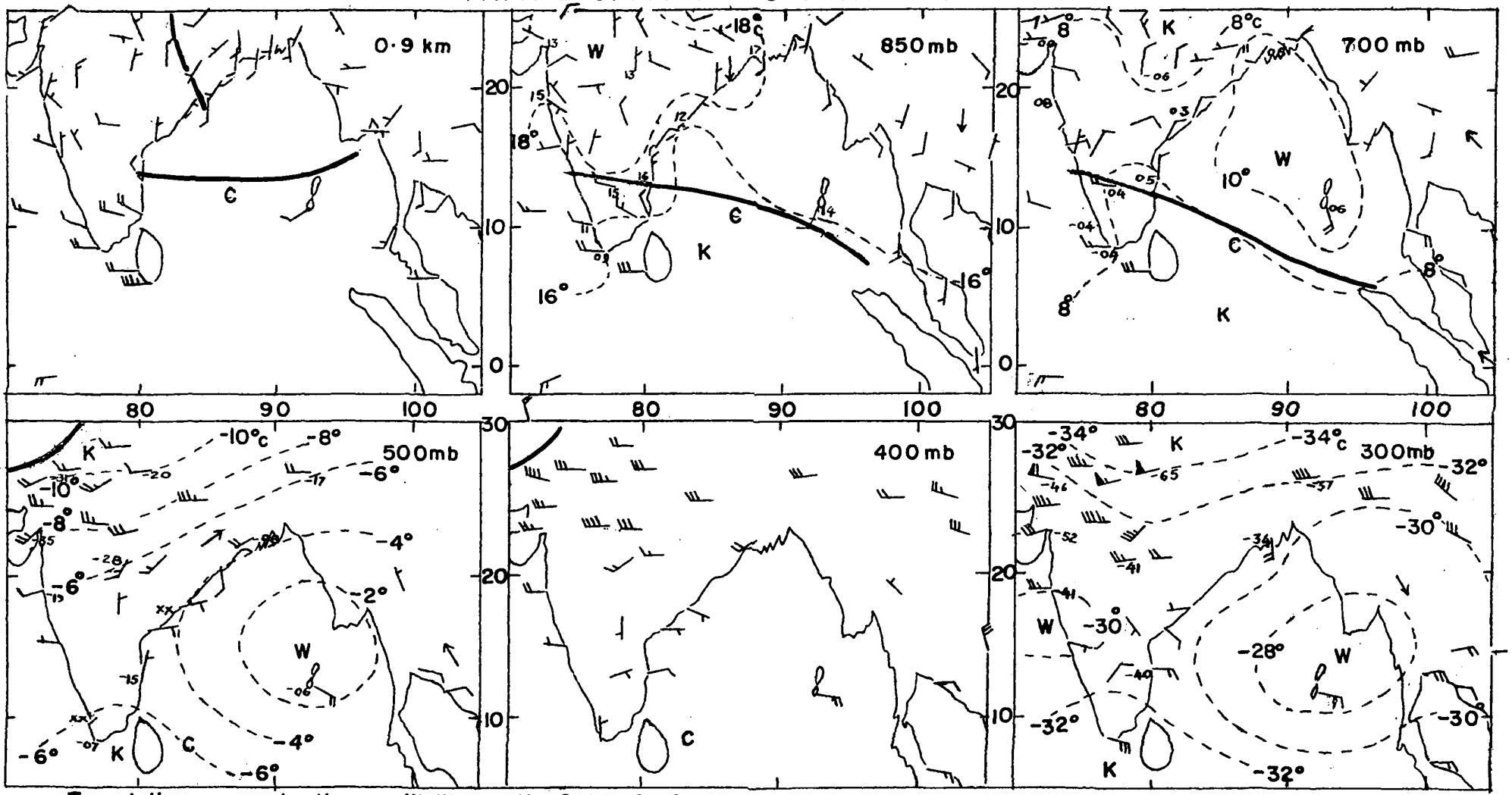
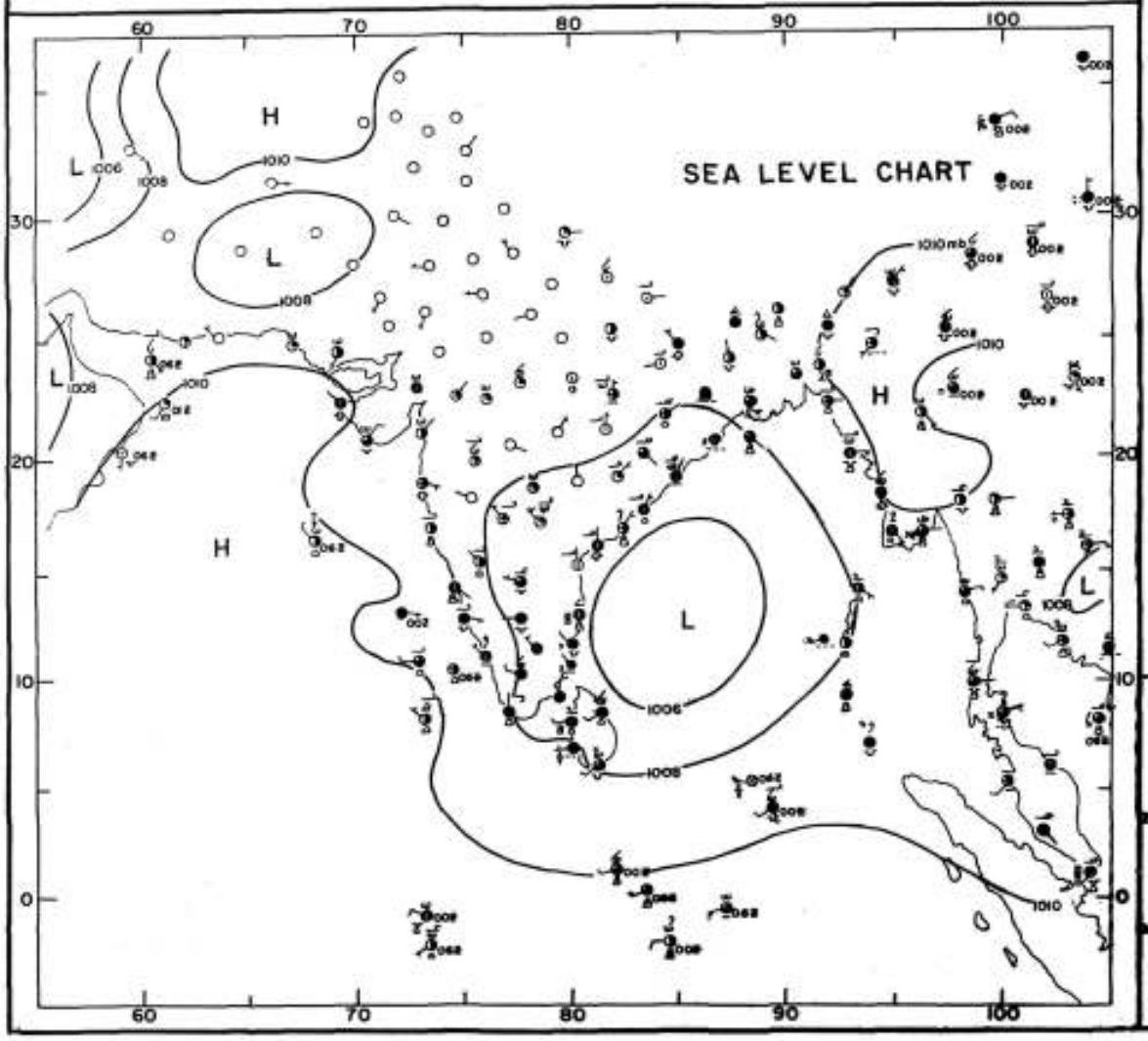


FIG. 16·3 SYNOPTIC CHARTS 0300 GMT 8 OCT. 70



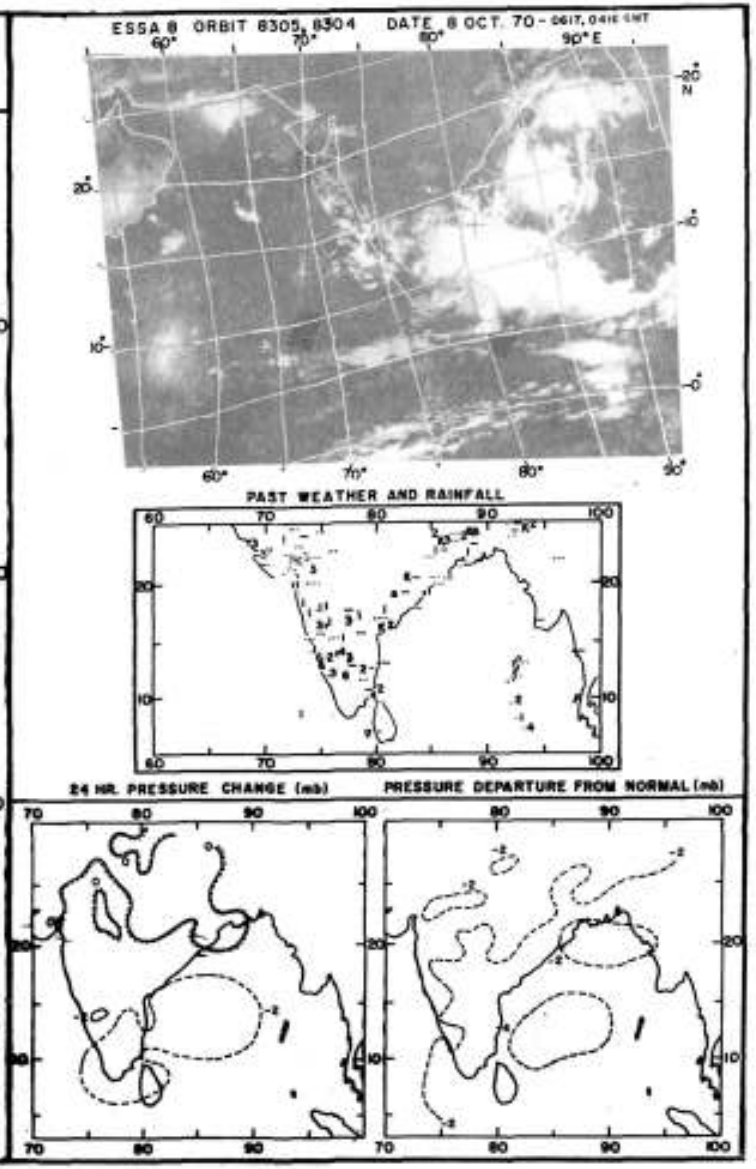
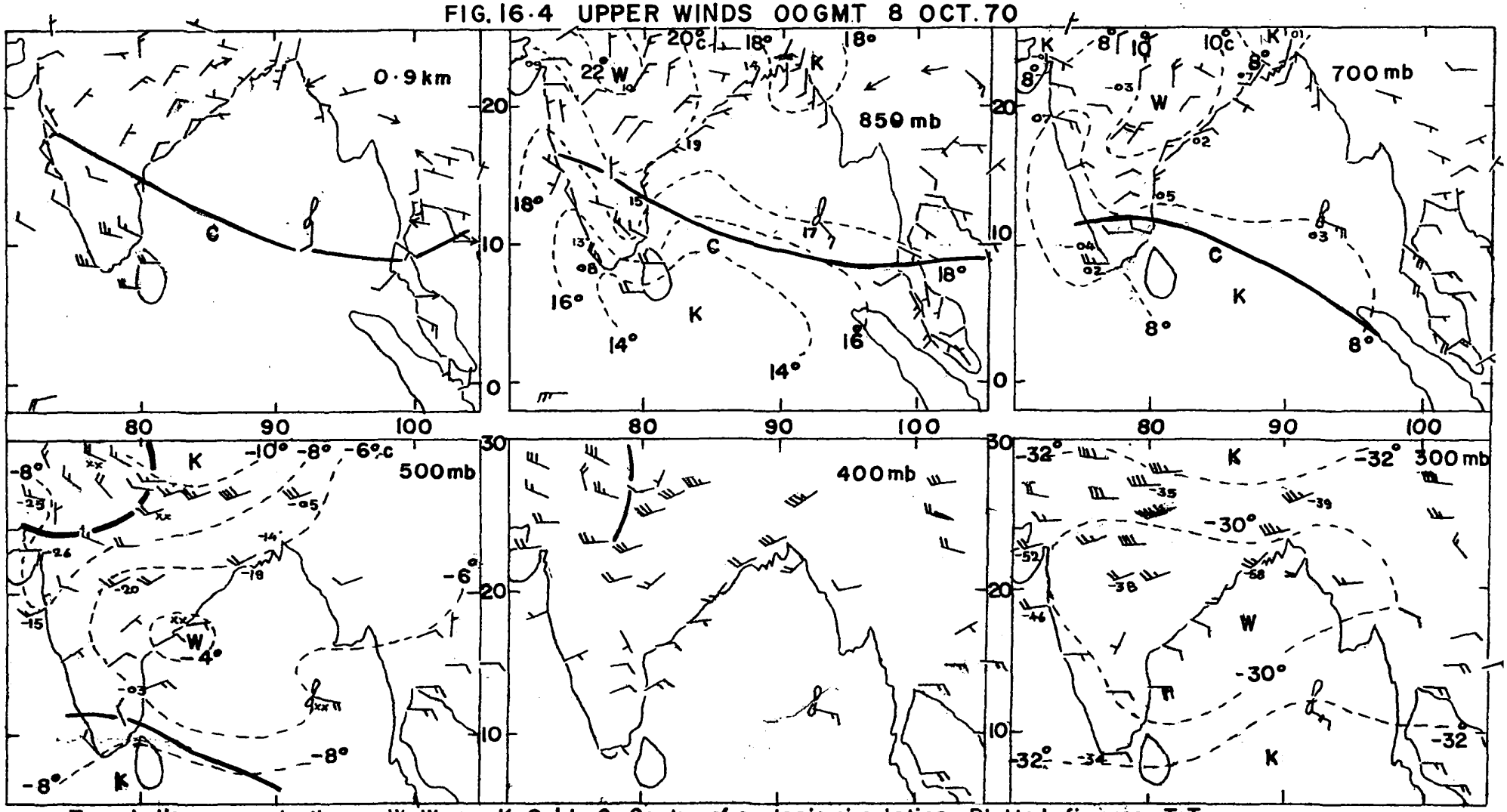
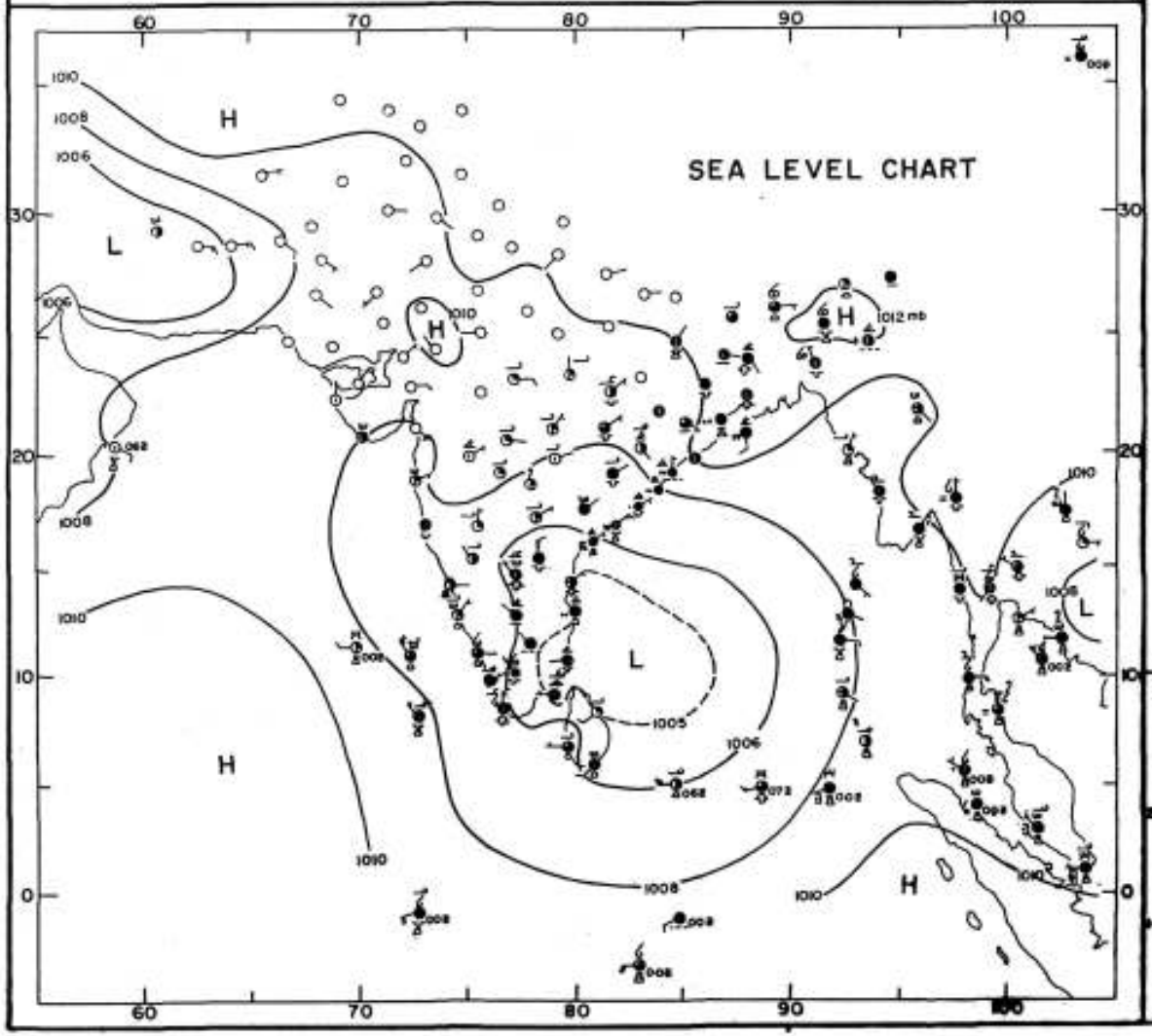


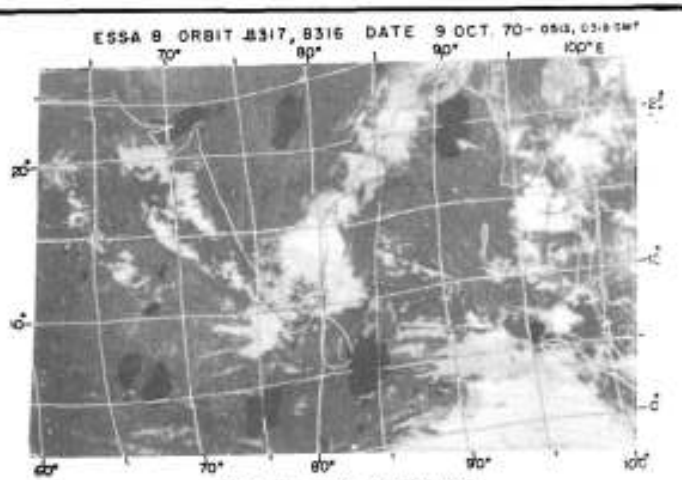
FIG. 16·4 UPPER WINDS 00GMT 8 OCT. 70

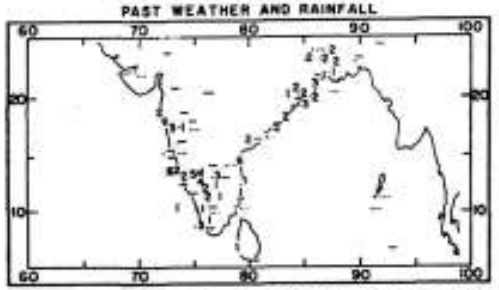


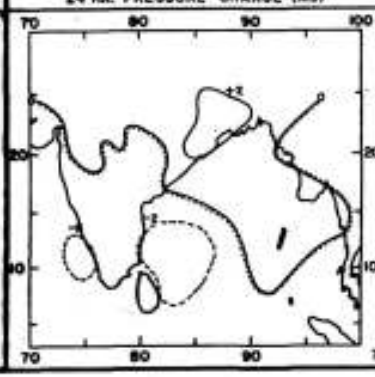
Trough line ----- Isotherm W-Warm K-Cold C-Centre of cyclonic circulation. Plotted figures $T_d T_d$

FIG. 16·5 SYNOPTIC CHARTS 0300 GMT 9 OCT. 70









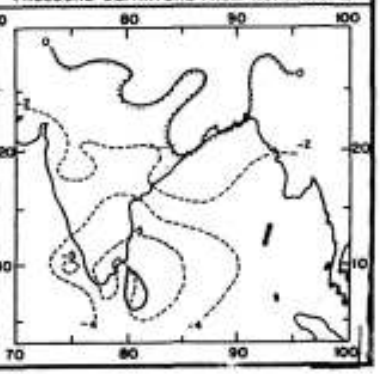
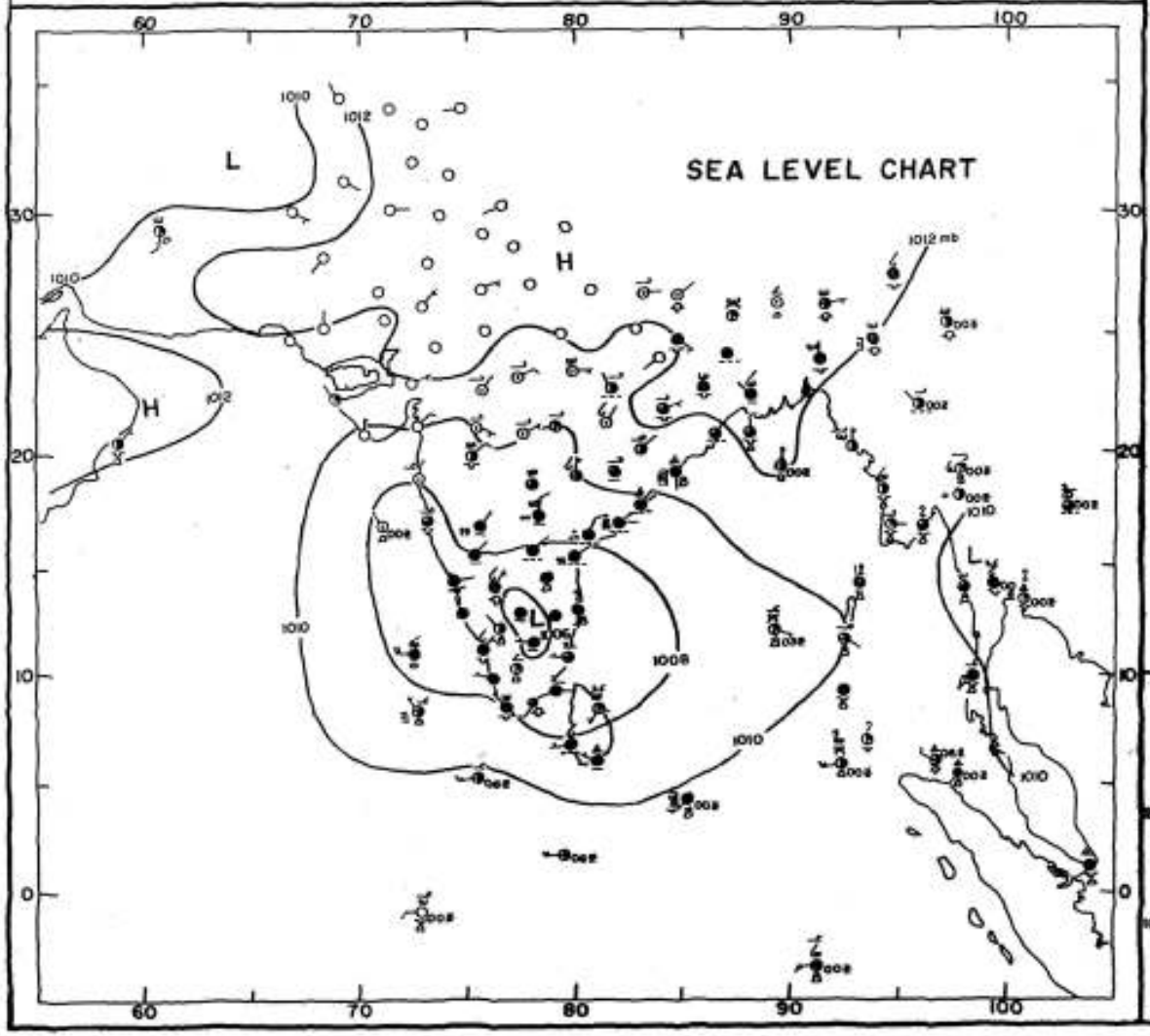
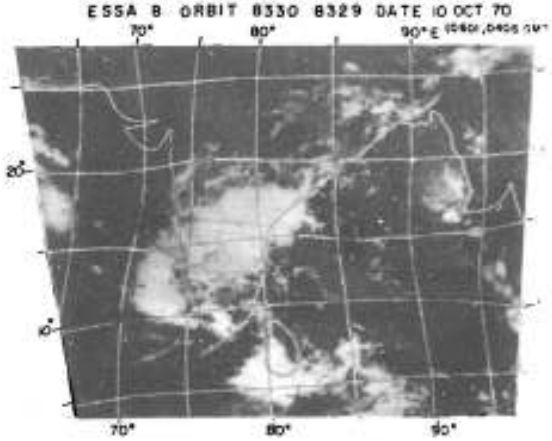
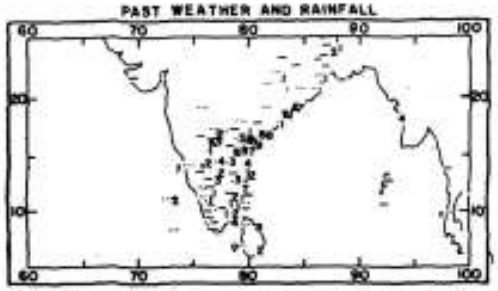


FIG. 16·6 SYNOPTIC CHARTS 0300 GMT 10 OCT. 70







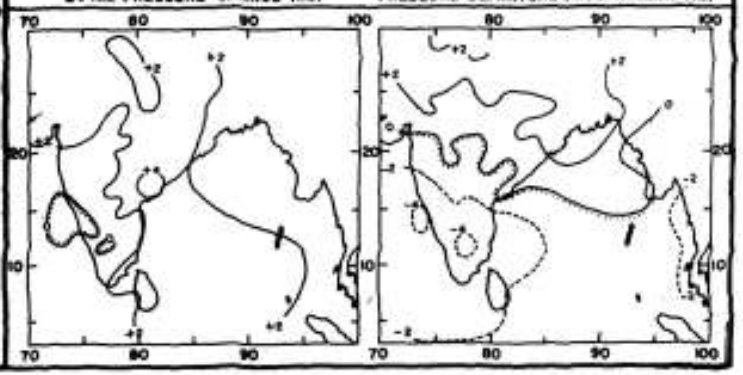
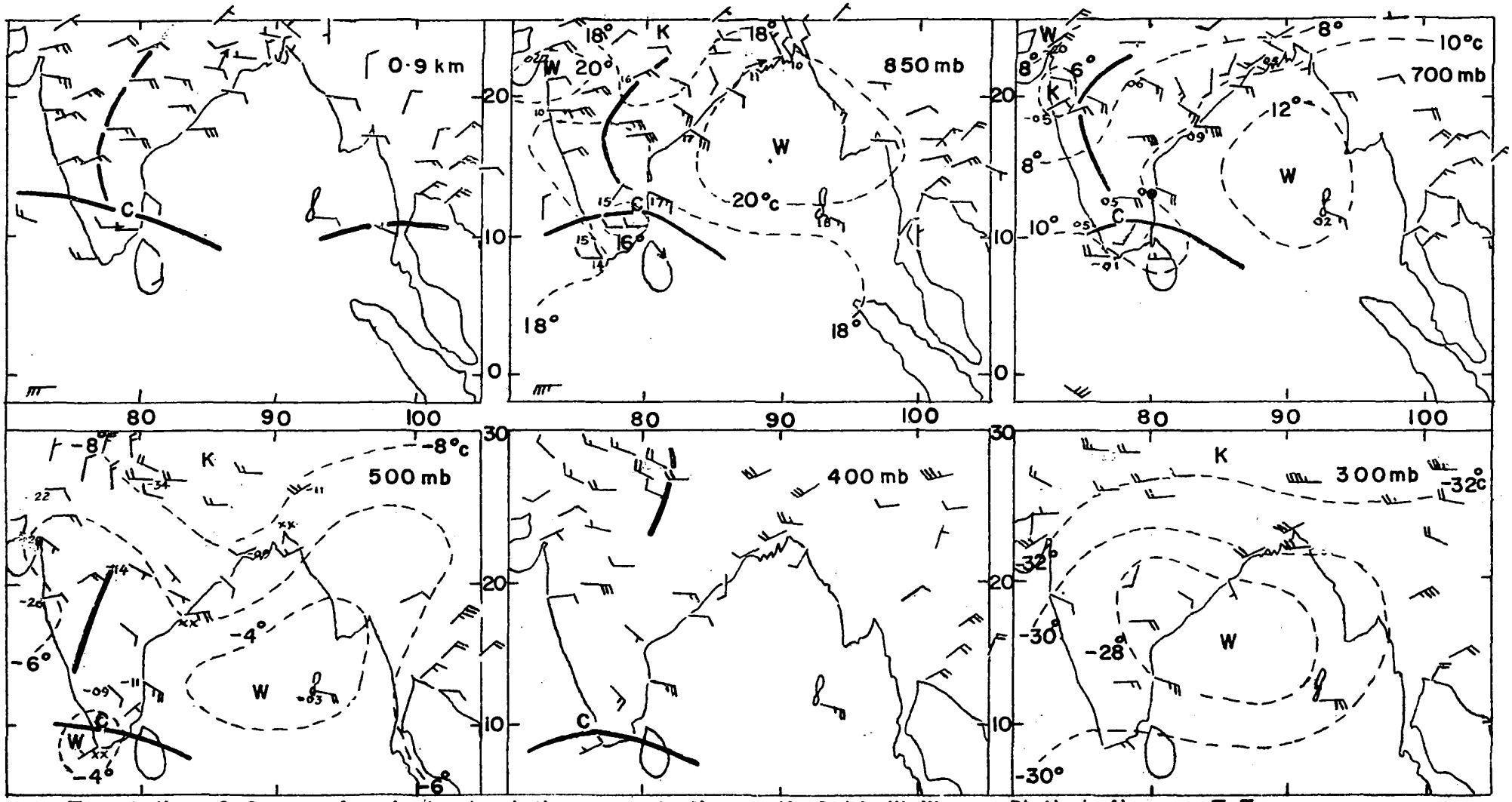
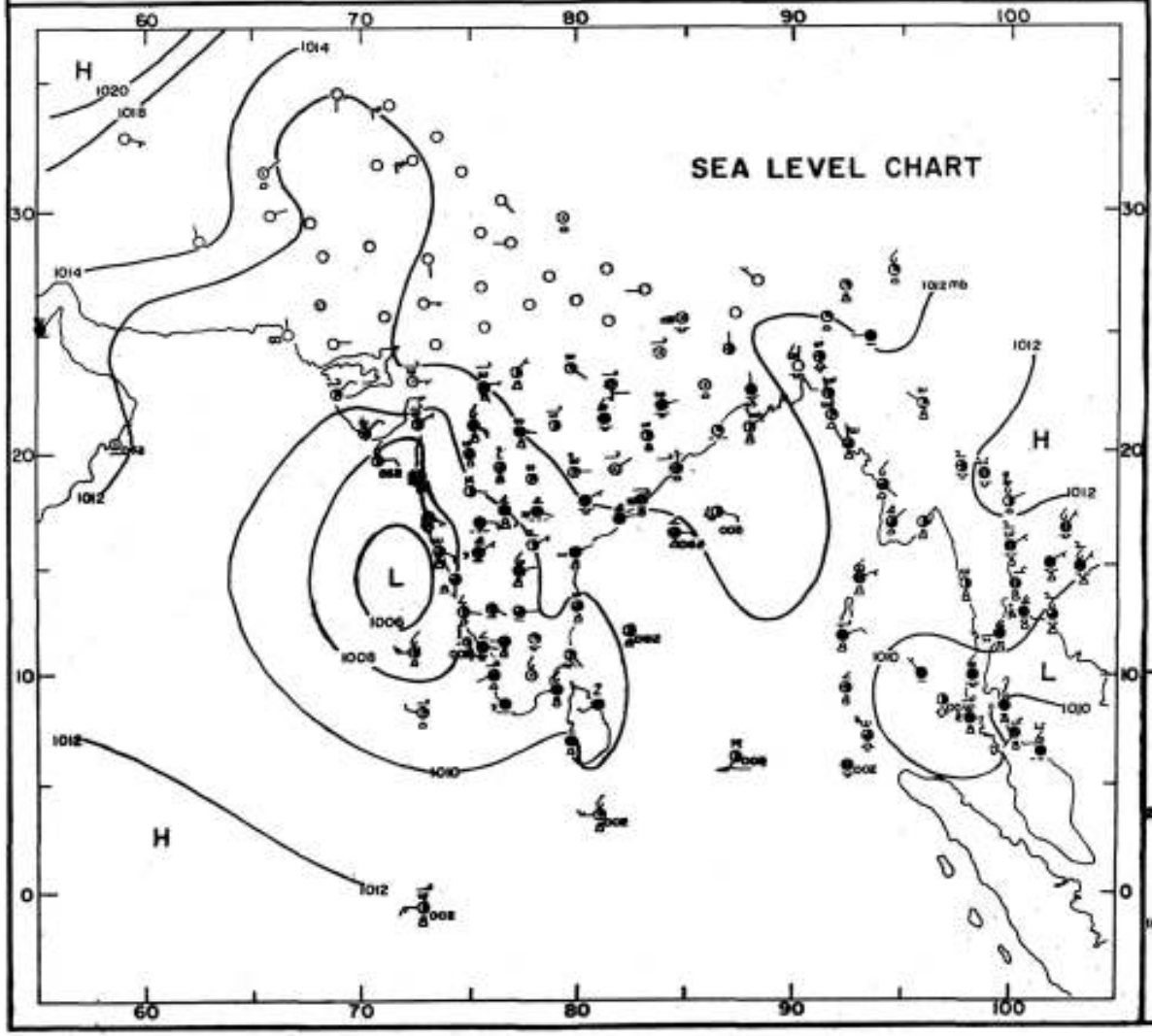


FIG. 16·7 UPPER WINDS 00 GMT 10 OCT. 70



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

FIG. 16·8 SYNOPTIC CHARTS 0300 GMT 11 OCT. 70



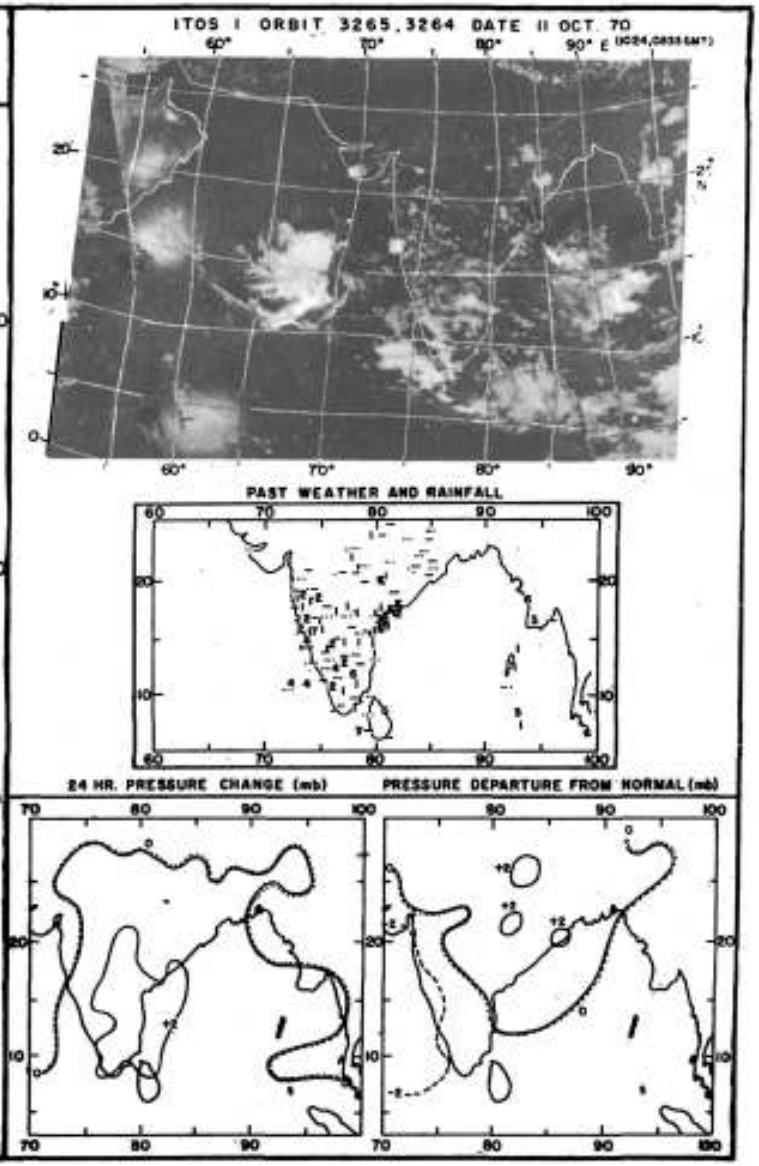
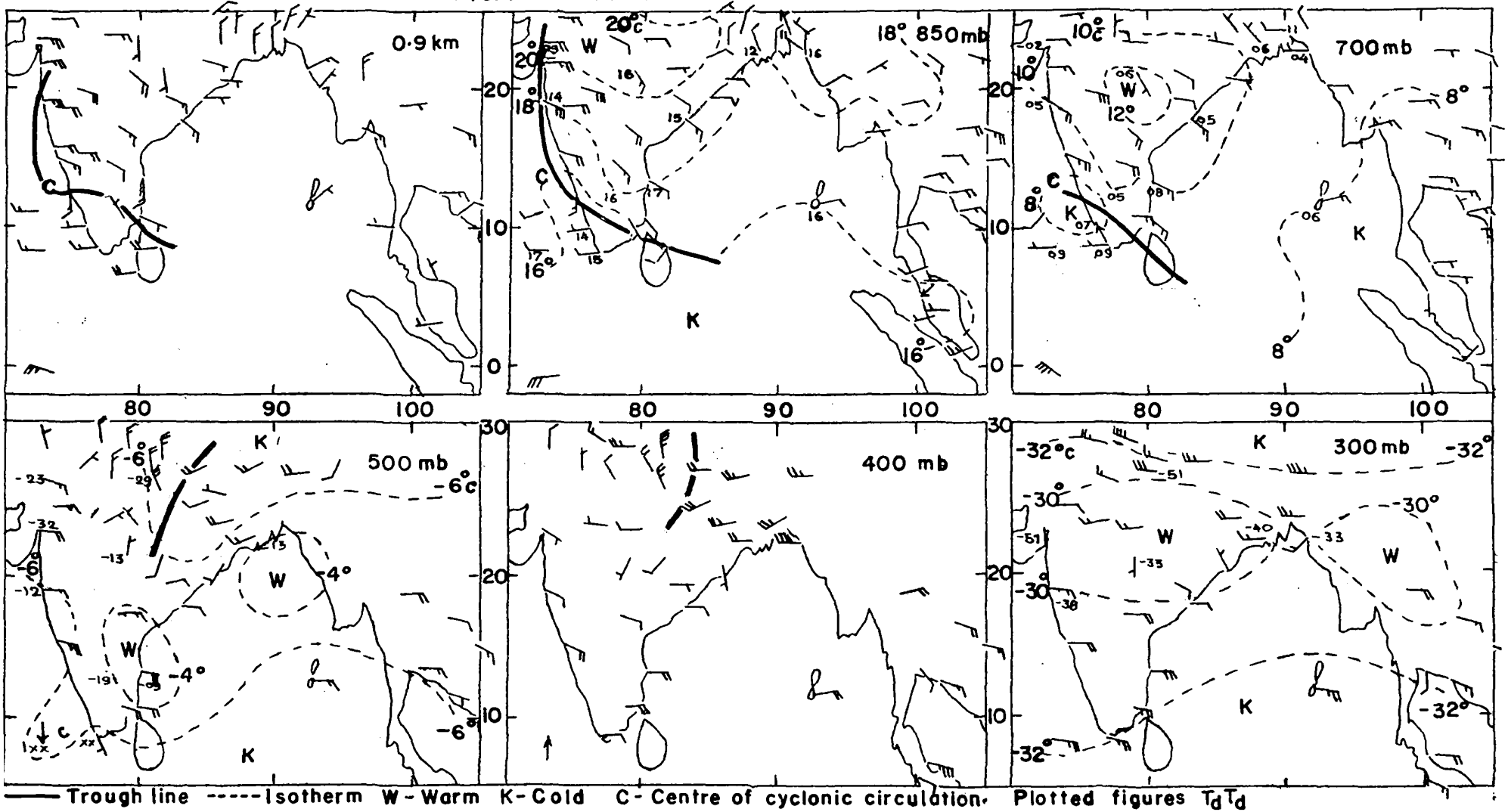


FIG. 16·9 UPPER WINDS 00GMT 11 OCT. 70



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

FIG. 16·10 TIME CROSS SECTION CHART FOR PORT BLAIR
(5-10 OCT. 70)

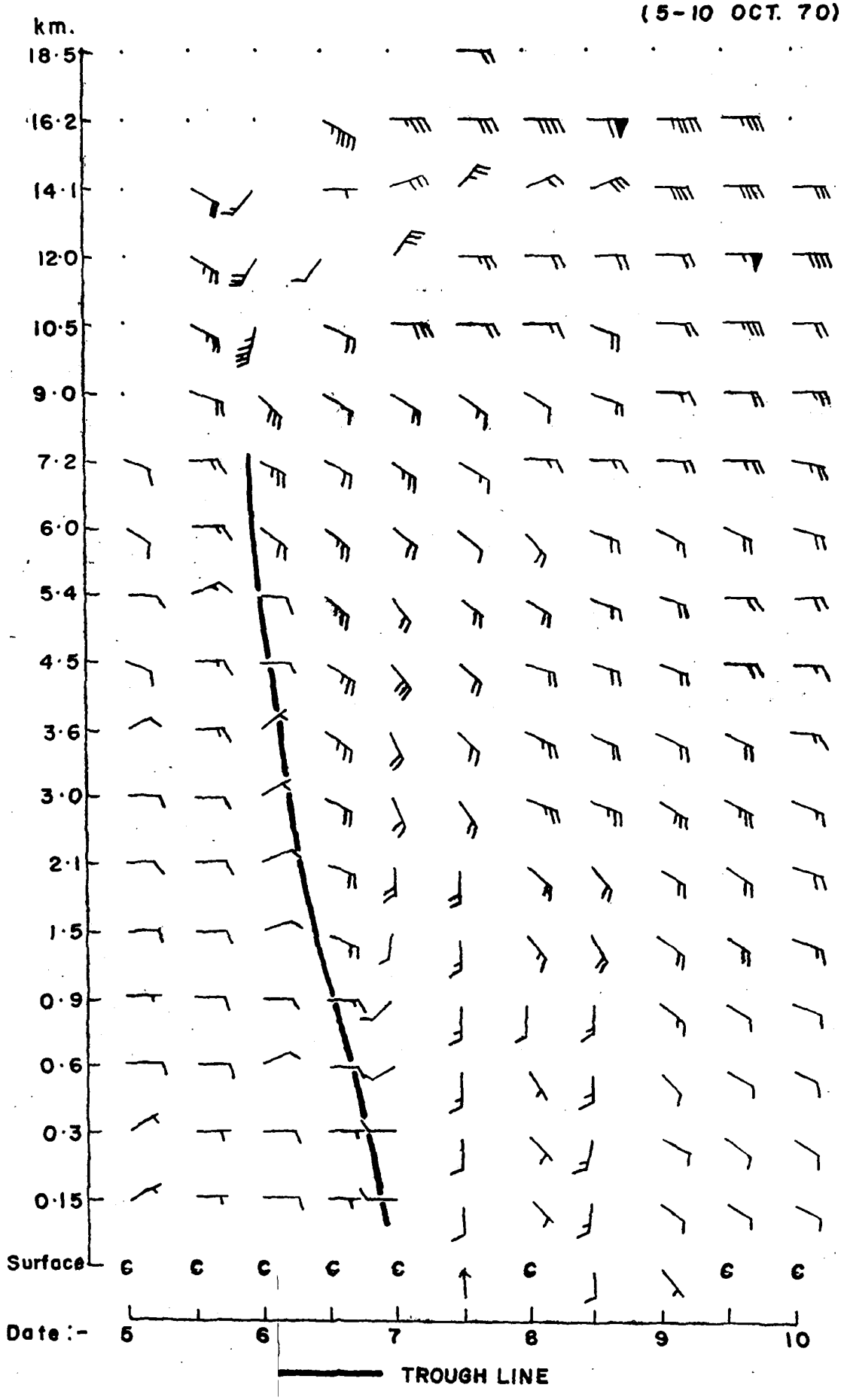


FIG. 16·11 TIME SECTION CHART FOR MADRAS (6 - 11 OCT. 70)

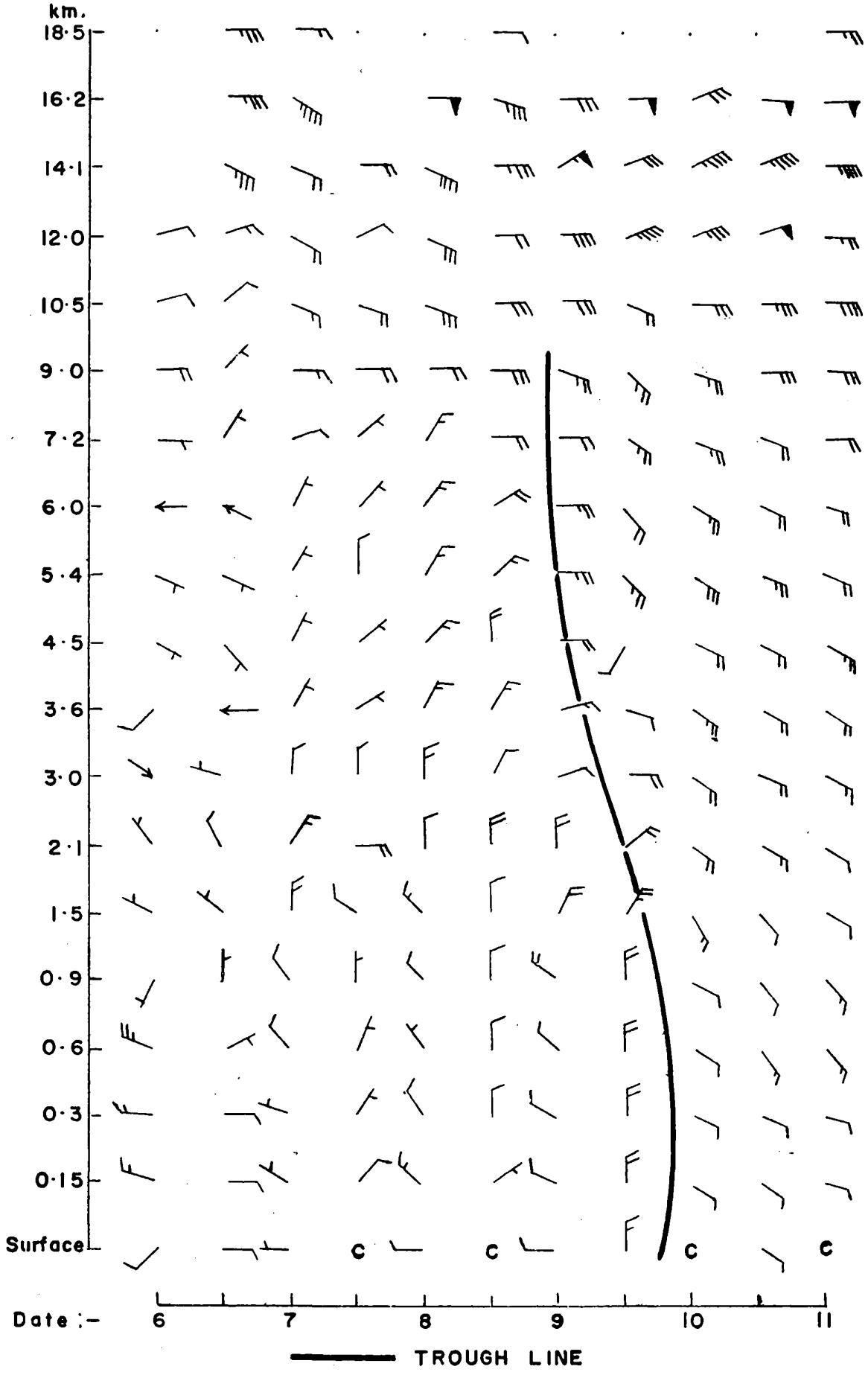
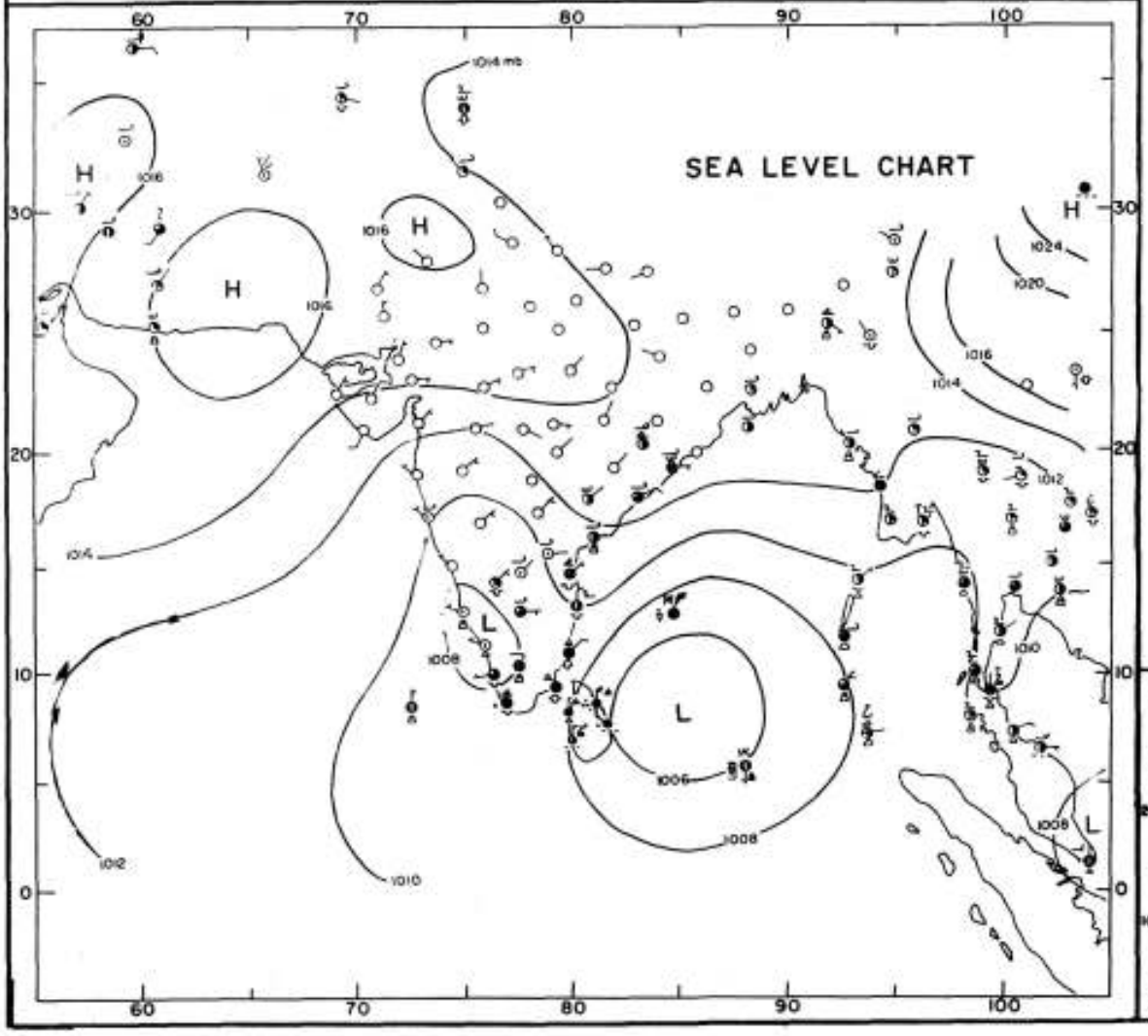


FIG. 17·1 SYNOPTIC CHARTS 1200 GMT 6 DEC. 71



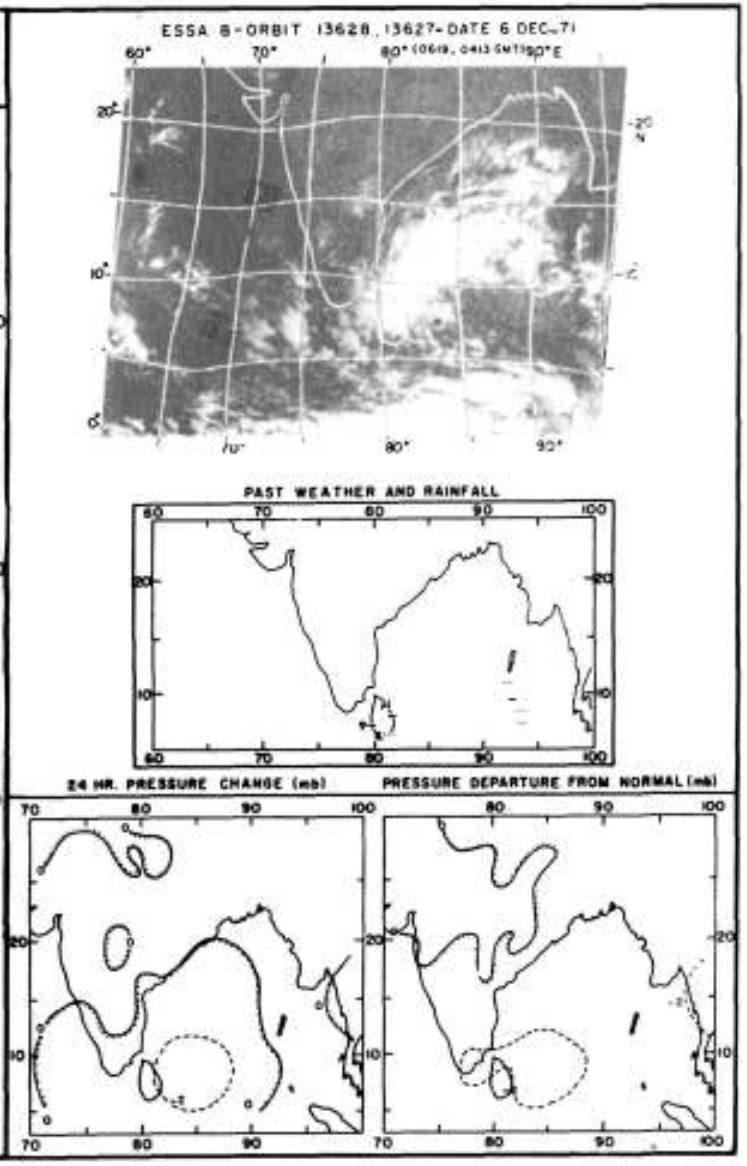
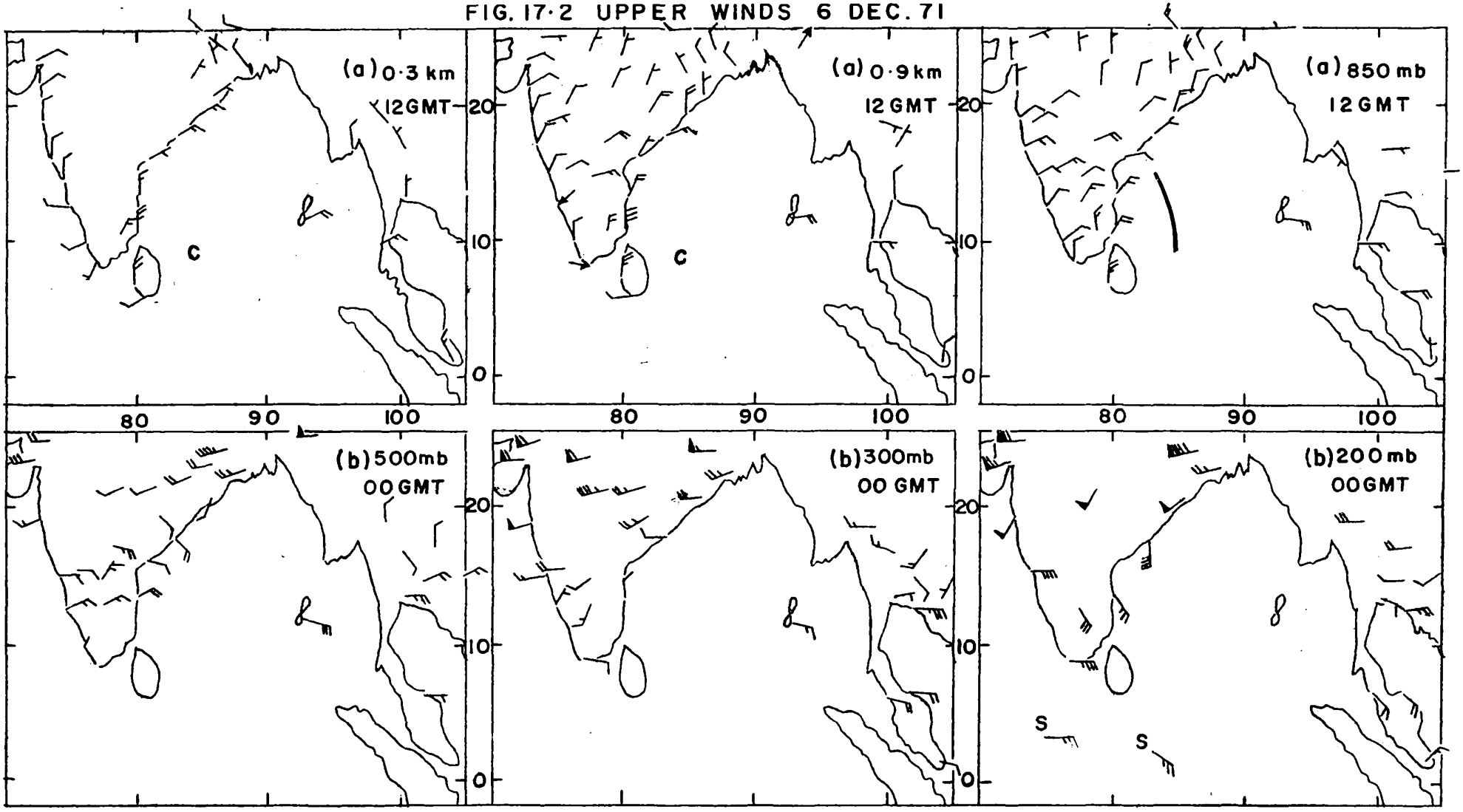
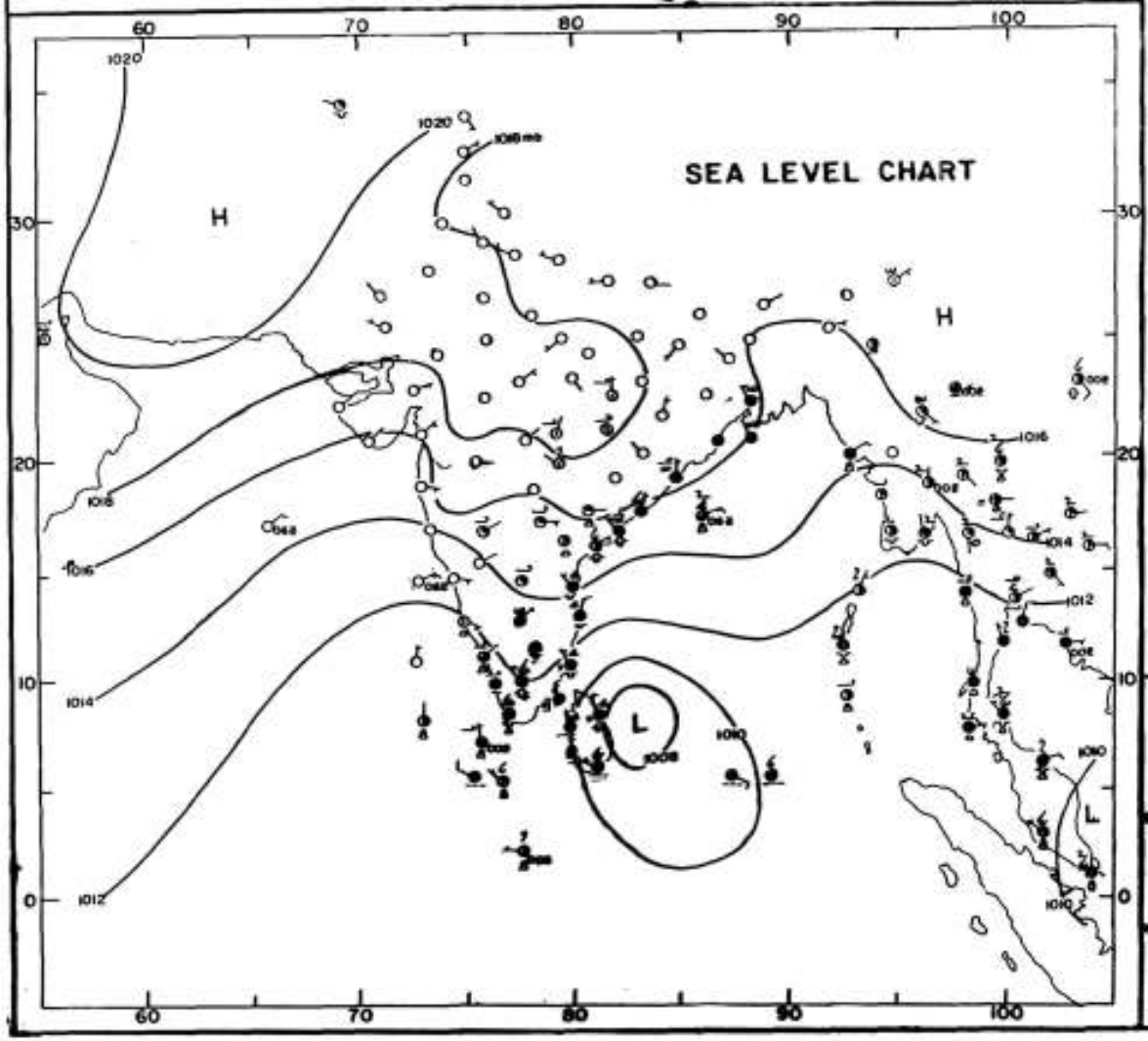


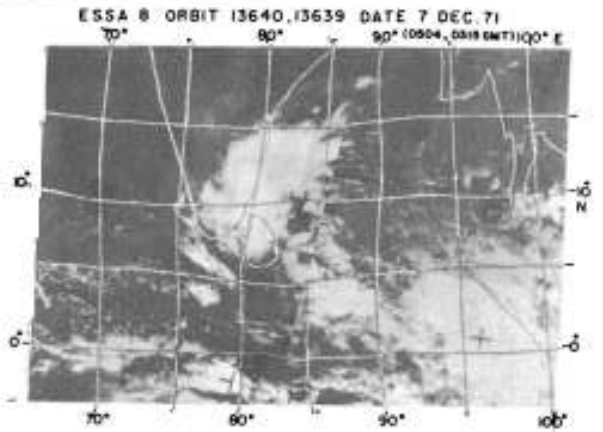
FIG. 17·2 UPPER WINDS 6 DEC. 71

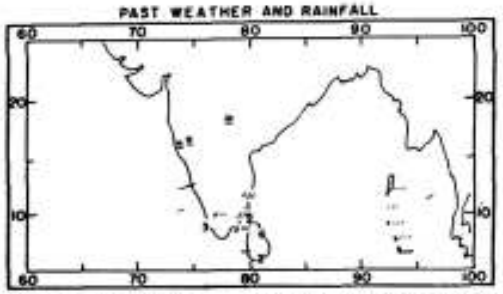


Trough line. C- Centre of cyclonic circulation, S-Satellite Wind

FIG. 17·3 SYNOPTIC CHARTS 0300 GMT 7 DEC. 71







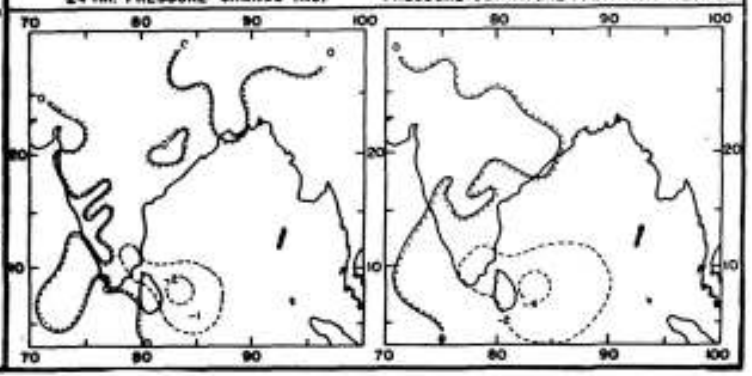
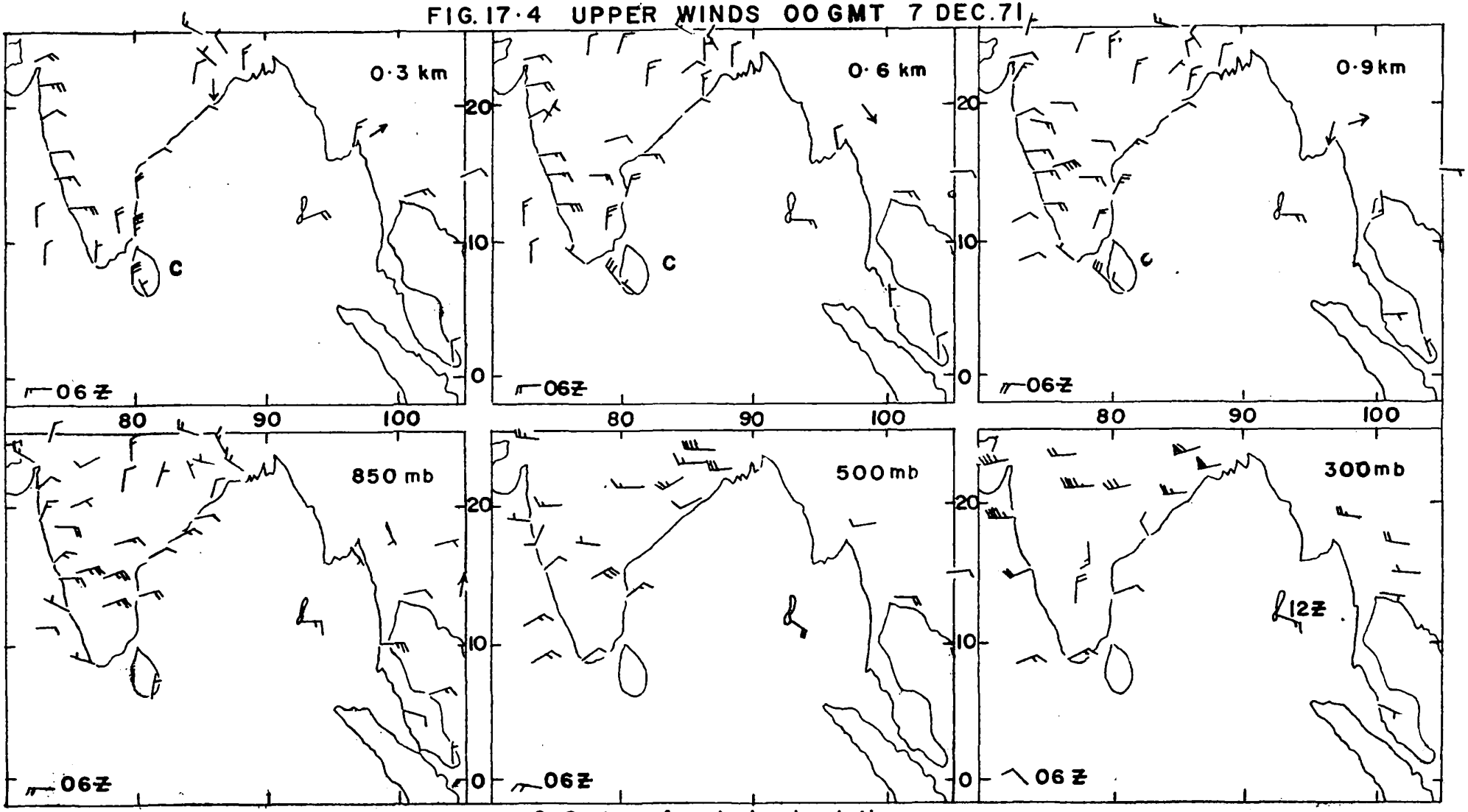
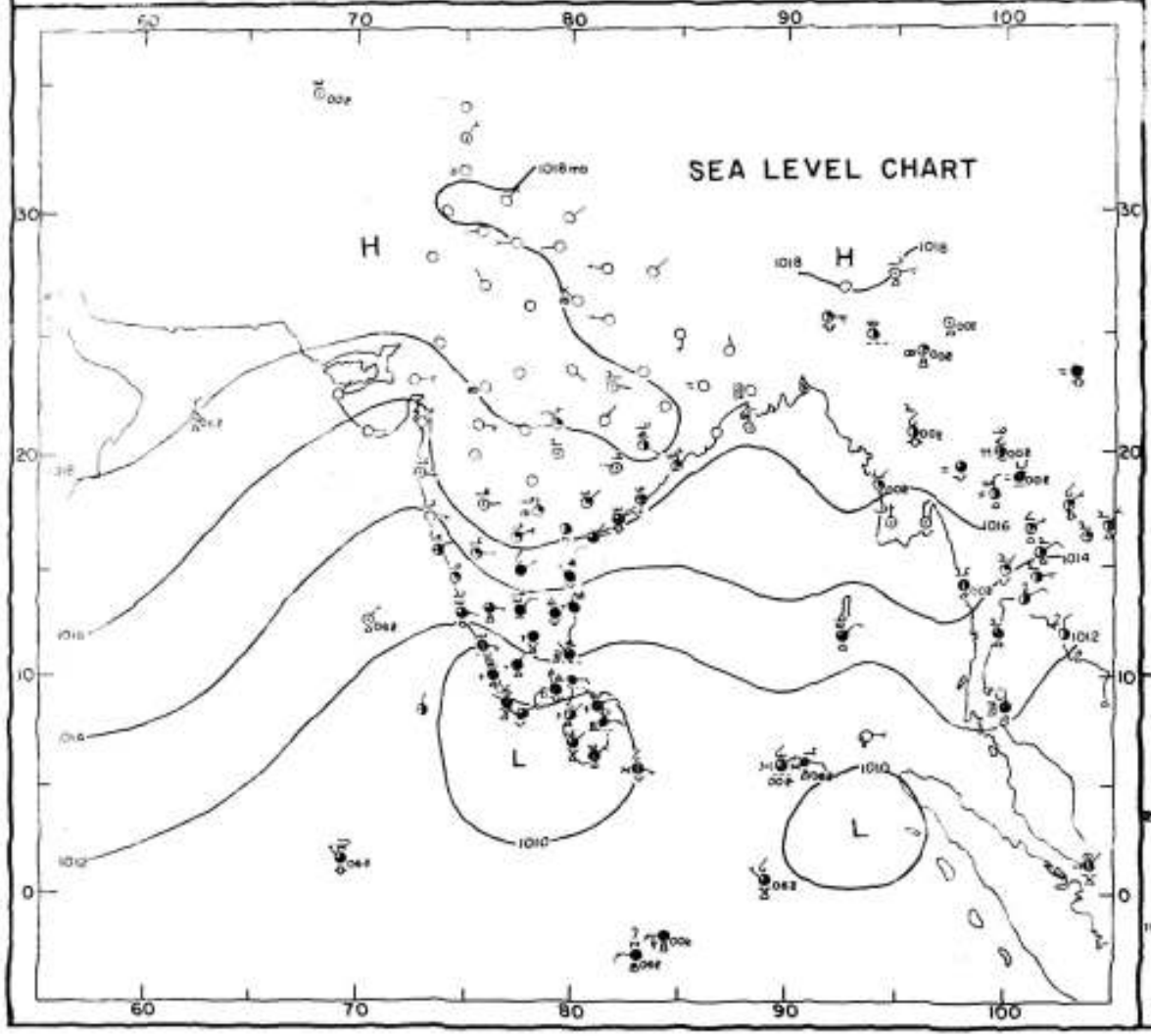


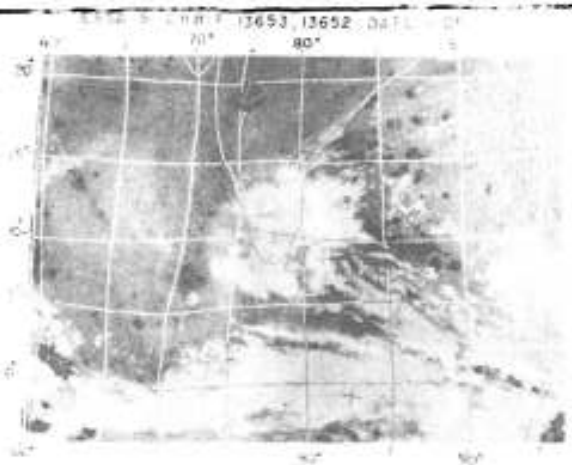
FIG. 17·4 UPPER WINDS 00 GMT 7 DEC. 71

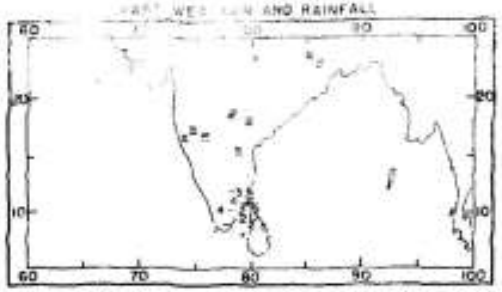


C-Centre of cyclonic circulation

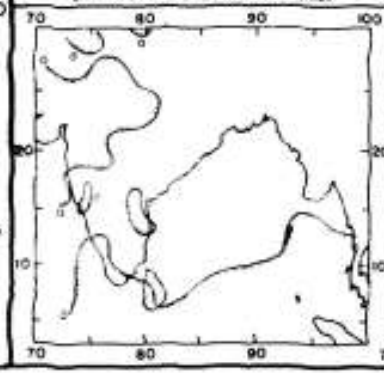
FIG. 17-5 SYNOPTIC CHARTS 0300 GMT 8 DEC. 71







24 HR PRESSURE CHANGE (mb)



PRESSURE DEPARTURE FROM NORMAL (mb)

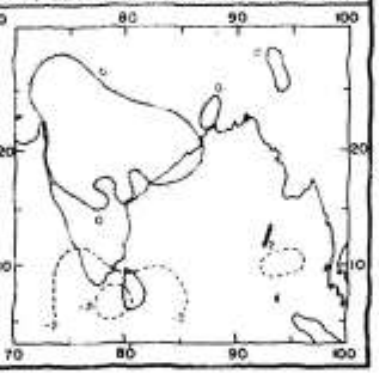


FIG. 17·6 UPPER WINDS 00 GMT 8 DEC. 71

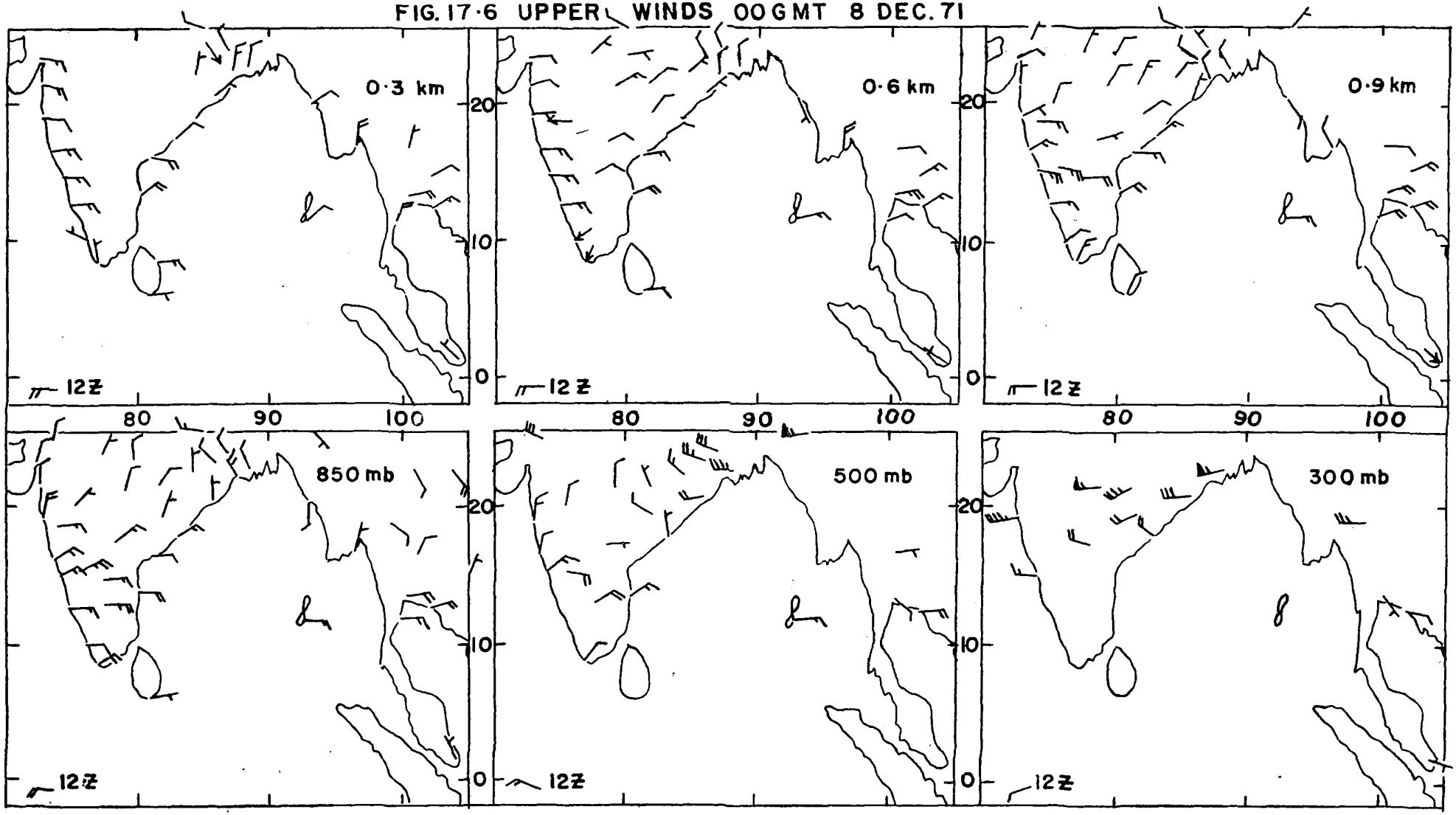
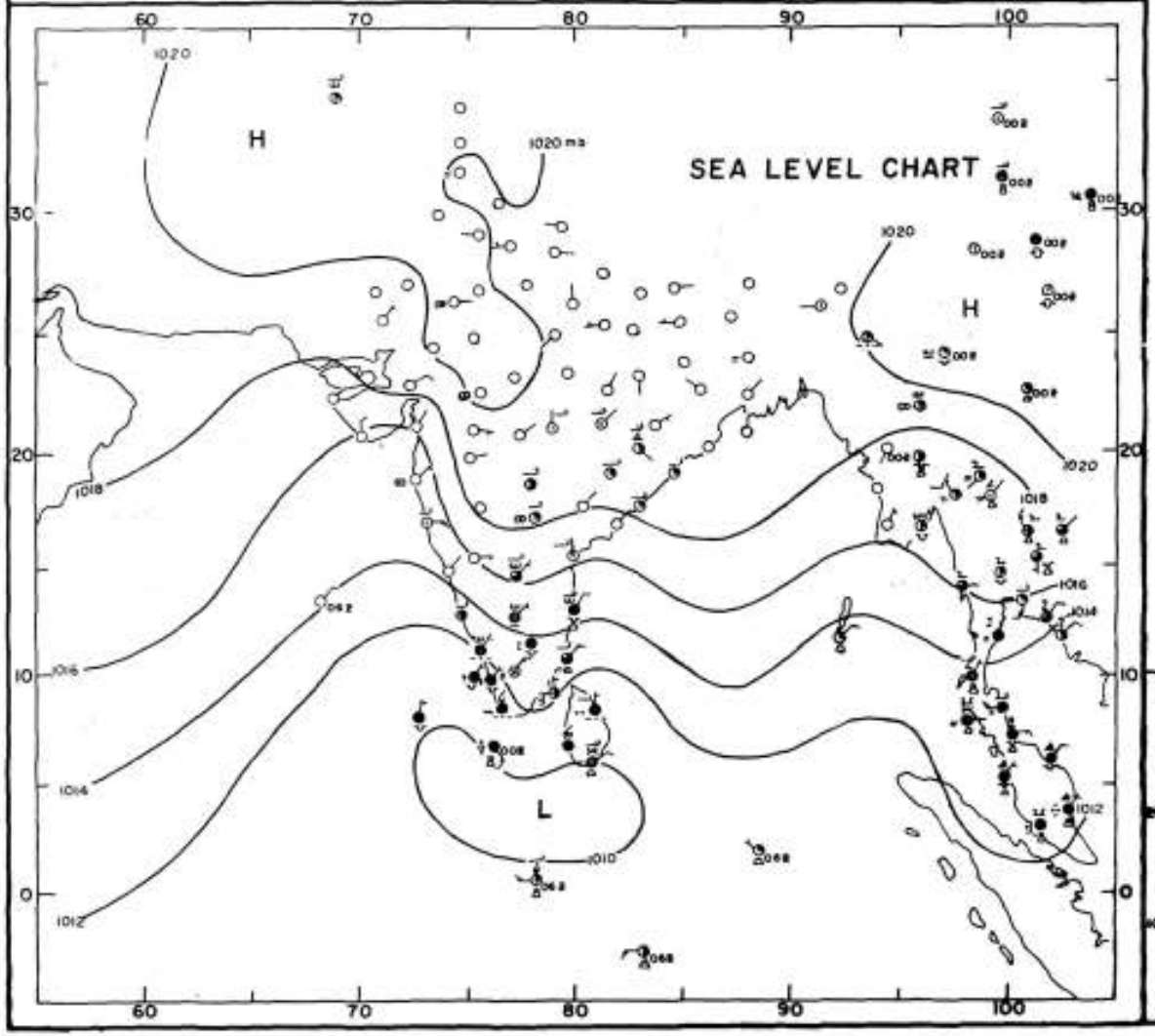
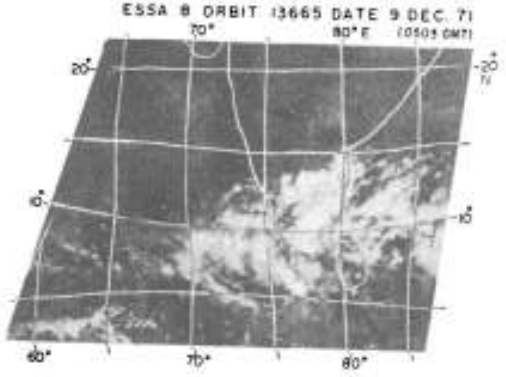
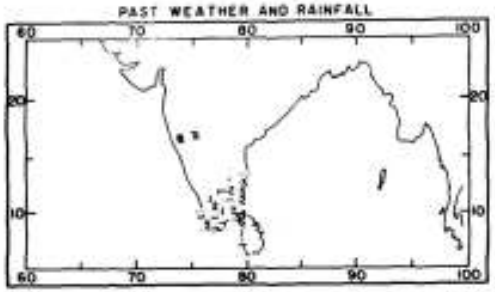


FIG. 17·7 SYNOPTIC CHARTS 0300 GMT 9 DEC. 71







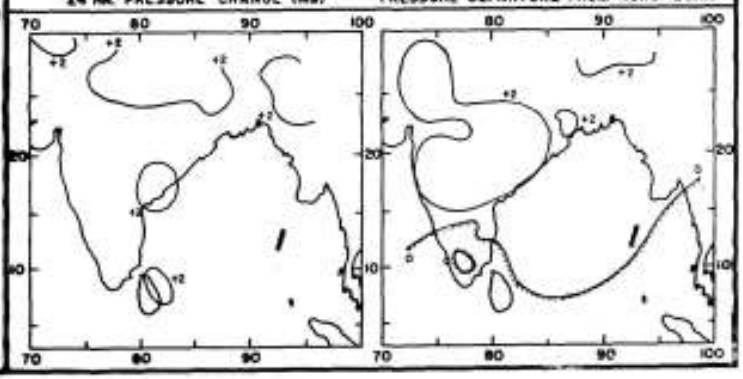
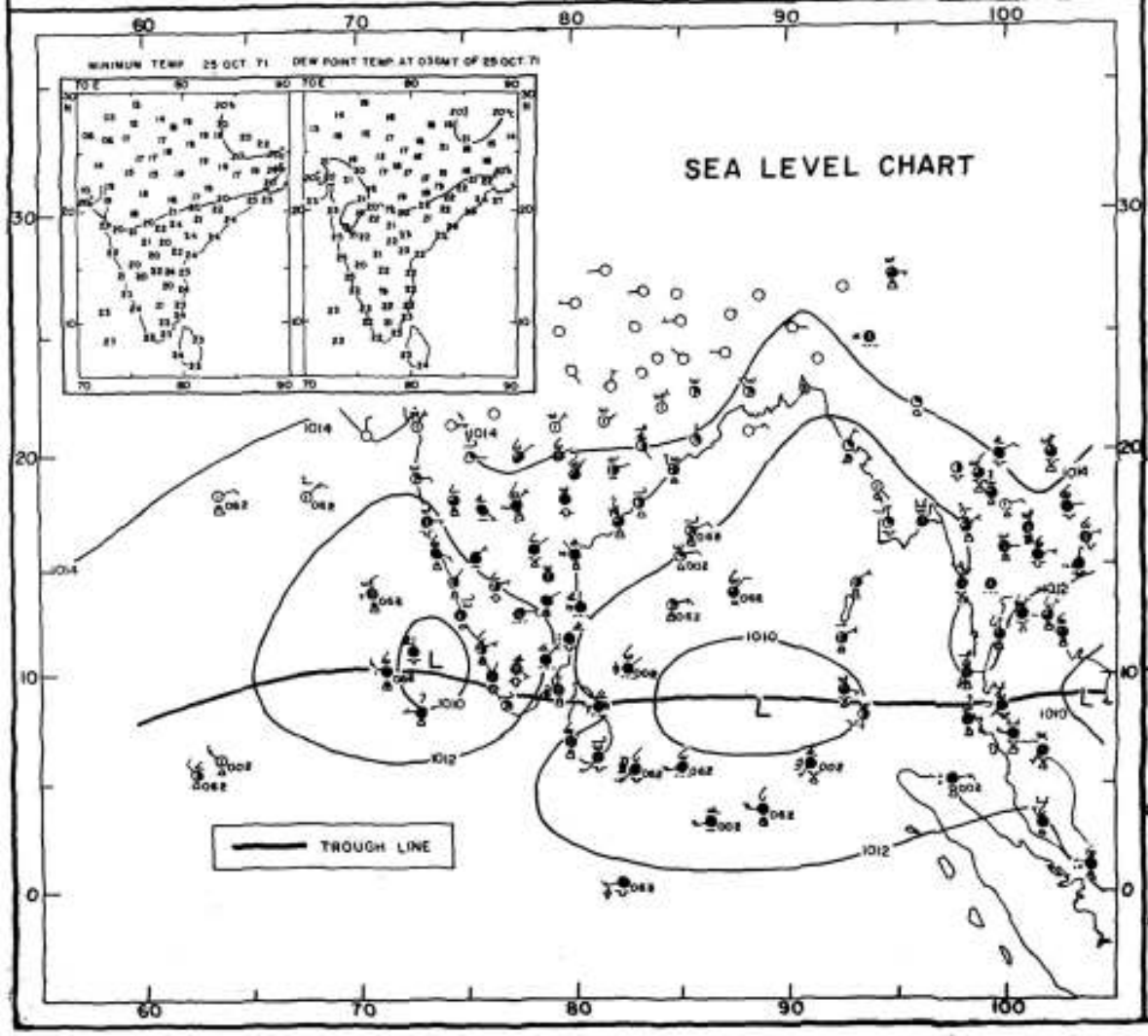
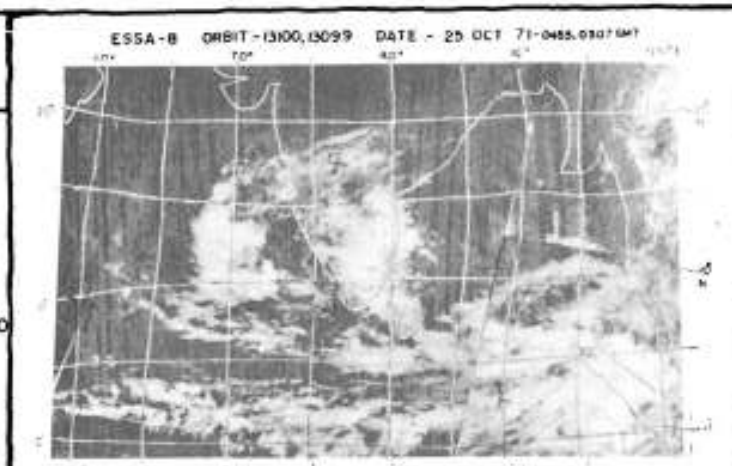
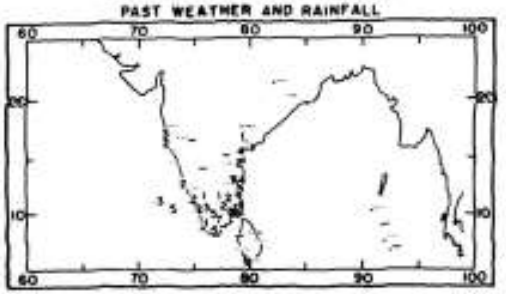


FIG. 18·1 SYNOPTIC CHARTS 0300 GMT 25 OCT. 71





PAST WEATHER AND RAINFALL



24 HR. PRESSURE CHANGE (mb) PRESSURE DEPARTURE FROM NORMAL (mb)

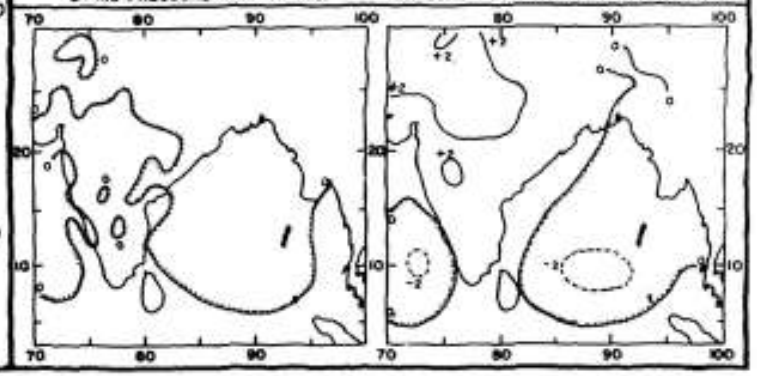


FIG.18·2 SURFACE CHART 0000GMT 25 OCT. 71

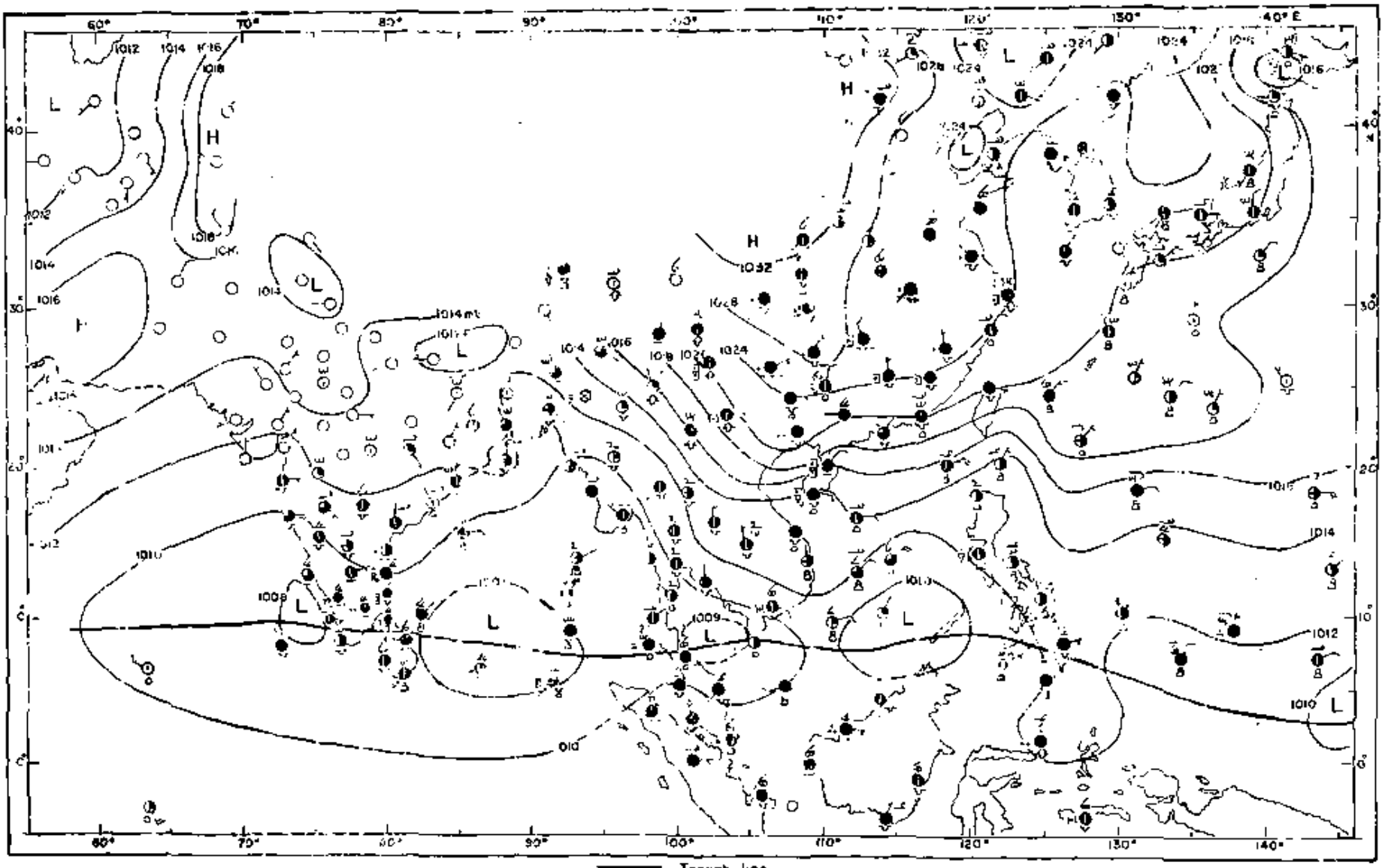


FIG. 18-3 UPPER WINDS 00GMT 25 OCT. 71

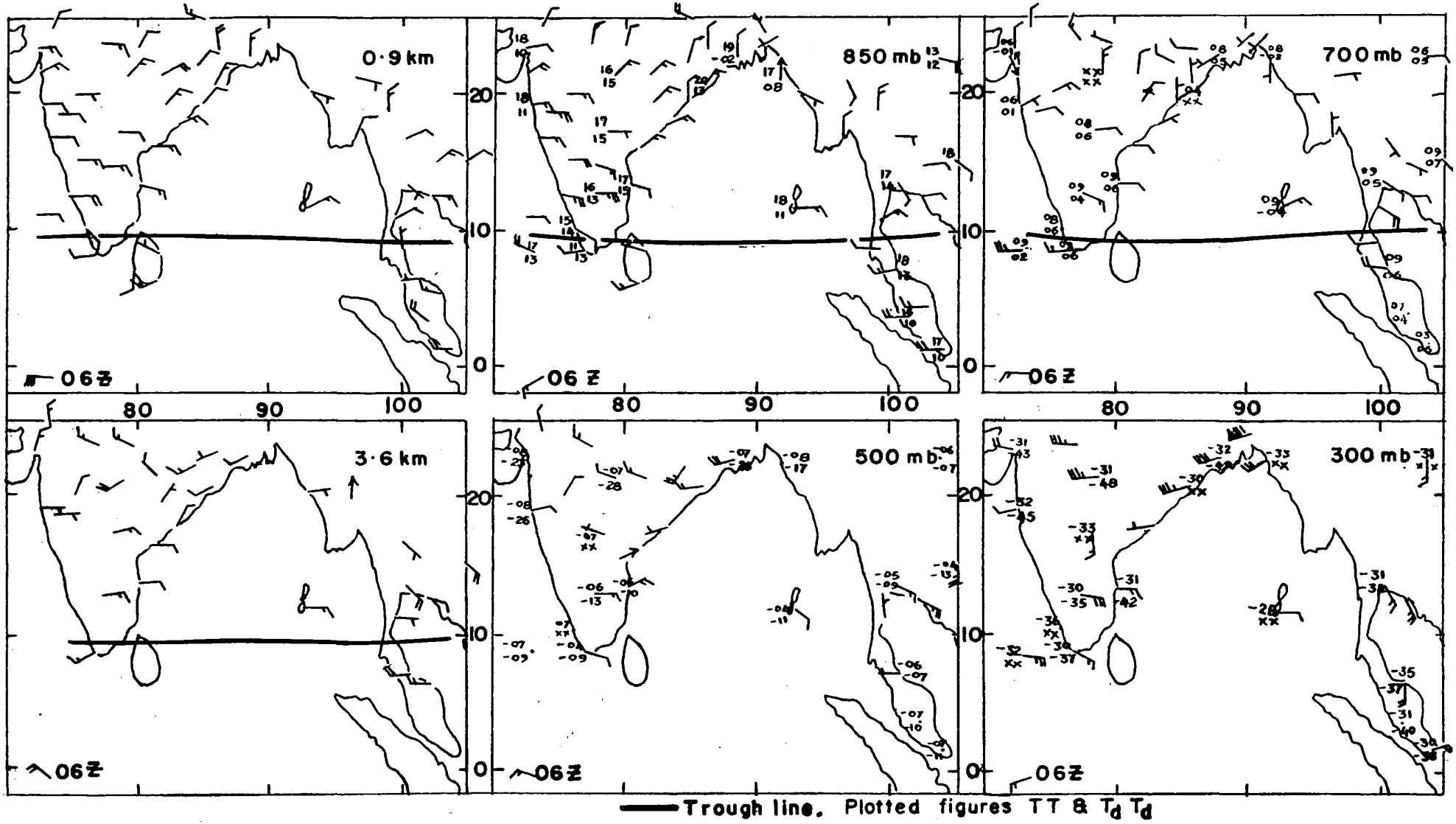
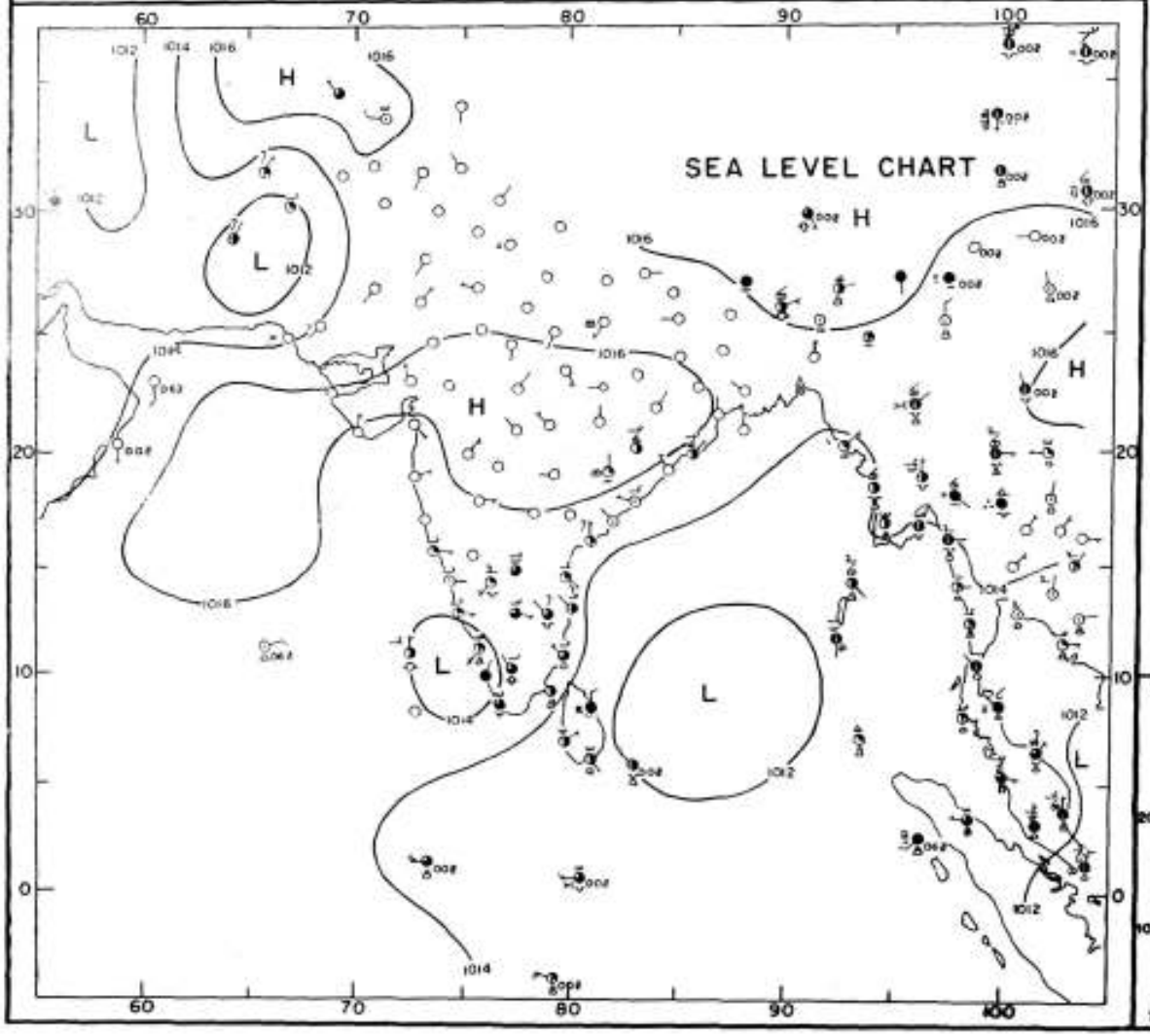
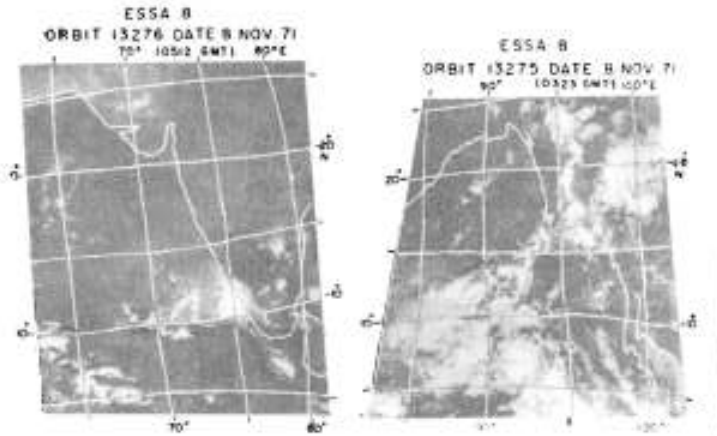
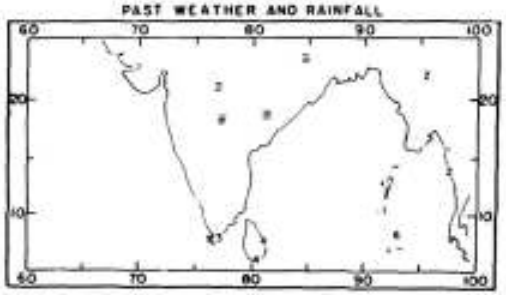


FIG. 19·1 SYNOPTIC CHARTS 0300 GMT 8 NOV. 71







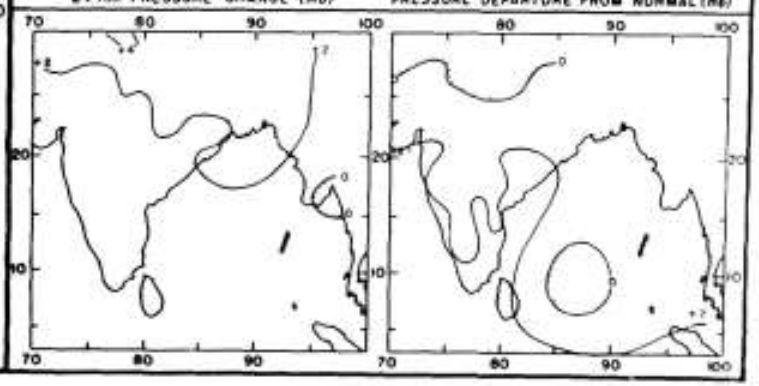


FIG. 19·2 UPPER WINDS 00GMT 8 NOV. 71

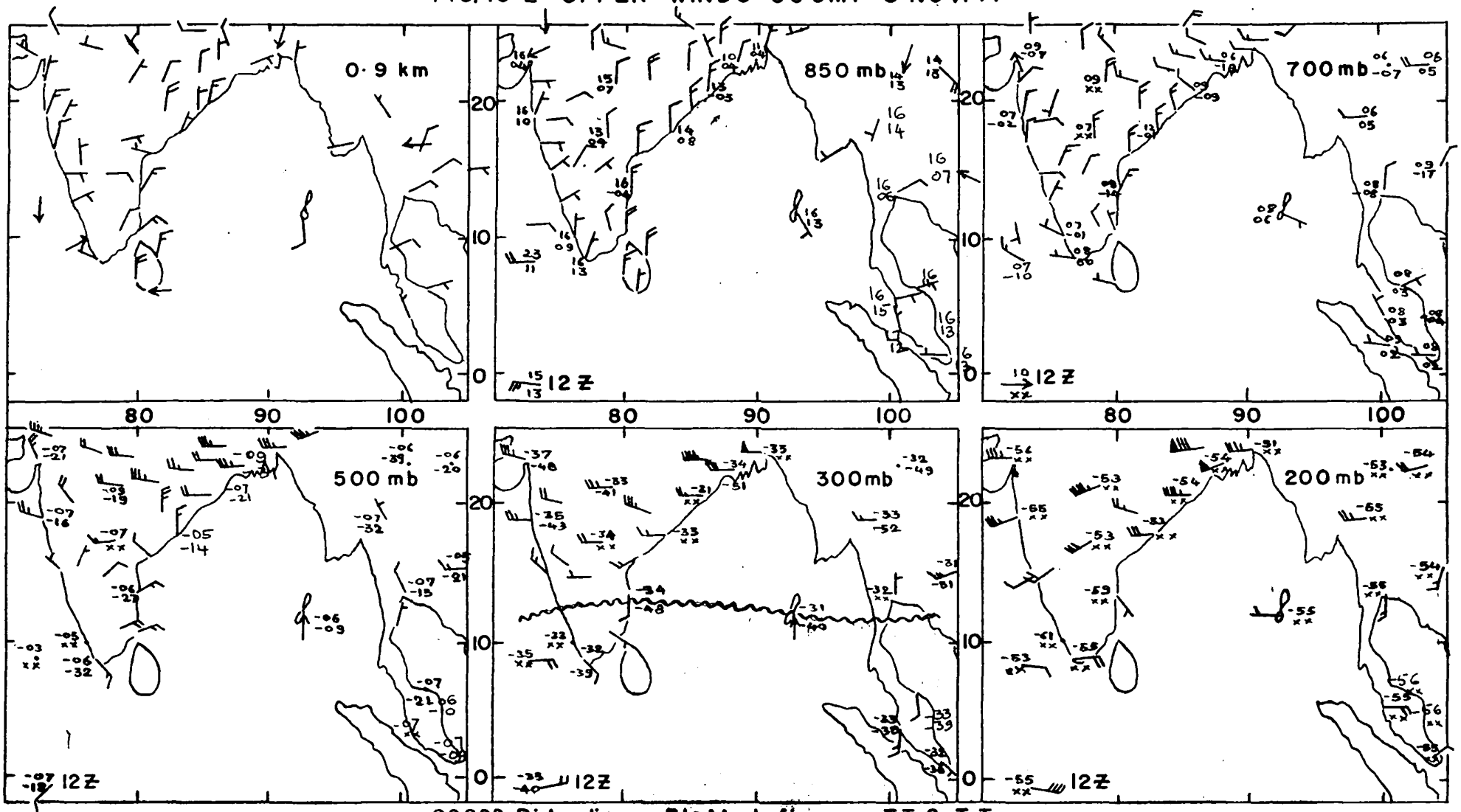
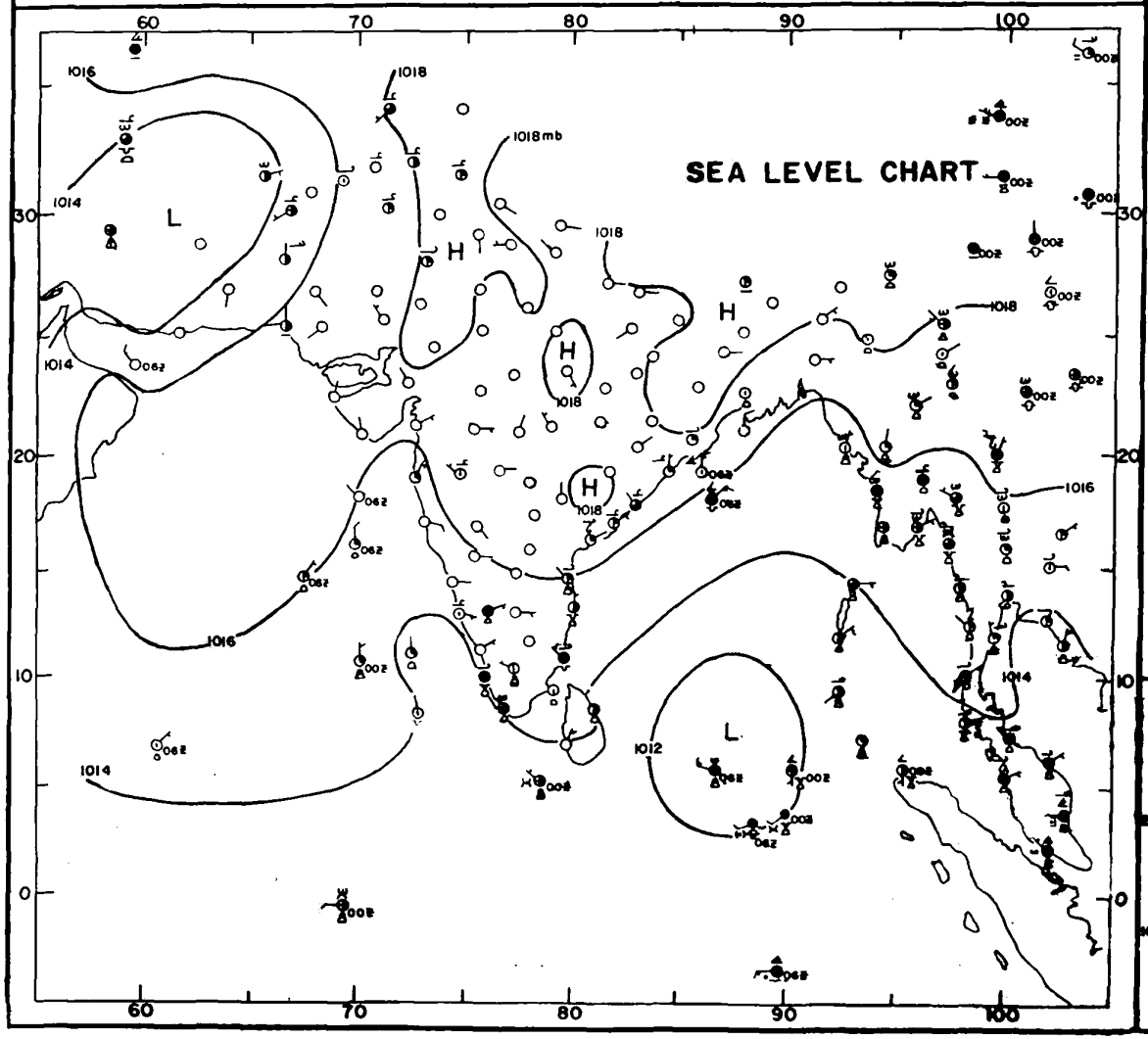
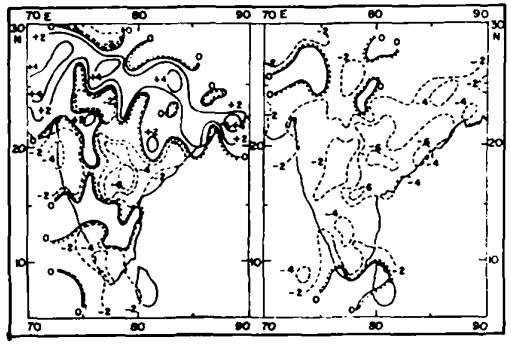


FIG. 19·3 SYNOPTIC CHARTS 0300 GMT 9 NOV. 71

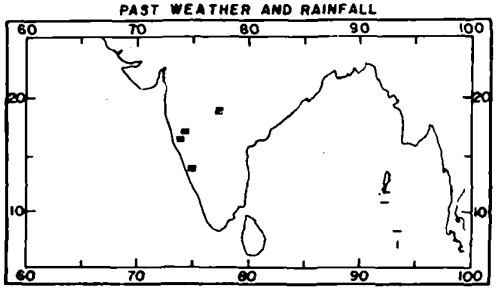


DEW POINT CHANGE FOR 24 HOURS

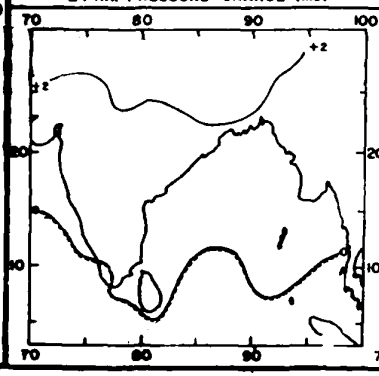


MINIMUM TEMP. DEPARTURE FROM NORMAL

PAST WEATHER AND RAINFALL



24 HR. PRESSURE CHANGE (mb)



PRESSURE DEPARTURE FROM NORMAL (mb)

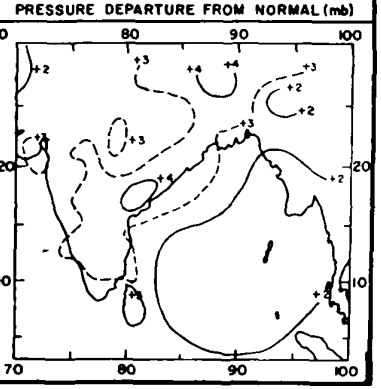


FIG. 19·4 UPPER WINDS 00GMT 9NOV.71

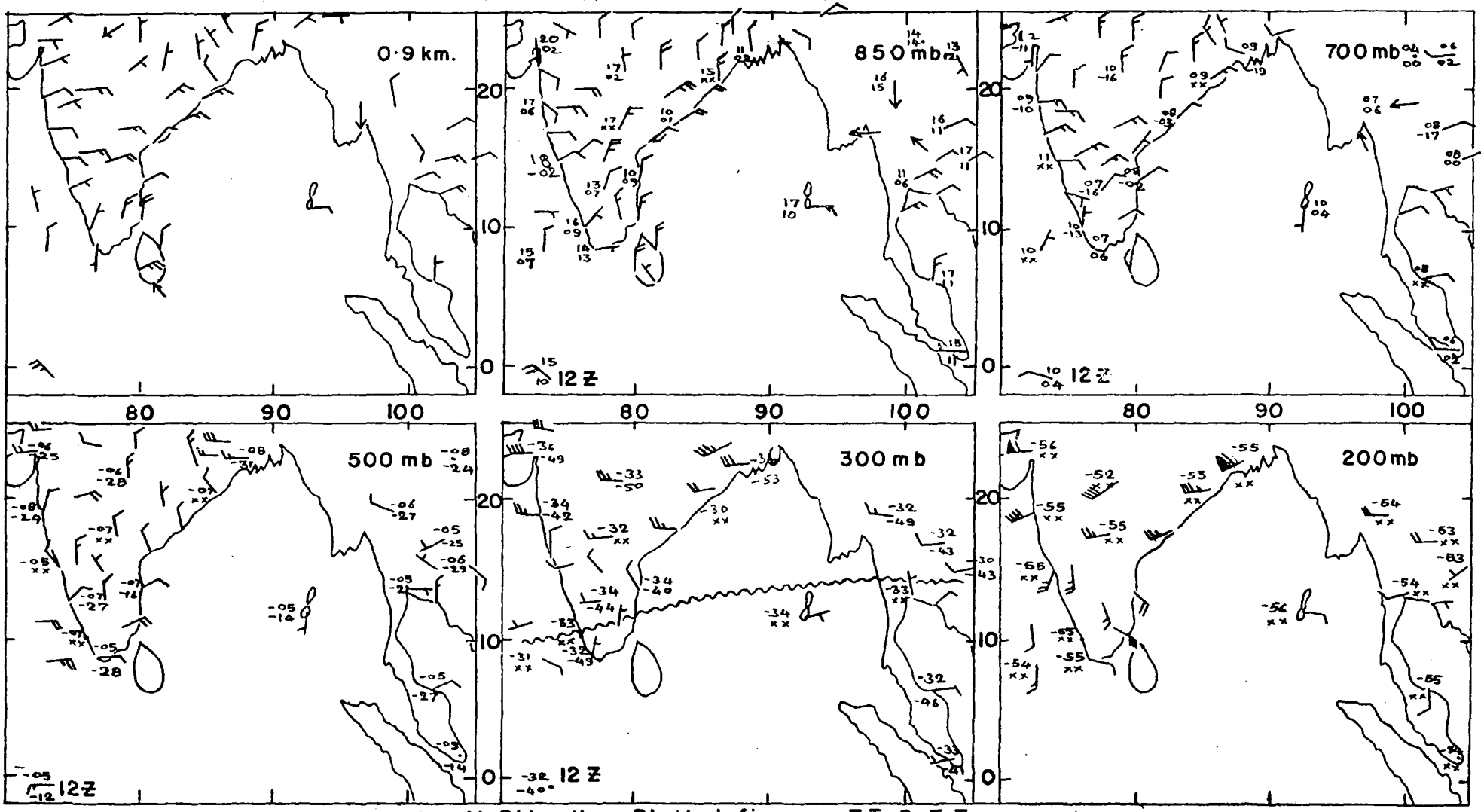
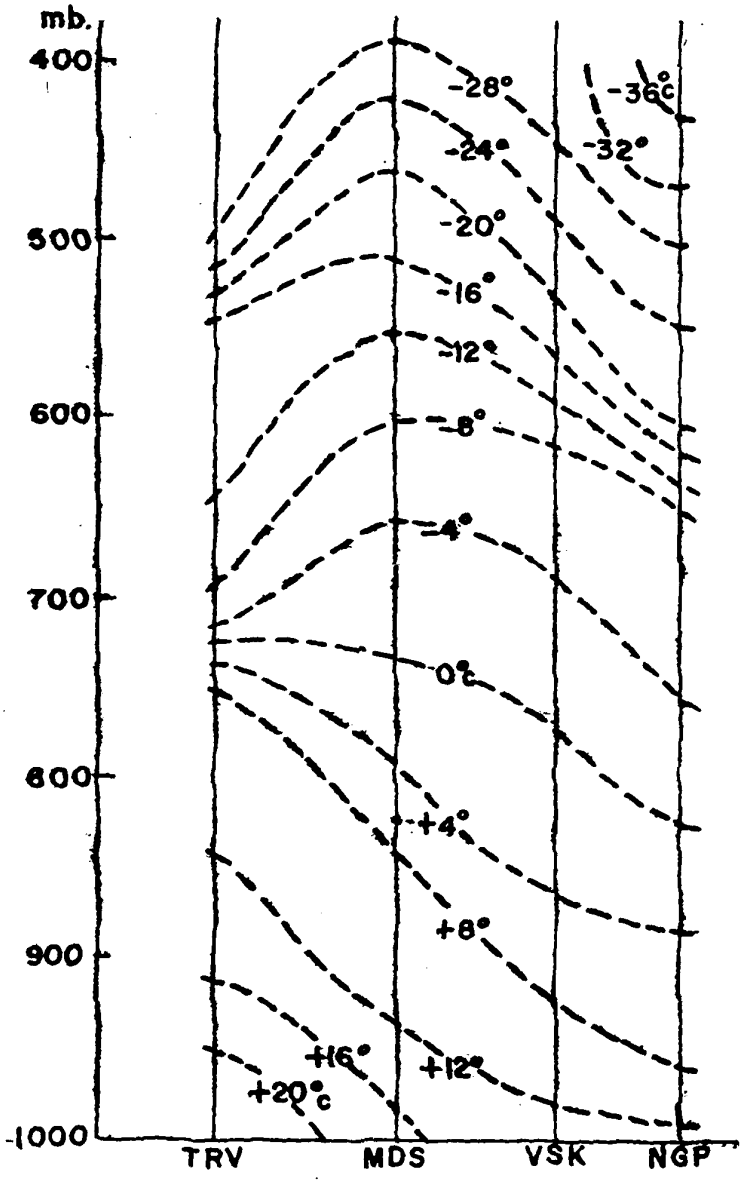


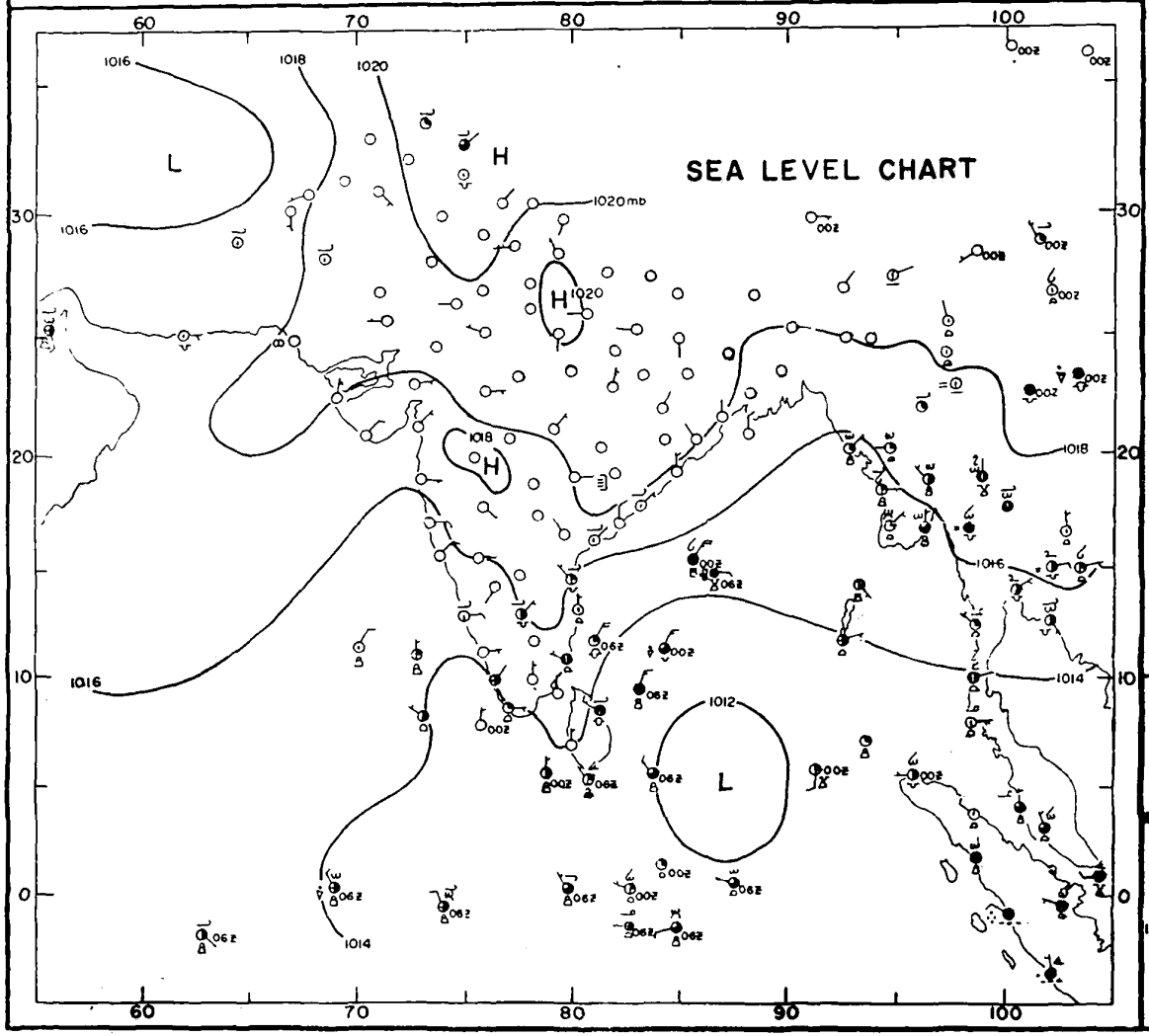
FIG. 19·5 SPACE CROSS-SECTION

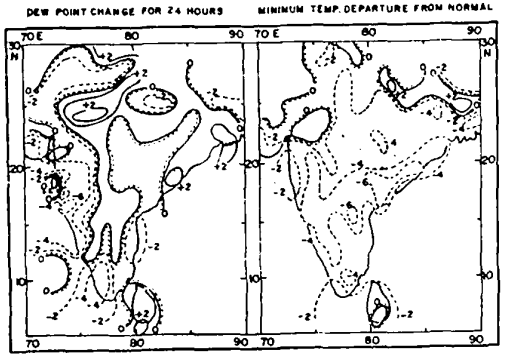
9 NOV. 71 – 00 GMT

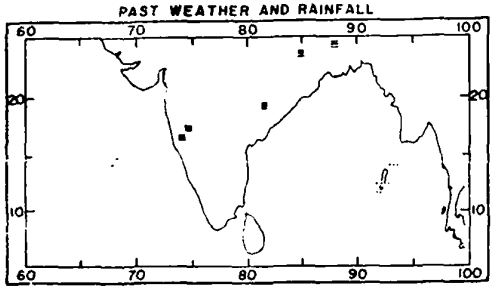


—— Isopleths of dew point temperatures.

FIG. 19·6 SYNOPTIC CHARTS 0300 GMT 10 NOV. 71







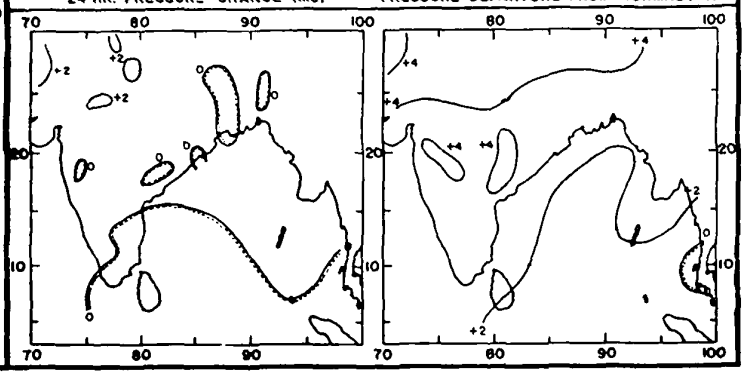
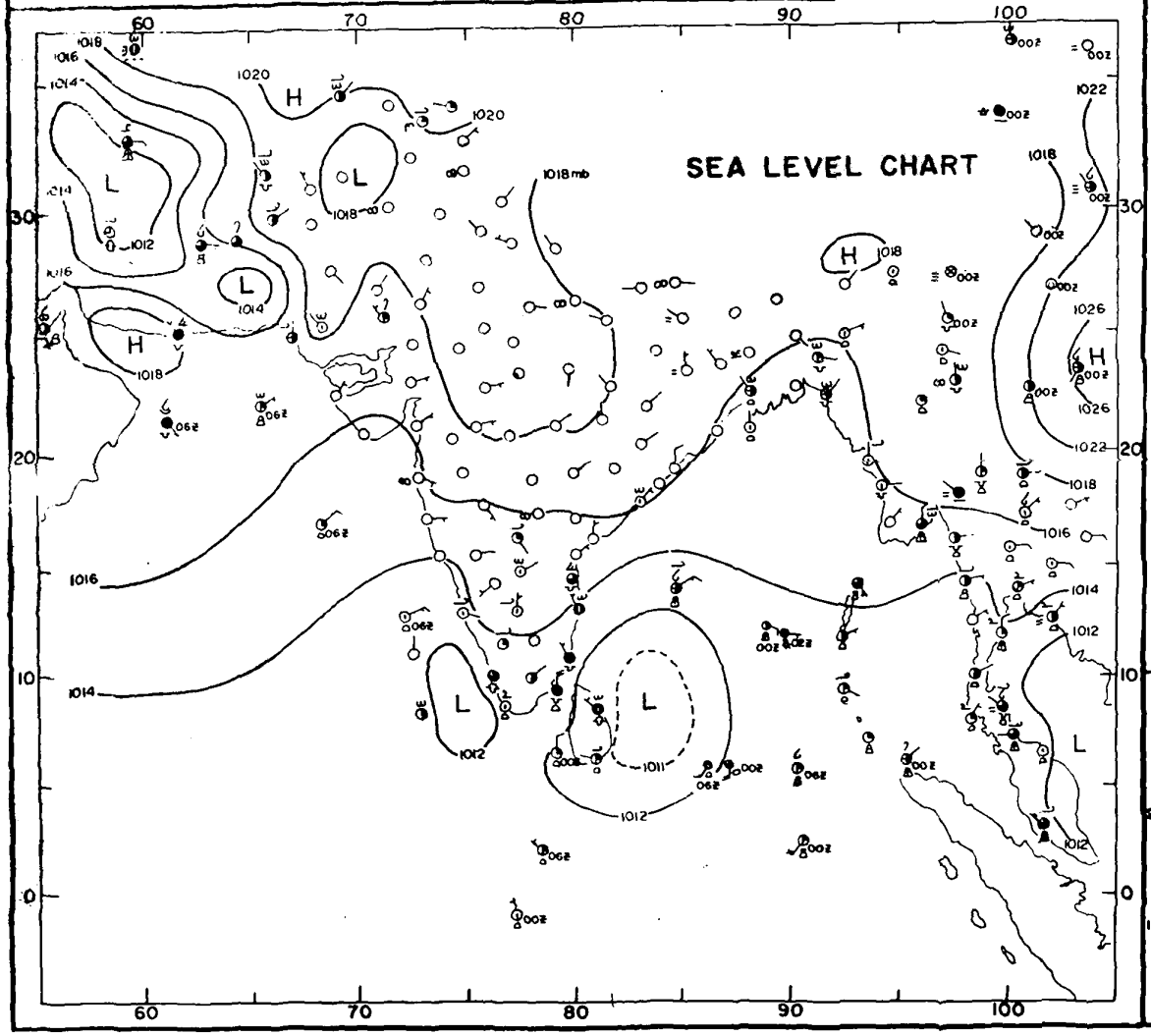
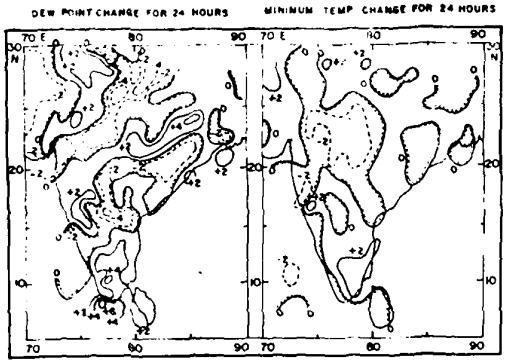
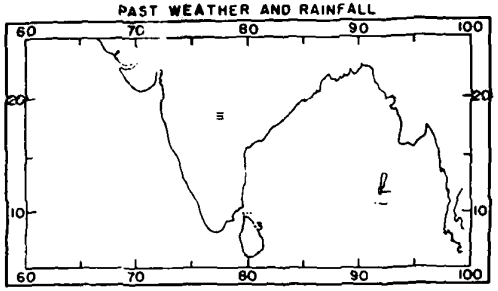


FIG. 19·7 SYNOPTIC CHARTS 0300 GMT 11 NOV. 71







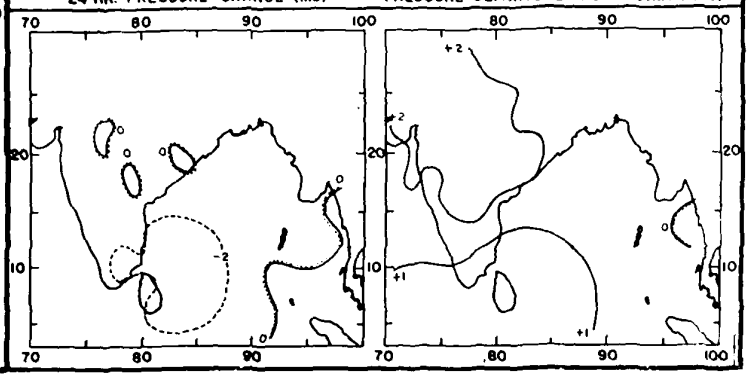


FIG. 19·8 UPPER WINDS 00 GMT 11 NOV. 71

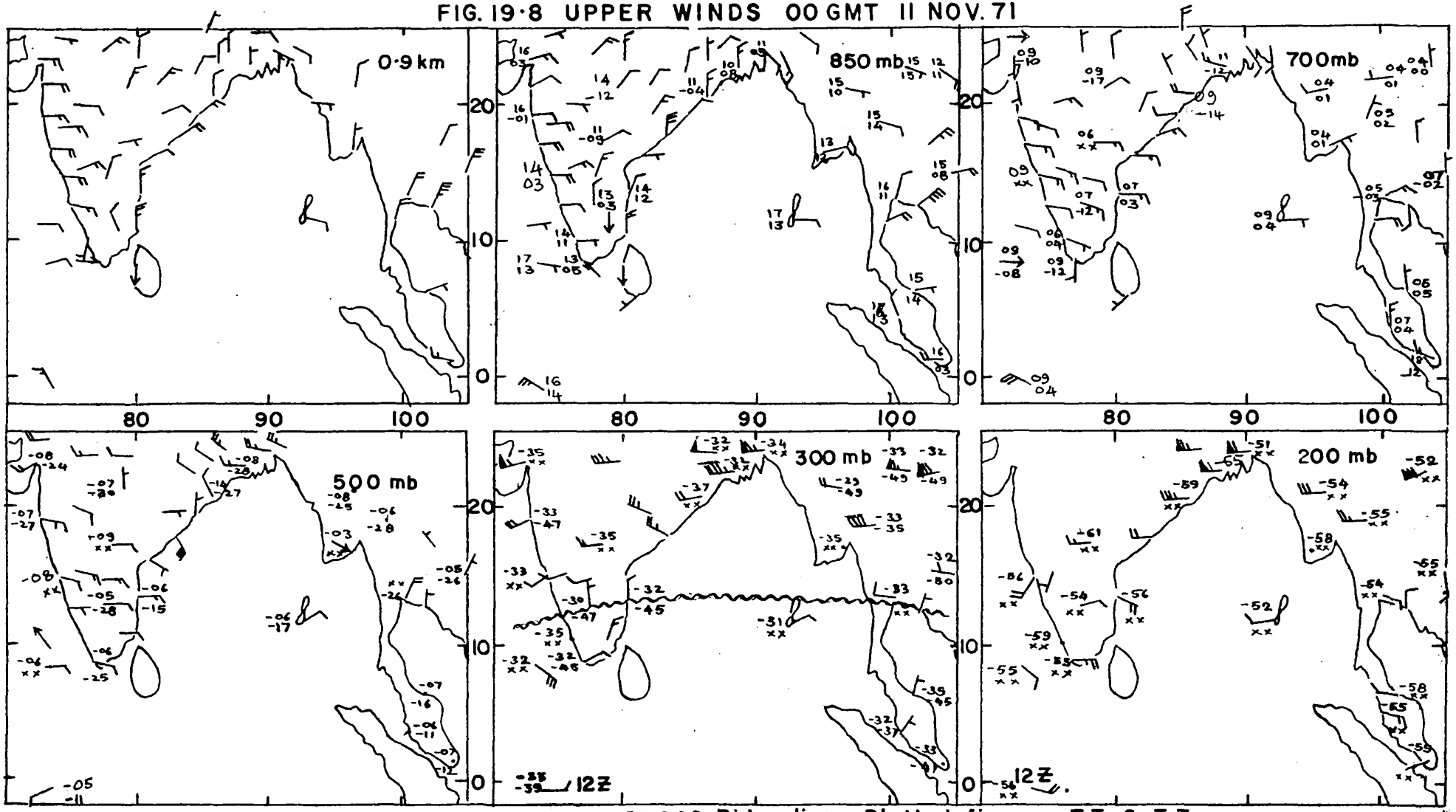


FIG. 19·9 TEPHIGRAM OF BANGALORE & VISAKHAPATNAM — 9 NOV. 1971

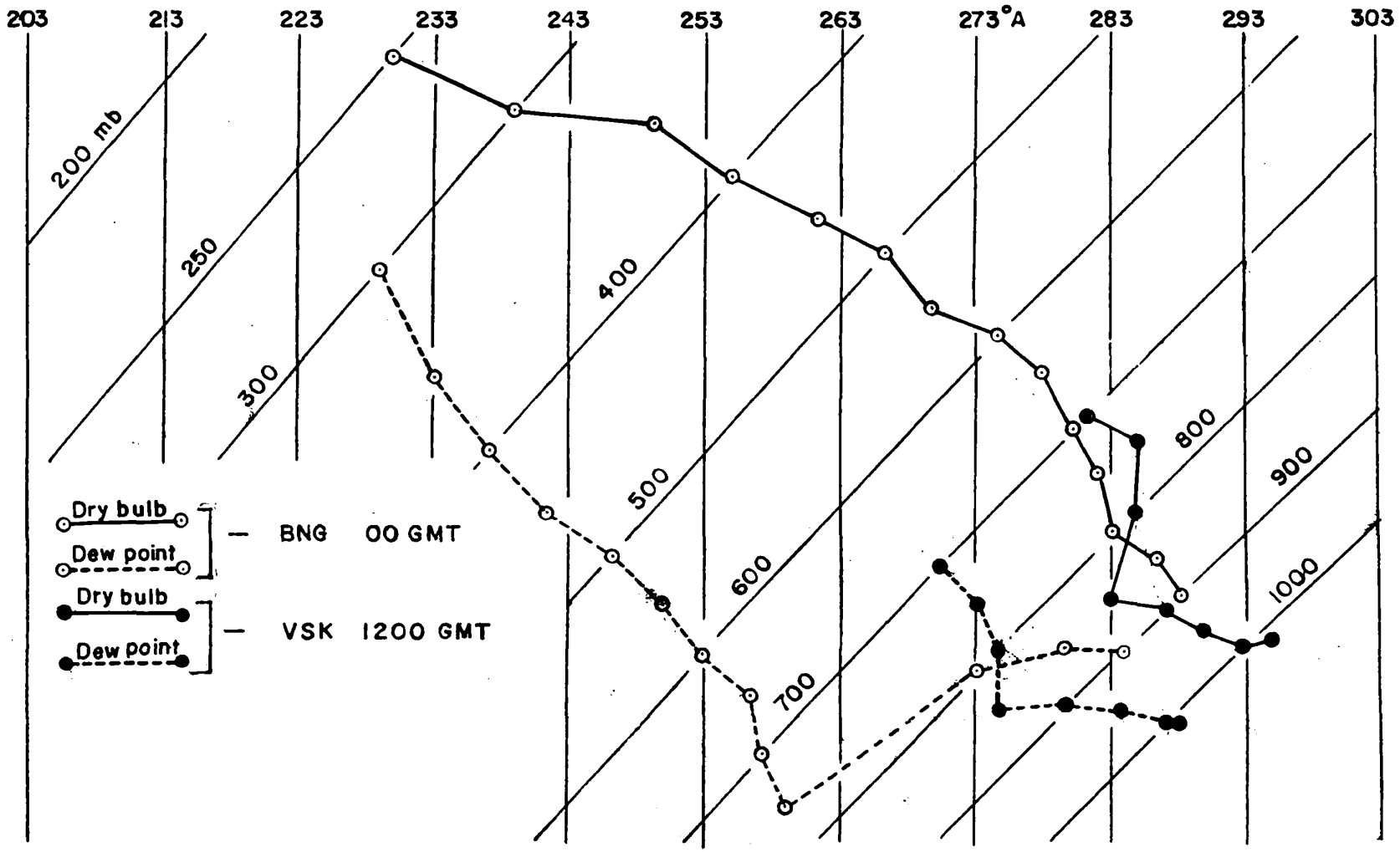
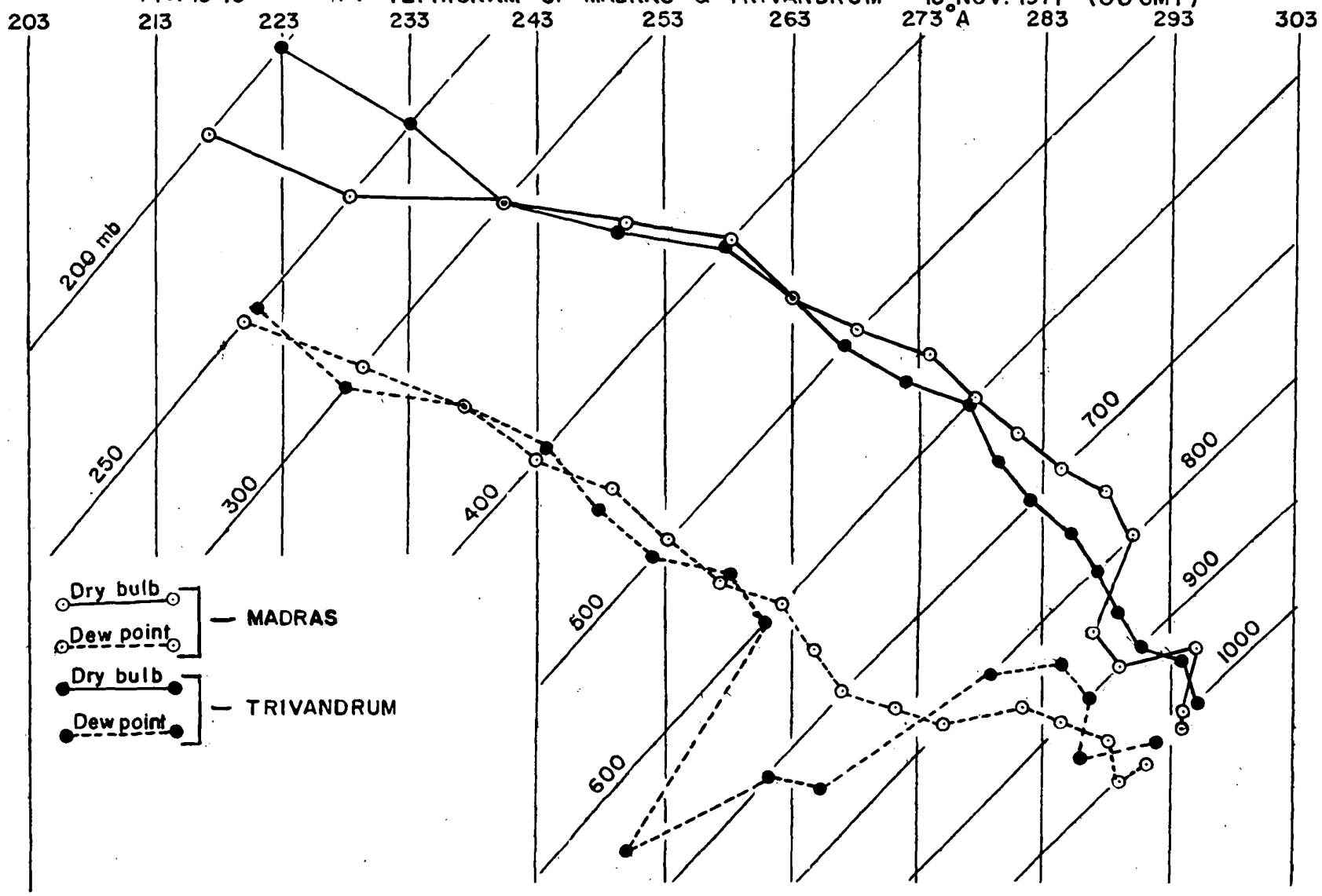


FIG. 19.10 TEPHIGRAM OF MADRAS & TRIVANDRUM — 10 NOV. 1971 (00 GMT)



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