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INDIA METEOROLOGICAL DEPARTMENT

FORECASTING MANUAL

PART III

DISCUSSION OF TYPICAL SYNOPTIC WEATHER SITUATIONS

1.1 : WINTER—WESTERN DISTURBANCES
AND THEIR ASSOCIATED FEATURES

BY

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Part III. Discussion of Typical Synoptic Weather Situations

1.1 Winter - Western Disturbances and their Associated Features

by

Y.P. Rao and V. Srinivasan

1. Seasonal Distribution of Pressure, Rainfall, Thunderstorms and Fog.

1.1 The months of January and February form the winter period. However, for northern India December may also be considered as a winter month. During this season pressure over India increases from south to north as part of the Siberian High. A ridge runs from central parts of the country to the east coast of south peninsula and there are two troughs, one along the west coast of peninsula and another from Tenasserim coast to Assam. In December the ridge runs more into south peninsula than along the coast. None of these pressure systems appears to have a direct bearing on the development of weather over northern and central India.

1.2 Rainfall is more in January and February than in December in the northern and central parts of the country. In December mean monthly rainfall greater than 1 cm is confined to Jammu and Kashmir, Punjab, Haryana, Himachal Pradesh, hills of West Uttar Pradesh and northeast Assam. In January the rainfall not only increases over the above areas but also rainfall exceeding 1 cm extends over East Rajasthan, Uttar Pradesh, Madhya Pradesh and northeast India. From January to February, there is an increase in rainfall by about 1 cm in West Bengal, Bihar Plateau, Orissa, southeast Madhya Pradesh and adjoining Vidarbha and 1 to 3 cm in Assam. There is a slight decrease in Jammu and Kashmir, Punjab, Haryana, southeast Rajasthan, West Madhya Pradesh and the adjoining areas. During all the three months, rainfall decreases southwards from the lower slopes of the Himalayas; there is less rain along the foot-hills of the Himalayas between East Uttar Pradesh and west Assam, than either to the west or east. Significantly, in January and February a rainfall maximum of the order of 2 to 3 cm occurs over northeast Madhya Pradesh and Bihar Plateau; this is due to the formation of induced lows in this neighbourhood. This is also reflected in the mean monthly number of rainy days. The Himalayan ranges of Himachal Pradesh and Kashmir get 4 to 9 cm of rain in Dec; it increases to 12 to 20 cm in January and February. Northeast Assam gets about 6 cm in February. The maximum number of rainy days is along and near Western Himalayas and northeast Assam. They are about 6-11 days per month in Himachal Pradesh and Jammu and Kashmir in January and February and 3 to 6 days in northeast Assam.

1.3 During the winter period, rainfall over northern and central India, particularly the plains, is frequently associated with thunder. In Kashmir and Himachal Pradesh precipitation is not so much associated with thunder. The frequency of thunderstorms is very small in December. It is about one day in a month in December (which is the maximum) in the hills of West Uttar Pradesh. It is 0.5 day per month, in Punjab, Haryana, Himachal Pradesh, West Uttar Pradesh and adjoining East Rajasthan, West Madhya Pradesh, southern parts of East Uttar Pradesh and North Assam. In January, there is a slight increase in the thunderstorm activity and the isoline of one day covers Punjab, Haryana, Himachal Pradesh, Uttar Pradesh, north Madhya Pradesh and Bihar Plateau, with a small area of two days over north Madhya Pradesh and hills of West Uttar Pradesh. February is similar to January, except that there is an increase in the frequency to three days over northeast Assam and the frequency of one day per month extends to north Orissa and Gangetic West Bengal. The duststorm frequency is very insignificant during the winter.

1.4 The number of days when different parts of the country are affected by synoptic systems likely to cause rain or thunderstorms is more than the number of days of rain or thunderstorm at any station. Not all stations in an area get rain at the same time even when affected by appropriate synoptic systems.

1.5 Though fog is infrequent over India considering the whole year, northern India is most susceptible to morning radiation fog in winter. Assam valley and Gangetic West Bengal have the highest frequency. In parts of the Assam valley there are more than twenty days of fog in each of the months, December and January. Fog statistics at many Indian observatories are under-estimates as by the usual time of observation of 0830 IST (03 GMT) fog would have dispersed and the earlier phenomenon may not have been carefully observed.

2. Western Disturbances

2.1 During winter cloud and precipitation belts are seen to move from west to east over northern India. The cause of these cloud and precipitation systems came to be referred to as "western disturbances". The adjective "western" implies that the disturbances approach from the west, in contrast to most of the rain-giving systems in the principal rainy season approaching India from the east. At present the term "western disturbance" is applied to low or trough either at surface or in upper air in the region of westerly wind regime (north of 20°N) while clouds and rain are occurring. In the absence of clouds and rain it is more usual to refer to them as troughs. When two or more closed isobars at 2 mb interval can be drawn on the sea level chart, the disturbance is described as a "western depression". (See Appendix I and II for Departmental Circulars on the subject.)

2.2 The usual sequence of precipitation with western disturbance is first over Jammu and Kashmir and even Himachal Pradesh, Punjab and Haryana and the next day over East Rajasthan and West Uttar Pradesh as well. Many times rainfall may cease at this stage. In other cases, rainfall now commences over Madhya Pradesh and during the following two days (though not always) spreads to East Uttar Pradesh, Bihar, Orissa, West Bengal and Assam while it stops to the northwest. This is the broad pattern of synoptic development of rainfall belts though wide variations are possible. The main point to note in this sequence is that precipitation commences north of Lat. 30°N and may stop with it. Next it develops between 26°N and 30°N to the west of 80°E. If precipitation now starts in the area near about Lat. 24°N Long. 80°E, it can spread to the east. Even with disturbances which do not affect northwest India south of Lat. 30°N, North Assam sometimes gets precipitation two to three days after the western disturbance has caused weather over the western Himalayas.

2.3 In this season depressions or troughs are known to move in an eastnortheasterly direction across southern Russia, Turkey and Iran and occasionally even further south. Areas north of Lat. 30°N may lie at the periphery of these systems which accounts for the first rainfall there. Weak circulation now develops over Rajasthan and neighbourhood which causes the second rainfall belt. Either with the slow shift eastward (or more correctly eastnortheastward) and extension southwards, of this system or by independent development, a weak low or trough may appear over Madhya Pradesh which is associated with the third rainfall belt. Weak low pressure systems may also form over Gulf of Cambay and neighbourhood, which while moving in an easterly direction affect the weather over Gujarat and north Maharashtra States. However such 'lows' are very rare.

2.4 In earlier days, the system first affecting Kashmir used to be referred to as the "primary western disturbance" and those developing south of Lat. 30°N as "secondaries". However, the current practice is to call the systems that develop over Rajasthan, Madhya Pradesh etc. under the influence of disturbance moving further north across India or West Pakistan, as 'induced lows'. The terms 'primary' and 'secondary' are no longer in use. The western disturbances are mainly lower tropospheric systems which show variations in strength and vertical extent with superposition of mid- and upper tropospheric troughs in westerlies. Movement of 'induced lows' is very slow - five degrees in a day, sometimes much less. Faster movement occurs under the influence of mid- or upper tropospheric trough. In a general way it may be said that 'induced lows travel relatively faster to the east of Long. 85°E. When they reach Assam or Sub-Himalayan West Bengal, they become very diffuse. Life period of a simple sequence of a western disturbance is two to four days, induced lows tending to fill up within that time. Longer periods of disturbed weather occur over northern India, even upto ten days, if a fresh western disturbance from west comes over India while the induced low of the previous disturbance has not decayed. In such situations trough line complex may develop extending to even south of 20°N and cause extensive rainfall over the country. Western disturbances causing rainfall over Punjab or Uttar Pradesh seem to come in succession at intervals of 2 to 5 days while they last. At other times, it is usual for periods of one to two weeks to be continuously free from such western disturbances in any month. Roughly on one half of the occasions, the activity of western disturbances is confined to Jammu and Kashmir, Himachal Pradesh, Punjab, Haryana and the hills of West Uttar Pradesh, while during the remaining spells the weather extends to the south also. On an average there are six to seven disturbances per month (including the induced lows) moving across India during the winter. A depression in South Bay of Bengal or Arabian Sea seems unfavourable for activity of western disturbances over northern India.

2.5 The average numbers of low pressure centres per month on the surface chart over Europe and Asia in every five degree square are shown in Fig. 2.1; these were calculated from the northern hemisphere charts published by the USSR in which the isobars have been drawn at 5 mb interval and centres of lows have been indicated. The charts for five winter periods (Dec., Jan. and Feb.) were looked into and the data collected. The water surfaces of Mediterranean Sea, Black Sea, Caspian Sea and Lake Balkash form a zone of cyclogenetic regions. Of immediate interest to India is the cyclogenetic region over Caspian Sea and Aral Sea areas. The southward extension of the 1.0 and 0.5 isopleths towards

Iran and adjoining Baluchistan would suggest that the lows forming over Caspian Sea and Aral Sea areas have a tendency to induce fresh lows to the south. The southwest-northeast run of the 0.5 isopleth from north Baluchistan to Lake Balkash shows that the lows either weaken as they approach the seasonal high over east Asia or have a tendency to be steered around the periphery of the high. Formation of the induced lows over north India and their movement eastwards are indicated by the appearance of a maximum over the area. Features of western disturbances are further discussed below by presenting some case studies.

3. Western Disturbance, 15 - 19 December 1961.

3.1 The western disturbance from 15th to 19th December 1961 which caused precipitation over northern and central parts of India is now discussed to illustrate the various features of western disturbances. Figs. 3.1 to 3.5 show the surface pressure distribution over India, West Pakistan and Iran, day by day, from 15 to 19 December. On 15th the seasonal high has been replaced by a low over Baluchistan and to west. This, along with the pressure fall and high clouds over Sind and Rajasthan, would indicate the approach of a western disturbance. Stations in Afghanistan were heavily clouded, precipitation having occurred in the past twentyfour hours. By 16th a low pressure area had come between longitudes 70°E and 75°E and latitudes 25°N and 30°N with a southwestward extension to Sind and Baluchistan. Rain had occurred to the north of 30°N with snowfall over Kashmir. On 17th the low pressure system over northwest India and neighbourhood was very diffuse and two low centres seem plausible from data - one near 28°N, 74°E and the other near 25°N, 73°E. There is also a tendency for a diffuse trough to develop to the southeast of these lows. Rainfall belt has spread south upto about 25°N and to 81°E in the east; the amounts were higher north of Lat. 30°N. On 18th a trough lay over Punjab, Haryana and neighbourhood, a low near 24°N 78°E and another diffuse low pressure area over Vidarbha, East Madhya Pradesh and nearby Orissa. The first two systems can be regarded as displacement eastwards of the lows of the previous day while the third is a fresh development. Present weather precipitation was reported by stations in and near the Himalayas to the east of 76°E and in the Gangetic plains to the east of 80°E; rain had also extended to Sub-Himalayan West Bengal. During the past 24 hours, there was fairly extensive weather over the whole area between 75°E and 86°E, to the north of Lat. 23°N. Falls of the order of 3 to 5 cm were confined to over and near western Himalayas. By 19th the system weakened rapidly and we notice only a very diffuse low over Assam which may be a remnant of the eastward displacement of the low over East Madhya Pradesh on the previous day. Present weather precipitation is now confined to the east of 89°E and it is also very light and isolated. The 24 hour precipitation, though fairly well distributed over northeast India outside Gangetic West Bengal, over East Uttar Pradesh, East Madhya Pradesh and in and near hills of western Himalayas, was generally light. In the rear of the western disturbance there was widespread fog and low stratus on the morning of 18th and 19th. Ahead of the disturbance there was also fog at a few places in Gangetic West Bengal on 18th. Extensive thick and prolonged fog occurred daily over Uttar Pradesh and neighbourhood for nearly ten consecutive days. Moderate to severe cold wave conditions also prevailed over Uttar Pradesh, Bihar State and north Madhya Pradesh for over a week.

3.2 The chief points to note in the above sequence are :

(i) progressive eastward displacement of pressure system and rainfall belt,

(ii) tendency for lows to form or extend to more southerly latitudes to the east on succeeding days, a feature which is confined to the area to the west of 85°E and

(iii) more northerly course and faster movement to the east of 85°E.

These are usual features noticed.

3.3 Among the pressure systems affecting India, excluding depressions and cyclonic storms, western disturbances have conspicuous 24 hour pressure changes associated with them, which are useful in detecting the approach and movement of the western disturbances. In this particular case these changes were quite pronounced. Fig. 3.6 shows the pressure fall at the approach of the western disturbance and the rise in its rear.

3.4 Figs. 3.7 to 3.10 show the winds at upper levels between 16th and 19th. A trough is seen to the west of India near 65°E at 700 and 500 mb levels on 16th. A weak circulation at 30°N, 72°E is also noticed at 900 mb, corresponding to the surface pressure pattern. On 17th the troughline is near 74°E at 850 mb and 700 mb and perhaps slightly to the west at 500 mb. By next day (18th) the trough was along 78°E at 700 mb and 500 mb and extended southwards to Madhya Pradesh. On 19th the trough was near 87°E at 700 mb and 500 mb and was decreasing in amplitude over India. At 850 mb in the area of this system, the trough line runs east to west along 26°N. Weather had started over India even while this trough was far to the west. The passage of the trough across India from 17th to 19th was responsible for accentuating the surface system on the 17th and subsequent extension of weather to northeast India. Such passage of upper air trough after surface low has developed is favourable for extension of weather to the central and northeast India. While this trough moved fairly systematically, such is not the case with all. Some troughs weaken rapidly near 80°E. A feature to be noted in this case was the occurrence of the precipitation entirely in the forward sector of the trough at 500 mb level.

3.5 The relationship of this disturbance to systems to north and west as noticed in hemispherical charts* published by the USSR is now discussed. On 14th a low without frontal structure was located over the Caspian Sea and another similar system over Lebanon and Israel. Only one of these lows could be identified the next day, at 40°N, 65°E. This seemed to have now a warm front

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* The hemispherical charts (surface and upper-air) in this report are copied from "Synoptic Bulletins of the Northern Hemisphere" published by USSR.

from the centre to Kashmir and a cold front upto Caspian Sea, with a very open warm sector. On 16th (Fig. 3.11) this low was getting occluded, centred at 42°N, 70°E. The seasonal high over east Asia was weak. By 17th, this surface low might have filled up against the mountains, though the trough between 35°N and 40°N and 85°E and 95°E could have been its residual. On the 15th morning, when this low was centred at 40°N, 65°E, an induced low was forming over Iran and adjoining Baluchistan. As the main low moved eastwards to 70°E on the next day (16th), the induced low also came over to Rajasthan and adjoining Sind (which has already been discussed in para 3.1). Thus it will be noticed that the induced low which came over Rajasthan was directly connected up with an extra-tropical low further to the north in the latitudes 35°N to 45°N. Although the main low weakened on the 17th, the induced low became more marked under the influence of the upper air system.

3.6 On 15th, (Fig. 3.12) the extratropical low at 40°N, 65°E was extending upto 300 mb as a closed cyclonic circulation and with a trough extending southwards upto Baluchistan at 500 mb level. While the surface low weakened as it moved across the Himalayas on 17th, the upper trough maintained its identity and came over northwest India. During its passage over India, the trough intensified on the 18th and extended southwards; however on the 19th, it was decreasing in amplitude over India (The positions of this trough over India day-by-day have already been discussed in the earlier para 3.4).

3.7 Fig. 3.13 shows the hourly sequence of weather at New Delhi during the period of this western disturbance. High and medium clouds appeared on the morning of 16th and before the next morning thick altostratus. Drizzle commenced at 00Z on 17th and continued as drizzle or rain upto 06 GMT. During this time thick altostratus covered three quarters or more of the sky. The sky then partially cleared and there was a thunderstorm from 13 to 15 GMT after which sky cleared. Morning and night, during the next three days, fog occurred. The sequence of clouds and precipitation was as if a warm front had passed over the station in the forenoon of 17th and cold front in the evening. As the skies cleared on 17th night, after the ground had become wet during the day due to precipitation, radiation fog developed early next morning. The above sequence is usual to the north of 25°N, particularly over northwest India. To the south, cumuliform low clouds develop at an early stage itself with advection of moist air to the east of the low.

3.8 Fig. 3.14 shows the upper-air temperature variations at Delhi during the period. The temperatures dropped significantly on 18th morning. Whether the rather high temperatures on 17th at 12Z can be regarded as representative of likely warm sector is debatable. Temperatures on 17th morning when precipitation was just commencing are also low, though not as much as on the 18th. Primary disturbances have probably some diffuse frontal structure, at least in an occluded form. But frontal analysis has not developed due to apparent lack of utility. Surface temperatures cannot be used to locate fronts, as effects of clouds and precipitation overwhelm any airmass differences. Frontal type of precipitation cannot often be distinguished from that due to other types of convergence. Movement of fronts cannot also be related to surface geostrophic winds. In this case initially the weather sequence at Allahabad (five degrees of longitude to the southeast) was somewhat similar to Delhi but delayed by ten hours. Such displacement of likely fronts could not be related to winds below 700 mb level. Precipitation at Allahabad was prolonged by the influence of the upper trough on 18th. Induced 'lows' which develop over the Indian area have definitely no frontal structure.

3.9 Fig. 3.15 gives a sequence of radiosonde ascents at New Delhi showing the changes in upper air temperatures and humidities during a spell of wet weather over the place, associated with a western disturbance. The normal curves are also shown for comparison. *Three ascents are given here, as representa-

* Although the ascents for the period 15-19 December 1961 would have been more appropriate, the illustrations are taken from January 1969 as the radiosonde ascents at New Delhi after December 1967 when the audiomodulated instruments were introduced, are considered to be more reliable.

tive of conditions prior to, during and subsequent to the spell of rain over New Delhi. On 9th January 1969 the weather was dry over New Delhi and neighbouring areas. On 12th and 13th light precipitation was recorded at New Delhi and subsequently weather cleared. The features to be noticed in these ascents are :-

(i) The ascent on 13th shows a marked increase in the dew point temperature above 850 mb level and a cooling of the air between 850 mb and 300 mb level compared to the 9th ascent.

(ii) The ascent on 16th shows a large decrease in moisture content compared to the 13th. However, the dry bulb temperatures do not indicate any advection of fresh cold air over New Delhi.

This comparison brings out the greater role of moisture rather than advection of warm or cold air even in winter over Indian latitudes.

4. Western Disturbance, 10-12 January 1962

4.1 This is an example of a western disturbance which gave rain in Jammu and Kashmir only. A low which was over West Iran on 9th morning (Fig. 4.1) moved to the border of West Pakistan by the evening. Nokkundi pressure fell by about 4 mb. On the 10th morning it was over Afghanistan and adjoining West Pakistan. The main 'low' was centred further to the north, near 43°N, 64°E on 9th and near 48°N, 71°E on 10th (Fig. 4.2 a). The western disturbance over Afghanistan and West Pakistan (~~Fig. 4.2 b~~) on the 10th was seen as a trough running from the main low into Afghanistan. On the 10th morning a trough was present at 500 mb along 67°E, to the south of Lat. 40°N, over Afghanistan and northern parts of West Pakistan (Fig. 4.2 b). By 1200Z a weak low also appeared over upper Sind and southwest Rajasthan on the surface chart (Fig. 4.3). Over this area the 24 hrs pressure changes were about 2 mb (falling) with a rise further to the west (Nokkundi 7 mb rise) and the pressure departures were 6-7 mb negative (Fig. 4.4); in the lower levels (0.3 to 0.9 km) two circulations were seen (1) over north Rajasthan and (2) over Sind. Trough/circulation was also present over the

Punjabs at 850 mb and 700 mb (Fig. 4.5).

4.2 On 11th morning (Fig. 4.6) the main low moved northeastwards to 54°N, 82°E, while the previous day's trough over Afghanistan was seen along 75°E between 30°N and 40°N. Precipitation had occurred over Jammu and Kashmir. The induced low was also seen as a trough between 23°N and 30°N over East Rajasthan and adjoining Gujarat. The circulation/trough in the upper air was seen over the Punjabs upto 4.5 km. On 12th the trough over extreme north of India moved northeast and was extending from 40°N, 84°E (Sinkiang) to Kashmir (Fig.4.7) while the induced low was over East Uttar Pradesh and adjoining north Madhya Pradesh (Fig. 4.8). The upper air circulation (Fig. 4.9) was generally weakening. The induced low did not cause any precipitation or significant clouding. By 12th evening as the induced low moved to Bihar there was light precipitation over Sub-Himalayan West Bengal and nearby; and the precipitation extended to northeast Assam on 13th and 14th, as the induced low moved across upper Assam.

4.3 In this case we can trace three 'lows' -

(i) a well marked low pressure system moving from southeast of Aral Sea (43°N, 64°E) on 9th to north of Mangolia (54°N, 96°E) on 12th,

(ii) a second low moving from West Iran (34°N, 52°E) on 9th to Sinkiang (40°N, 84°E) on 12th across Kashmir and

(iii) an induced low moving from Sind on 10th to Assam (13th).

The second low gave some precipitation over Jammu and Kashmir and Himachal Pradesh while the induced low was feeble and gave rain only in Sub-Himalayan West Bengal and Assam. In the upper air, the trough which was over Afghanistan and parts of West Pakistan on the 10th, did not extend southwards over India and was weakening afterwards. The hemispherical charts for 500 mb level for the period show that the middle latitude westerlies were more or less zonal with no marked large amplitude perturbations - i.e. showing features of high index type circulation.

5. Western Disturbances, 15-19 February 1962

5.1 This case is interesting for causing rainfall in the south peninsula and the associated marked trough in upper troposphere. Its entry into the Indian sub-continent seems to have been a little more to the south than most cases, near Lat. 25°N-30°N. On the 15th morning light precipitation commenced near Lat. 30°N over the plains of West Pakistan with a surface low over Lower Sind and south Baluchistan (Fig. 5.1). The low level circulation over Sind and southwest Rajasthan could be seen upto 2.1 km over this area. Mid- and upper tropospheric trough was present further to the west with its axis along Long.65°E (Fig. 5.2). Hemispherical charts (Fig. 5.3) showed that this upper trough was a part of the low over Russian Turkistan. A closed high was situated further to the north. These conditions were suggestive of a low index type circulation with blocking highs and cut off lows. The low over south Baluchistan and Sind was seen on 16th morning (Fig. 5.4) as a surface trough over Rajasthan. Fairly widespread precipitation had occurred over the country to the north of 30°N with isolated thundershowers to the south upto 27°N to the west of 75°E. Upper winds (Fig. 5.5) at 0.9 km showed two circulations, one near the surface low and another over the Punjabs. Taken with the surface pressure falls (Fig. 5.6) over the Punjabs, it would appear that a low was developing over this area, which could not be traced with the available data as having come from the west. This circulation could be identified upto 3.6 km with centre near 32°N, 72°E. (It could be traced as a trough on the surface also by 12Z). Mid- and upper tropospheric trough was near 68°E from Afghanistan to Sind. On 17th the surface trough was between 72°E and 80°E and 23°N and 31°N. Precipitation had been mainly to the north of 26°N and west of 81°E and in two patches, one north of Lat. 30°N and the other over Uttar Pradesh with a precipitation - less area in between presumably due to the two systems, one travelling to the north of 30°N and another travelling from lower Sind to Uttar Pradesh. Sky did not clear up over West Pakistan and northwest India to the rear of the western disturbance, as a fresh western disturbance was approaching West Pakistan in a relatively low latitude. At 12Z of 17th the upper tropospheric trough was near 70°E. On the 18th morning (Fig. 5.7) the trough line at surface and in the lower tropospheric levels was near 77°E and the trough was extending to the south upto 15°N (i.e. from West Uttar Pradesh to north Mysore). Precipitation had reached upto 83°E in the east and 14°N in the south in association with this trough and again in three patches, with precipitation - free areas in between. The upper tropospheric trough (Fig. 5.8) was most marked at 200 mb with axis near 74°E and extended as far south as 15°N. This trough was however less marked at 500 mb than at 200 mb. By 12Z of 18th (Fig. 5.9) this trough had weakened at 200 mb, its axis at 300 mb had moved to 80°E and the trough was more pronounced in mid-troposphere, as if vorticity had been advected downwards into these layers. By 19th morning precipitation belt was to the north of 15°N and between longitudes 77° and 86°E.(Rainfall further south seems to have been due to other causes also.) Pressure field became very diffuse (Fig. 5.10). The trough line was between 80°E and 85°E at most levels indicating that the upper level trough was overtaking the low level system, though the trough had relaxed considerably at 300 mb and 200 mb (Fig. 5.11). By 20th morning the upper tropospheric trough had relaxed further and rain had fallen between 83°E and 90°E to the north of 23°N.

5.2 The chief features to note in this case are:-

(i) The lower tropospheric trough/low came under an upper tropospheric trough reaching upto 15°N which caused precipitation belt to extend far southwards.

(ii) The weather was confined between the trough and ridge line in the upper troposphere. The precipitation decreased and the low level system filled up when it was overtaken by the upper system.

(iii) Vertical advection of vorticity from the system in upper troposphere to mid-troposphere is an interesting feature.

(iv) Rainfall first occurred in the plains of Punjab(P) and then extended northwards. The low was first seen in the lower latitudes. Af far as available observations show the low to the north of 30°N developed later locally over the Punjabs. This is in contrast to the usual sequence of a western disturbance appearing in the higher latitudes first and the induced low in the lower latitudes later.

(v) During this period the subtropical jet stream was to the south of its mean position over India.

6. Upper Air Trough, 1-2 December 1962

6.1 Even a well-marked upper air trough may not cause weather, as is illustrated by the case of 1-2 December 1962. At 1200Z of 1st (Fig. 6.1) there was a trough/low over the Punjabs and neighbourhood extending from 850 mb to at least 300 mb. This was about the time of its maximum intensity. At the surface, (Fig. 6.2) the seasonal high pressure pattern continued below this upper low, although the 24 hrs pressure changes suggested the movement of a weak low across the extreme north of the country. On 1st and 2nd, the seasonal high over Asia (Fig. 6.3) was a little over 10 degrees of latitude to the south of normal position. The upper trough (500 and 300 mb) moved to Tibet and Sinkiang the next day (2nd) and weakened considerably on 3rd. Relative humidity of the air over north India was very low in this case, less than 35% (both at the surface and upper air).

6.2 During this period a well marked system in easterlies was affecting the peninsula with northward extension of weather almost upto 20°N.

7. Western Depression, December 1967

7.1 The western disturbance in the last week of December 1967 is an example of a disturbance

(i) of depression intensity and

ii) which developed outside India and moved into the Indian sub-continent.

7.2 On 23rd December (Fig.7.1) there was a very pronounced upper low/trough in westerlies extending roughly along Long. 40°E from ~~east~~ Russia (70°N) to the south of Turkey (30°N). In the forward portion of the trough a north-south frontal system was located between the longitudes 45°E and 55°E. With the movement of the system eastwards, a depression (with at least three closed isobars at 2 mb interval) was seen on 24th (Fig. 7.2) over extreme east Iran, while another 'low' was centred to the north of it near Lat. 41°N, Long. 65°E. The depression over Iran was stationary for the next 24 hrs, although the upper trough showed an eastward movement. An induced low also formed off Mekran-Sind coast on 25th morning (Fig. 7.3).

7.3 By 26th morning the depression over Iran moved into West Pakistan and adjoining Rajasthan with centre near Khanpur (West Pakistan) (Fig. 7.4). The induced low had also apparently moved eastwards and caused extension of the depression as a trough over Gujarat State. The central pressure of the depression was 1002 mb and the departure - 17 mb; five closed isobars at 2 mb interval could be drawn. The lower level winds (upto 0.9 km) in the circulation were 20/30 kt strong (Fig. 7.5). The precipitation during the past 24 hrs was fairly widespread over West Pakistan and northwest India and Saurashtra and Kutch. At 500 mb a low was centred at Lat. 40°N Long 64°E with a trough extending southeastwards upto Punjab (India) across Afghanistan (Fig. 7.6). The depression retained nearly the same intensity in the evening of 26th also. During the 24 hr. period ending on 27th morning the precipitation extended eastwards upto as far as Long. 83°E, and moderate to heavy falls occurred in and around western Himalayas, the heaviest being 18 cm at Banihal. In the south, the precipitation (although light) extended upto Bombay. By 27th the system weakened considerably without appreciable movement and pressure rose by as much as 5 to 10 mb. There was no marked change in the 500 mb pattern, though the trough line towards India was not as marked as on the previous day. It is difficult to explain why the depression weakened so rapidly. A significant feature was the considerable rush of dry air over the depression area at this stage - as evidenced by the changes in surface dew point temperatures and the radiosonde ascent at Jodhpur.

7.4 This case was characterised by the intensity of the systems both at the surface and in the upper air and the extensive weather caused by it. The disturbance could be traced from the west atleast two days before it came to the Indian border, although the intensity of the disturbance while over Iran could not be judged precisely due to paucity of data. The satellite picture of the western depression is given in Sec. 16.

8. Western Disturbance over North Arabian Sea and Gujarat State, 2 to 4 February, 1961

8.1 The first week of February 1961 was characterised by active western disturbances and induced lows affecting in quick succession and causing a large excess of rainfall over India north of Lat. 20°N. During this period the hemispherical charts showed a pronounced "low index" circulation and a persistent blocking high in the middle latitude westerlies over Asia. Out of the disturbances during this period the one which came into India at a very low latitude between 20°N and 25°N across the north Arabian Sea, will be described to illustrate a few points.

8.2 An active western disturbance was moving across the north Punjab(P) on 2nd February and simultaneously another low was noticed over Oman Peninsula (Fig. 8.1). A pronounced ridge could be seen over Baluchistan in between these two disturbances. Bahrein was raining. By the next morning the low moved eastward into Gulf of Oman and was well marked. Available data would suggest even two closed isobars at 2 mb interval. The low moved to north Arabian Sea off Mekran-Sind coast by the evening (Fig. 8.2) where pressure changes were about 4 to 5 mb negative. The pressure departures were about 4 mb in defect.

The circulation could be seen upto 0.9 km only.

8.3 On the 4th morning (Fig. 8.3) the low travelling across north Arabian Sea lay as a trough extending from southwest Rajasthan to off Sind coast, with the main centre over southwest Rajasthan and north Gujarat where the negative pressure changes and departures reached about 10 mb (Fig. 8.4). Over this area, the disturbance was seen as a circulation upto 0.6 km and as a trough upto 1.5 km; at higher levels (500 mb - 300 mb) the winds were strong westerlies and a wind maximum was noticed. (Fig. 8.5). A low/trough was also located between Aral Sea and Afghanistan from surface upto 700 mb which was affecting northern parts of West Pakistan and adjoining India (Fig. 8.6). During the next 24 hrs rainfall occurred over most of Gujarat State and extended southwards upto Bombay (which is a very rare feature) while Rajasthan had no rain. The low moved eastwards to north Madhya Pradesh and the subsequent history of the low is not being followed as not being of direct interest.

8.4 The chief features to be noticed in this case are :-

(i) the movement of the low from as far to the west as Gulf of Oman (it could not be tracked further to the west due to lack of observations),

(ii) its travel over sea area (north Arabian Sea) and entry into Gujarat State which is very rare (over sea there seems to have been an intensification of the system),

(iii) extension of rain belt as far south as Bombay,

(iv) the large pressure changes and departures associated with the low and the very shallow circulation (at no stage probably it extended above 1.5 km),

(v) the absence of upper air trough over the area (In fact the strong upper westerlies shifted to the south of the normal position and a belt of west winds lay over the area of the disturbance from 500 mb level upwards. Aircraft reports suggested that at 200 mb level winds over the area were about 100 kt) and

(vi) the pronounced low index circulation over ~~south~~ central Asia during this period (Fig. 8.6).

9. Western Disturbances - General Conclusions

From the cases discussed in the above paragraphs it will be seen that western disturbances are quite varied in nature -- in their structure, in respect of the weather they cause and the extent of the area they affect. However there are some noteworthy similarities which are summarised below

(i) Western disturbances are low pressure systems which move across the extreme north of the country or sometimes even further to the north. They may be seen on the surface chart or in the lower troposphere as a closed low or even a trough. Usually there is a trough to the west in the mid- and upper troposphere. As the western disturbance comes over longitudes of Indo-Pakistan area, an induced low sometimes forms over Sind or West Pakistan. If at this stage the upper trough extends well to the south, the induced low may be active. The induced low is generally shallow and its circulation does not extend as high as the main disturbance.

(ii) Western disturbances are usually associated with recognisable 24 hr. pressure changes - fall of pressure ahead of the disturbance and rise in the rear. The pressure gradient associated with the high in the rear of the western disturbance is sometimes strong and may extend over north and central Arabian Sea causing moderate to strong winds. Rise in the minimum temperatures and dew point temperatures is also useful indicator of approaching western disturbance.

(iii) Simultaneously there can be more than one low level system over the Indian area and they may appear as a complex low pressure area with a diffuse isobaric configuration. Even otherwise, surface isobaric configuration associated with western disturbances is generally quite weak and isobars may have to be drawn at 1 mb interval, so that weaker systems are not missed. When there is more than one low present, each low causes its own belt of weather.

(iv) Without the appearance of a low either at the surface or in the upper air below 1.0 km, weather does not occur over India to the south of Lat. 30°N. However, to the north of Lat. 30°N weather can occur due to disturbances seen mainly in the upper air or due to systems moving to the north of India. The converse may not be always true - i.e. even when a low or trough has appeared on the chart (surface or upper air) weather may not occur in some cases. North of 30°N weather may commence over hills earlier than over plains. Western disturbances are very diffuse and often difficult to identify on the chart when they move across Assam and cause weather there.

(v) The intensification of the seasonal high over east Asia, its more southerly location and its extension as a pronounced ridge southwestward into Iran and West Pakistan appear to inhibit active western disturbance over India and so also depressions in the Arabian Sea and the Bay of Bengal are seen to inhibit the western disturbance.

(vi) The activity of the disturbance is closely related to the position of the low level circulation in relation to the upper level systems (such as trough or wind maxima). Thus there is a need to recognise the systems in the lower and upper tropospheres and follow their sequence It is far easier to trace the upper troughs and locate the favourable regions of development on the charts, than the wind maxima.

(vii) The existence of surface low to the north of India as well as the intensity and the latitudinal extent of the upper air trough can be followed more systematically with the extended charts and hence a better understanding of the behaviour of the western disturbance is possible to some extent. Still the behaviour of the upper air systems themselves is a matter not clearly understood - for example, their intensification or weakening and their amplification or relaxation.

(viii) In the middle latitudes during periods of low index circulation westerly troughs may be expected to develop large amplitude and affect lower latitudes. On such occasions we may perhaps anticipate more induced lows over the Indian sub-continent and the extension of weather over large areas. During high index type circulation, upper air troughs may affect only the extreme north of the country and may also move away quickly.

10. Cold Waves

10.1 Apart from clouding and precipitation, another feature associated with western disturbances is the cold wave. Cold waves occur in the rear of western disturbances. According to the departmental convention, when the minimum temperatures drop 6-7°C below normal it is called a 'moderate cold wave' and when they drop 8°C or more below normal a 'severe cold wave'. No absolute minimum temperature limit is included in the definition of the cold wave which is always with reference to the normal minimum temperature for the stations in the area. It is often noticed that when the minimum temperatures fall sufficiently, there is also a drop in the maximum temperatures; the range through which the maximum temperatures drop may, however, not be the same as for minimum temperatures. Ground frost may also occur in association with cold wave.

10.2 Severe cold waves occur in northwest India, West Uttar Pradesh, Madhya Pradesh, Gujarat State, Madhya Maharashtra and Vidarbha between December and April, although the number of occasions are less in December and April. Occasionally they also extend eastwards to East Uttar Pradesh, Bihar, Orissa and West Bengal and southwards to Marathwada, Telangana, Rayalaseema and North Interior Mysore. During the cold waves, the minimum temperatures have dropped as much as 10 to 12°C below normal and over Jammu and Kashmir 15°C to 20°C below normal. A spell of cold wave over northern India generally lasts for about 4 to 5 days and in exceptional cases about a week or ten days.

10.3 Although it is usual to associate cold waves with active western disturbances moving across India and West Pakistan, it is found that on some occasions when the temperatures are already below normal, even a small drop in the temperature in the rear of a weak disturbance may bring the temperatures down sufficiently to be classified as a cold wave. In some rare instances, a disturbance to the north of the country also causes cold wave, when the high in the rear of the disturbance extends to Indo-Pakistan sub-continent. Three cases illustrative of the different features of cold waves are discussed in the following paragraphs.

11. Moderate to Severe Cold Wave, 22-29 January 1964

11.1 On 21 January 1964, a western disturbance was over the Punjabs and the adjoining areas, with an induced low over Rajasthan. It had caused fairly widespread precipitation over Jammu and Kashmir, Punjab and Himachal Pradesh, with isolated falls over Haryana, Rajasthan, Saurashtra and Kutch. An intense ridge of high pressure set in over West Pakistan in the rear of the disturbance. The pressure was 1029.4 mb at Nokkundi, about 10 mb above normal. Hemispherical chart (Fig. 11.1) showed that the centre of the high was near 36°N, 63°E, with a central pressure of 1040 mb. A ridge pattern was seen extending more or less uninterrupted from southern Europe to Afghanistan. The high in the rear of the western disturbance was a cold high, weakening by 700 mb level. The next morning (22nd) (Fig. 11.2), the western disturbance was moving away across the western Himalayas while the induced low was over southwest Uttar Pradesh. Precipitation was fairly widespread over western Himalayas, with isolated light rain in the plains. The ridge over West Pakistan now extended eastwards into northwest India. Low level winds (upto 0.6 km) changed to northwesterlies over Rajasthan and Gujarat State (Fig. 11.3).

11.2 Even on 21st minimum temperature had fallen appreciably over the western parts of West Pakistan. On 22nd dew point temperatures fell by 5° to 10°C over Punjab, West Rajasthan, Saurashtra and Kutch with a few stations in Rajasthan reporting falls upto 17°C. Minimum temperatures fell over northwest India, the highest falls being about 7°C to 9°C over West Rajasthan where near-freezing temperatures were recorded; moderate cold wave conditions started affecting West Rajasthan (Fig. 11.4).

11.3 The high pressure ridge extended further eastwards to West Uttar Pradesh and northwest Madhya Pradesh on 23rd and in the upper air (upto 0.6 km) there was an almost uninterrupted flow of northerlies from Jammu and Kashmir to Madhya Maharashtra and Konkan (Fig. 11.5). There was a further fall of dew points over northwest India and Gujarat State by 5°C to 10°C. Moderate to severe cold wave conditions extended over the whole of Rajasthan and Gujarat State and sub-freezing temperatures were recorded by many stations in Rajasthan. It is a point to note that on this day the lowest temperatures and larger negative departures were recorded over Rajasthan and Gujarat and not further to the north (Fig.11.6)

11.4 During the next two days (24th and 25th) the ridge extended successively upto Bihar and West Bengal (Fig.11.7). Over Uttar Pradesh, even by 23rd, the earlier easterlies upto 0.9 km were replaced by northwesterlies; the northwesterlies strengthened and extended southwards and eastwards reaching West Bengal by 26th (Fig.11.8). Minimum temperatures started falling over Uttar Pradesh, Bihar and north Madhya Pradesh on 23rd and the fall continued over these areas for the next three days. Fall of minimum temperatures commenced over northeast India by 26th and continued on the next day also. As the minimum temperatures over all these areas were previously above normal, it was only after two or three days of continued fall that the temperatures became sufficiently low to be classified as a cold wave (Figs. 11.9 and 11.10).

11.5 The description of the cold wave conditions over the various meteorological sub-divisions day-by-day is given in the following Table:

Table.

	Date							
	22	23	24	25	26	27	28	29
1.West Rajasthan	M	S	M	M	M/S			
2.East Rajasthan		M	M	-	M/S	M	M	M
3.Gujarat Region		M	M/S	M	M			
4.Saurashtra and Kutch		M/S	S	M/S	M/S			
5.Punjab and Haryana		M	M	M	M	M/S	M	M
6.West Madhya Pradesh					M	M/S	M	M
7.West Uttar Pradesh					M			
8.East Uttar Pradesh						M		
9.Bihar Plateau						M		
10.Bihar Plains						M		
11.West Bengal						M		

M - Moderate Cold Wave
M/S - Moderate to Severe Cold Wave
S - Severe Cold Wave

11.6 The cold wave was most intense in the northwest India and Gujarat State and became less severe as it progressed eastwards. The cold wave also lasted for more number of days over northwest India, West Madhya Pradesh and Gujarat State. Cold wave prevailed over East Rajasthan and Punjab-Haryana during the whole period while it abated in Gujarat State by 27th. It extended into Uttar Pradesh, Bihar and West Madhya Pradesh between 26 and 27th. It affected West Madhya Pradesh for 4 days and Uttar Pradesh, Bihar and West Bengal just for a day.

11.7 The recovery from the cold wave was very gradual and was spread over a few days, since there was no change in the circulation pattern due to approach of any western disturbance. The temperatures began to rise slowly by 27th over northwest India and Gujarat State. This continued over these areas on the subsequent days and extended eastwards also. By 30th except for a few pockets, the cold wave conditions abated.

11.8 During the period similar changes were also noticed in the maximum temperatures over the northern parts of the country. They were 5°C to 7°C below normal over many parts of north India between 22nd and 26th. Another feature was the strong pressure gradient which came in the rear of the western disturbance and extended over the north and central Arabian Sea where moderate to strong winds of speed 20-30 kt were reported by ships. On 20th and 21st strong winds were reported only in the western parts of Arabian Sea. Subsequently there were reports from the east Arabian Sea also. With the strong pressure gradient extending to the east central Arabian Sea, the seasonal trough off the west coast of the Peninsula intensified and northerly winds of speed 30 kts were reported off Maharashtra Coast.

11.9 Time sections of the sequence of low level winds, maximum and minimum temperatures for Jodhpur and Delhi affected by the cold wave are shown in Fig.11.11. They indicate, among other things, the fall in minimum temperature with the changes of the low level winds to a more northerly direction as well as the magnitude of changes when the cold wave set in and the slow recovery from the cold wave.

12. Moderate to Severe Cold Wave, 10 - 15 January 1967

12.1 The charts for the period 10 to 15 January 1967 are illustrative of a situation where a cold wave occurred in the wake of a western disturbance which affected only the extreme north of the country and caused light precipitation. The western disturbance was over Afghanistan and neighbourhood on 5th and 6th. Thereafter the system was not noticed on the surface chart. However, an upper air low was noticed on 7th over the northern parts of West Pakistan and adjoining India in the middle troposphere. This circulation persisted till the 12th.

Hemispherical chart (Fig.12.1) for 9th showed that the seasonal high over central Asia was intense (central pressure 1055 mb to 1060 mb. as against the normal value of 1035 mb) and a ridge was extending southwestwards into Afghanistan, Iran and West Pakistan. In the low level upper winds (upto 0.9 km)(Fig.12.2), a ridge was located over north Rajasthan on 9th; the ridge extended southeastwards upto Bihar on 10th so that the winds were more or less northeast/east to the south of Lat.25°N (Fig.12.3).

12.2 The minimum temperatures were generally below normal over northwest India, Uttar Pradesh, West Madhya Pradesh, Gujarat State and the western half of the peninsula even on 7th; they (the minimum) commenced falling by 2°C to 4°C over Punjab and Haryana and neighbourhood on 7th and continued to fall during the next three days. Moderate cold wave conditions set in over Punjab, Haryana and northwest Rajasthan by 10th (Fig. 12.4) where the minimum temperatures reached below freezing point at some stations.

12.3 By 11th the dew points and minimum temperatures fell (Fig.12.5) practically over the whole of north India north of Lat. 22°N. Moderate to severe cold wave conditions now prevailed over Punjab, Haryana, Rajasthan and northwest Madhya Pradesh. The cold wave persisted over these areas, during the next two days (12th and 13th) and also extended to West Uttar Pradesh. Sub-freezing temperatures continued over north Rajasthan, Punjab and Jammu-Kashmir. Presumably because of the pronounced easterly components of the wind to the south of Lat. 25°N, the cold wave conditions did not extend to more southerly latitudes.

12.4 The northwesterlies strengthened over the Gangetic Plains from West Uttar Pradesh to West Bengal on 13th (Fig.12.6); on 14th, (Fig.12.7) minimum temperatures fell appreciably over ~~northeast India~~ Bihar, East Madhya Pradesh and southeast Uttar Pradesh and moderate to severe cold wave conditions extended to East Uttar Pradesh and Bihar Plains. The cold wave affected Saurashtra and Kutch (particularly the northern portions) also on a few days.

12.5 With the arrival of a fresh western disturbance over Punjab(P) the wind pattern changed over north India during the 14th and the westerlies to northwesterlies gave place to easterlies. By 15th the cold wave began to abate. Below normal temperatures, however, continued for over a week.

12.6 Over Gujarat Region, Madhya Maharashtra and Konkan the minimum temperatures fell by 3°C to 4°C on 14th and 15th. This seems to have been associated with the winds over these regions becoming northerlies in the lower levels, which had a more easterly component earlier.

12.7 The maximum temperatures were also below normal over the areas affected by the cold wave, although it was not so significant as in the case of January 1964 (discussed in Sec.11).

12.8 Some of the features noticed in this case which could be contrasted with the case of January 1964 are :-

i) The western disturbance in the present case affected only the extreme north of the country and caused light precipitation over western Himalayas.

ii) The cold wave started from Punjab-Haryana and extended southwards and eastwards, whereas in the January 1964 case it first occurred over Rajasthan and later in Punjab.

iii) The drop in the minimum temperatures were more gradual and because they were below normal even earlier, these relatively small falls were able to cause cold wave conditions.

iv) Presumably because of the marked easterly component of low level winds south of Lat. 25°N, the cold wave did not extend much to the south.

13. Moderate to Severe Cold Wave, 16 - 18 January, 1962

13.1 The cold wave of 16 to 18 January 1962 was associated with a well marked low moving to the north of the country. An extratropical low* was moving between Aral Sea and Lake Balkash on the 10th. As it moved away northeastwards, a trough associated with it, was trailing behind over the extreme north of the country on the 12th. The high in the rear of the disturbance was centred near 45°N, 57°E. On the next day (13th) (Fig.13.1) the high shifted slightly southeastwards and a well marked ridge extended into West Pakistan and India. The central pressure of the high was about 1045 mb. At the same time the seasonal high over central Asia also strengthened and the pressure at the centre reached 1055 mb on the 14th. Simultaneously a feeble induced low also moved from southwest Rajasthan to Bihar between 10th and 12th, though it did not cause any precipitation or significant cloudiness. Marked changes in the low level wind flow occurred on 12th and 13th; on 13th morning the flow over the major portions of the country to the north of 20°N became northwest/north (Fig.13.2).

13.2 In association with these developments minimum temperatures began to fall over West Pakistan on 11th and 12th. In north and central India the minimum temperatures were nearly normal over most areas on 12th; from this day onwards they commenced falling over northwest India and Madhya Pradesh (Fig.13.3) and the fall continued and also extended eastwards during the next four days, the fall being very gradual. By 15th the minimum temperatures were 3° to 6°C below normal over the country to the north of 20°N. On 16th (Fig. 13.4) it became a moderate cold wave over East Rajasthan. It extended eastwards rapidly and on 17th (Fig. 13.5) moderate to severe cold wave conditions were affecting Gangetic West Bengal, Bihar Plateau, south Uttar Pradesh and adjoining North Madhya Pradesh and East Rajasthan. It is of interest to note that the cold wave intensified over Bihar where temperatures were 8°C to 10°C below normal, compared to Rajasthan and Uttar Pradesh where it did not go below 6°C-7°C. Although the minimum temperatures over Bihar Plateau were nearly of the same

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* This low has already been described in Sec.4 which may be referred to.

magnitude as those over north Rajasthan and the adjoining areas, the negative departures over Bihar Plateau were higher, since the normal values of minimum temperatures over Bihar Plateau are higher than over Rajasthan. By 18th the cold wave abated over the country except over a small portion of Gangetic West Bengal.

13.3 The following points are noteworthy in this case :-

i) The cold wave was preceded by a western disturbance moving to the north of the country. The feeble induced low did not cause any clouding or precipitation.

ii) The intense high in the rear of the disturbance extended south and southeast and was probably responsible for the lowering of temperature over north India. The fall in temperature was gradual, spread over a few days.

iii) The cold wave intensified over Bihar and adjoining areas.

iv) It travelled eastwards across south Uttar Pradesh and north Madhya Pradesh to Bihar Plateau and Gangetic West Bengal, while areas further to the north were free from the cold wave.

14. Cold Wave - Conclusions

14.1 The above case histories show that cold waves occur in the rear of active as well as weak western disturbances. (The adjectives, 'active' and 'weak' are based on the precipitation over India produced by the western disturbance.) In the case of active disturbances the drop in temperature is rather abrupt and appreciable. When the minimum temperatures are already below normal, sometimes we get a cold wave in the rear of even a weak western disturbance. In these cases the drop in temperatures is more gradual.

14.2 The lowest temperatures in the cold wave is usually reached on the second night of the cold spell.

14.3 Cold waves may enter northwest India from West Pakistan, or develop in situ over northwest India. They usually spread eastwards and southwards and may reach as far east as West Bengal or as far south as Telangana. On some occasions a cold wave intensifies over Bihar or East Uttar Pradesh.

14.4 Since cold waves occur in the rear of western disturbances where pressure gradient is somewhat strong, the resulting strong winds add to human discomfort. The pressure gradient sometimes extends over north and central Arabian Sea also. Generally the winds below 1.0 km are intimately related to the onset and progress of cold waves. The wind at 0.9 km has been found to be very useful in advecting the 10°C and 7°C minimum temperature isotherms during the subsequent 24 hrs. The winds at higher levels do not seem to have any significance in forecasting the cold wave.

14.5 Over Gujarat State, Madhya Maharashtra, Vidarbha etc. a more northerly component for the upper winds (0.3 to 0.9 km) is favourable for a cold wave than a northeasterly or easterly turning around the anticyclone over northwest India. Cold waves are associated with large drops in surface dew points, suggesting the invasion of extremely dry air.

14.6 A preliminary examination of some radiosonde ascents on days of cold waves shows that the changes in the dry bulb at a station when the cold wave advances, is much less than the changes in the dew point and whereas the dry bulb temperatures during the cold wave days are not very different (or in fact even warmer than) from the normal values for the station, the dew point temperatures are very much lower than the normal values, suggestive of the greater role played by the lack of moisture in the lowering of temperature. During period of cold waves the morning ascents show considerable stability in the lower level - sometimes extending from the ground to as high as 800-750 mb level. Two radiosonde ascents for New Delhi and Jodhpur during a cold wave period are illustrated in Fig. 14.1.

15. Fog

15.1 Fog is a localised phenomenan. However, under certain synoptic situations, conditions become favourable for the occurrence of fog over fairly large areas, although the actual occurrence or non-occurrence at any particular place is dependent on local features. The most important synoptic situation under which fog occurs over large areas, is the western disturbance. In the rear and sometimes ahead of western disturbance, the low level moisture, wind field and stability conditions become favourable for the occurrence of radiation fog - though there may not always be a favourable combination of these three factors If rain falls in the evening or night and immediately after the rain the sky clears up and strong winds have not set in, there is a good chance for thick fog on the next morning. Often fog occurs on the subsequent one or two mornings also. Such situations occur in the immediate rear of a western disturbance. Along the coastal areas of Orissa, West Bengal and East Pakistan fog generally occurs ahead of the western disturbance, when a shallow current of moist air is drawn over these areas under the influence of a western disturbance further to the west. Occasionally such conditions also occur over Bihar and Uttar Pradesh when an easterly stream in the very low levels extends over these areas under the influence of a western disturbance over northwest India.

15.2 When the low level moisture content is quite large, the fog may persist for a long period and may be accompanied or followed by very low and thick stratiform clouds. On occasions thick fog and stratus have persisted upto forenoon or even mid-day, though such instances are not very common.

15.3 In the following paragraphs an instance each of fairly widespread fog

i) in the rear of a western disturbance,

ii) ahead of a western disturbance along coastal Orissa and West Bengal and

iii) ahead of a western disturbance over Bihar and Uttar Pradesh, are given.

15.4 In association with the western disturbance discussed in Sec. 3 there was fairly widespread rainfall over Himachal Pradesh, Punjab, Haryana, East Rajasthan, West Uttar Pradesh and adjoining areas even by the evening of 17th December 1961. By 2330 hrs IST, low level winds(0.3 to 0.9 km)changed to light northerlies over Rajasthan. On the 18th morning (Fig. 3.4) in the rear of the western disturbance there was fairly widespread fog in Punjab and north Rajasthan; some stations reported thick fog with sky not discernible. The light winds, moisture in the lower levels due to the previous evening's precipitation and the subsequent clearance of the skies as the western disturbance moved eastwards, were quite favourable for the occurrence of fog. As the western disturbance moved further eastwards on 19th, fog recurred at a few stations in north Rajasthan and Punjab and also extended to Uttar Pradesh and north Madhya Pradesh (Fig. 3.5). Again on 20th a number of stations in north Rajasthan, Uttar Pradesh and north Madhya Pradesh reported fog. In this particular case thick fog over Uttar Pradesh and neighbourhood recurred for nearly ten consecutive days.

15.5 On the morning of 27 January, 1969, there was fog at many stations in Gangetic West Bengal and East Pakistan (Fig.15.1). The western disturbance was still over northwest India, but as it was intense, moisture was being drawn into northeast India ahead of the disturbance. The noteworthy features on the day are:-

(a) S/SWly upper winds over Orissa, Gangetic West Bengal and East Pakistan in the lower levels (Fig. 15.2),

(b) an anticyclone over north Bay on the surface chart and

(c) considerable rise in dew point and minimum temperatures over the above land areas indicative of the advection of warm moist air (Fig. 15.3). The morning radiosonde ascent at Calcutta on 27 January (Fig.15.4) shows a nearly saturated shallow layer close to the ground and a strong inversion layer above this. On the previous morning the inversion layer was from the ground to 985 mb.

15.6 Under the influence of a western disturbance over West Pakistan, easterlies were prevailing on 10 January 1962 (Fig. 15.5) over most of north India and Madhya Pradesh in the lower levels (very much different from the normal flow); the easterlies were rather light. The skies were clear over the plains of north India. Dew point temperatures were generally rising during the previous 36 hrs. over the area. Fog was reported on this day at a number of places in Bihar Plains and Uttar Pradesh (between Patna and Delhi) and at many stations they persisted even at 0830 hrs IST (Fig.15.6). On the previous two days also fog was reported from Uttar Pradesh and Bihar although the number of stations reporting fog was rather less.

16. Satellite Pictures of Western Disturbances

16.1 No systematic study of the satellite cloud pictures of western disturbances has been made so far. However, satellite cloud data are now regularly available, on an operational basis to the forecasting offices. The pictures indicate the extent of the cloudiness associated with the western disturbances, so that the forecasters who very often do not have adequate data coverage over the crucial areas to the west and northwest of India can infer from the satellite pictures the approach of western disturbances and the nature of their activity. Three satellite pictures of clouding associated with western disturbances have been presented below - more as a matter of interest than as any typical cases based on an exhaustive study of the subject. Very occasionally extensive low stratus and fog have also been noticed (picture not presented) in the pictures taken during morning hours.

16.2 The picture for 16th December 1967 (Fig. 16.1) shows an extensive frontal system from central Siberia westsouthwestwards to Egypt (the picture to the north of 50°N is black because of the absence of sunlight at the high latitudes). The hemispherical surface analysis is also shown in Fig. 16.2. The frontal system lies just over the extreme north of Jammu and Kashmir. The upper winds over the frontal system were more or less zonal. The cloudiness over central India is associated with a system in easterlies which lay off the west coast of the peninsula and adjoining areas.

16.3 The picture for 22nd December 1967 (Fig. 16.3) shows the cloudiness in association with a well marked western disturbance over Rajasthan (Fig. 16.4). Note the extensive cloudiness entirely to the north and east of the low and its extension southeastwards almost upto Nagpur. The relatively sharp eastern edge of the cloudmass near Long. 82°E roughly coincides with the upper ridge. Surface stations below the cloudmass (in the satellite picture) reported mixed types of clouds-cumuliform, stratiform and cumulonimbus. Fairly widespread rainfall occurred over these areas, many stations recording as much as 2 cm at 0830 hrs. IST of 23rd.

16.4 The picture for 26th December, 1967 (Fig. 16.5) is that of a western disturbance which lay as a depression centred near 29°N, 70°E on this morning (see Sec. 7). The extensive heavy overcast to the north, the rather sharp western edge of the cloudmass at 65°E and the cumuliform bands to the south and southeast more or less aligned along the strong lower tropospheric wind field, are noteworthy features in the picture. As suggested by the picture the rainfall was widespread and heavy to the north of Lat. 30°N, many stations reporting 4 cm and above.

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APPENDIX - I

R.Cs: Bombay/ Calcutta/ Madras/ Nagpur/ New Delhi.

Sub: Criteria for tracing western disturbances.

Ref: Recommendation 12 of Forecasting Officers Conference, 1956.

D.G.O. has approved the above recommendation dealing with the criteria for tracing western disturbances in the day to day analysis. Forecasting Offices under your control may kindly be informed accordingly.

Recommendation - 12.

1. When the disturbance is outside the Indo-Pakistan, area, the principal associated phenomenon like precipitation, cloudiness, pressure fall or wind shifts, which makes one infer the existence of the disturbance, should be mentioned in the inference.

2. When the disturbance enters the Indo-Pakistan area, we may describe it wherever possible in terms of the actual synoptic situations. For example:-

Western disturbance lies as an upper air trough,
,, ,, ,, ,, a sea-level trough,
,, ,, ,, ,, an upper air low,
,, ,, ,, ,, a sea-level low.

When two or more closed isobars at 2 mb intervals are discernible on the sea-level chart, the disturbance may be described as a western depression, as has been done in the earlier days.

3. The use of the term "Secondary western disturbance" be altogether avoided, as most of these so-called secondaries do not appear to form in our region in the same way as secondaries do in the middle latitudes. When a second 'low' forms over Rajasthan or Madhya Pradesh, it may be described as an 'induced low' or simply as 'a low'. (This would mean that term 'Primary western disturbance' would also be not used).

Sd/-
for D. D. G. F.

DDGF UOI No. W394/ Poona-5, dated the 11 February, 1957.

APPENDIX - II.

R.Cs: Bombay/ Calcutta/ Madras/ Nagpur/ New Delhi.

Sub: Need for evolution of uniform criteria for locating and tracing movement of western disturbances.

Ref: Recommendation 9 of F.Os' Conference, 1960 and in continuation of DDGF.UOI. No.W394 dated 11.2.1957.

D.G.O. has approved the above recommendation. Forecasting Offices under your control may be asked to adopt the recommendation with effect from 1.6.1961. Recommendation 9 of F.Os' Conference (1960) is reproduced below. For ready reference, copy of DDGF UOI No. W394 dated 11.2.1957 is also enclosed.

The receipt of this letter may kindly be acknowledged.

Recommendation - 9.

1. Paras 1 and 3 of the recommendation of the previous Forecasting Officers' Conference (1956) are to be strictly followed.

2. The adoption of terminology given in para 2 of the previous Forecasting Officers' Conference (1956) is to be continued, keeping in view the following:-

i) Sea level lows or troughs need not be referred to as "Western Disturbances" unless those systems are discernible at 0.9 km or aloft.

ii) In cases where sea level systems are complex and feeble but the upper air systems are more marked, then the 'disturbance' be described in terms of upper air systems.

iii) In the case of upper air systems, the appropriate levels (1.5 km and/or aloft or 850 mbs and/or aloft) at which the systems are discernible should be specified.

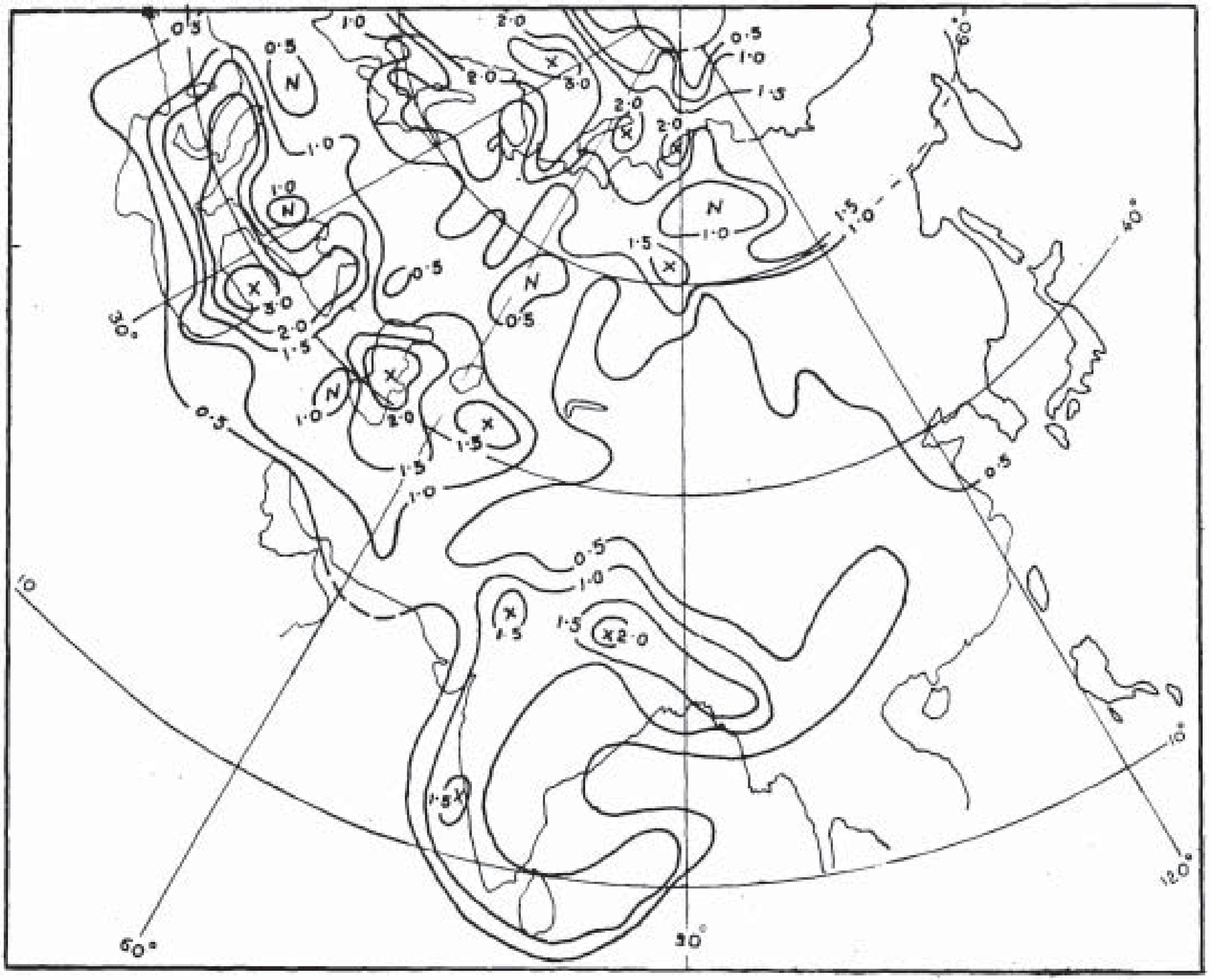
3. When there is evidence to infer that the system is affecting the Eastern Himalayas during its eastward travel and when it is not possible to describe the system in terms of paras 1 and 2 above, the term "Western Disturbance" may be used without any specification. The use of the term 'westerly wave' should be avoided in such cases.

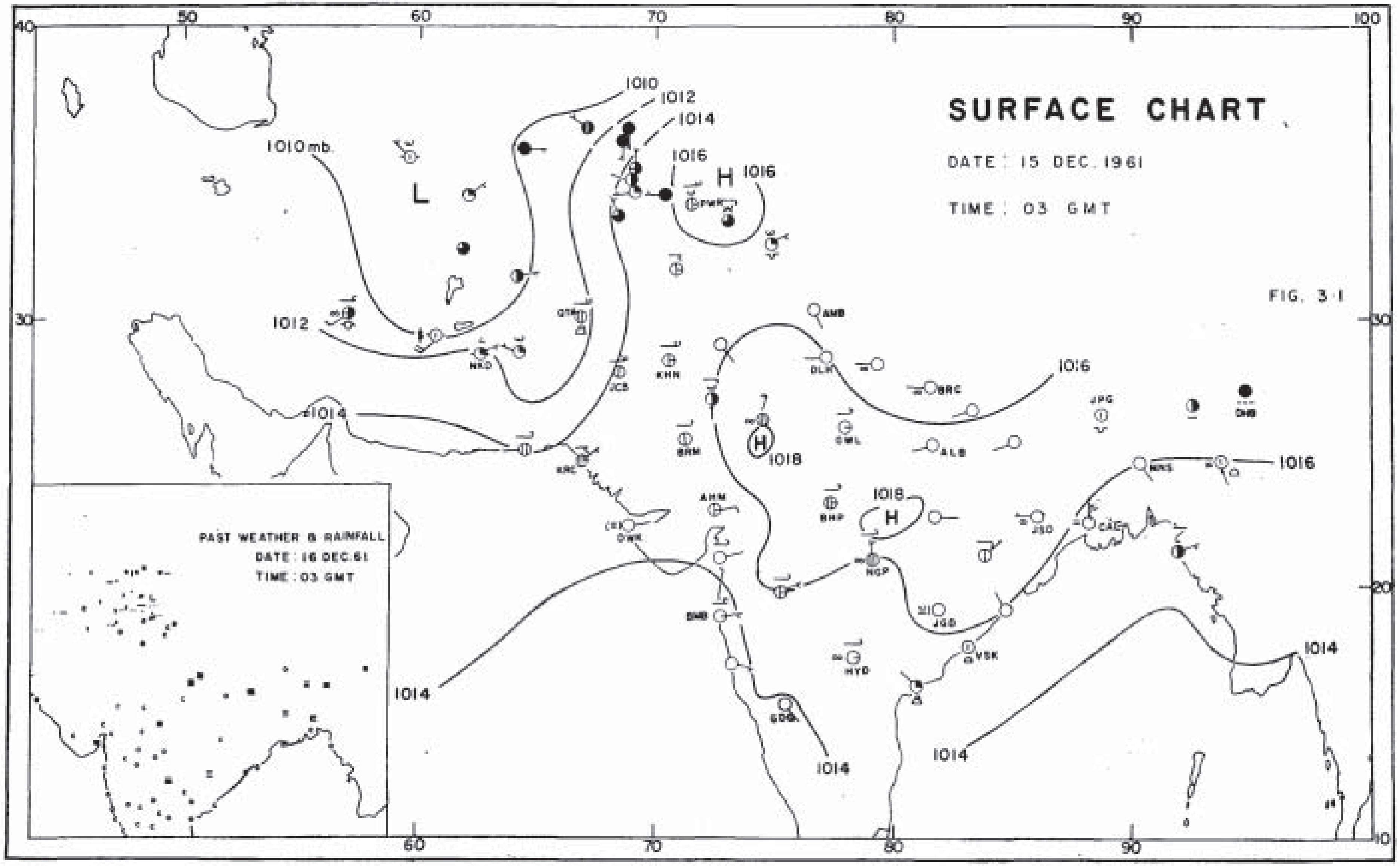
Sd/-

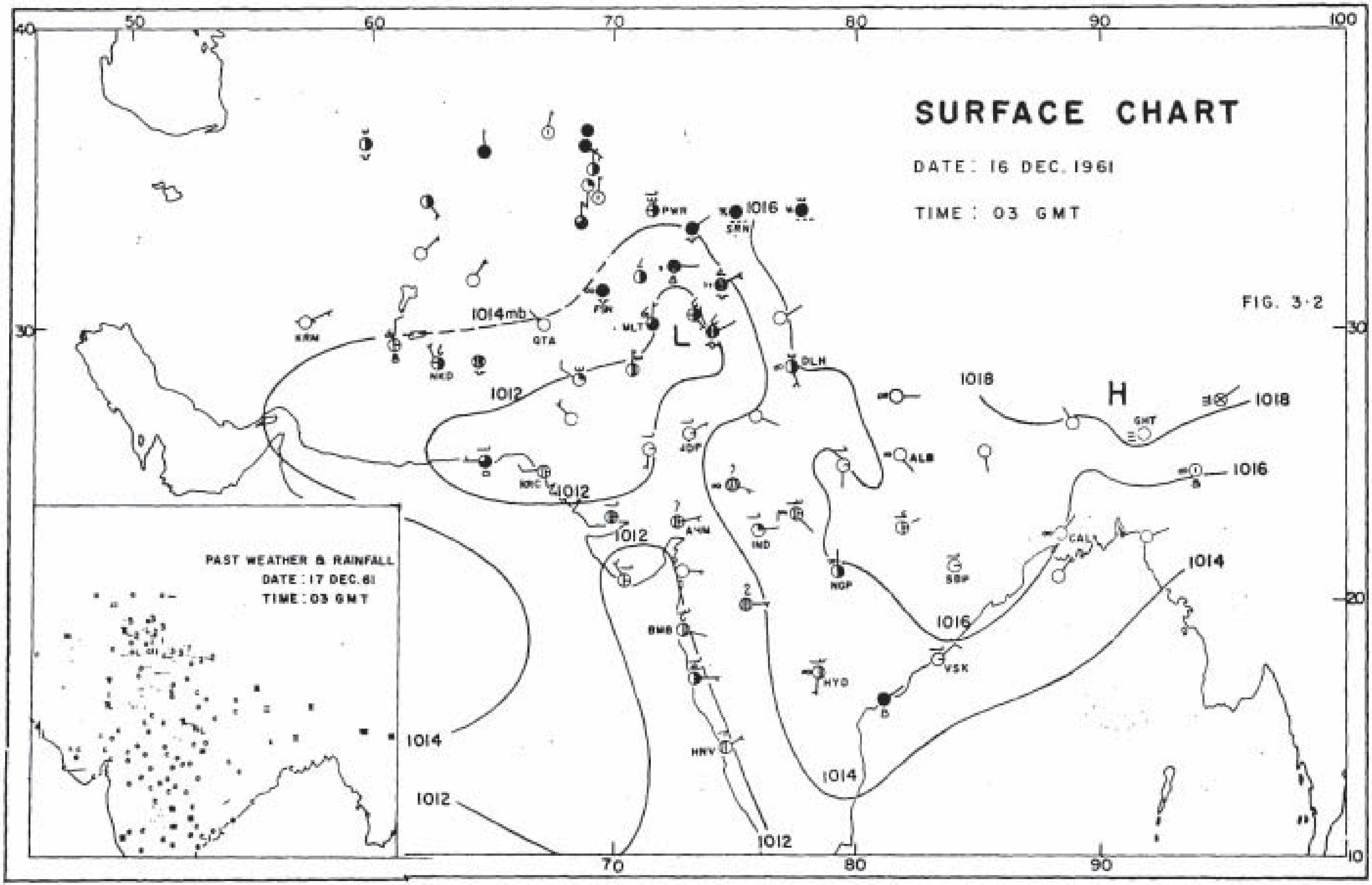
(T.M.K. Nedungadi)
for D. D. G. F.

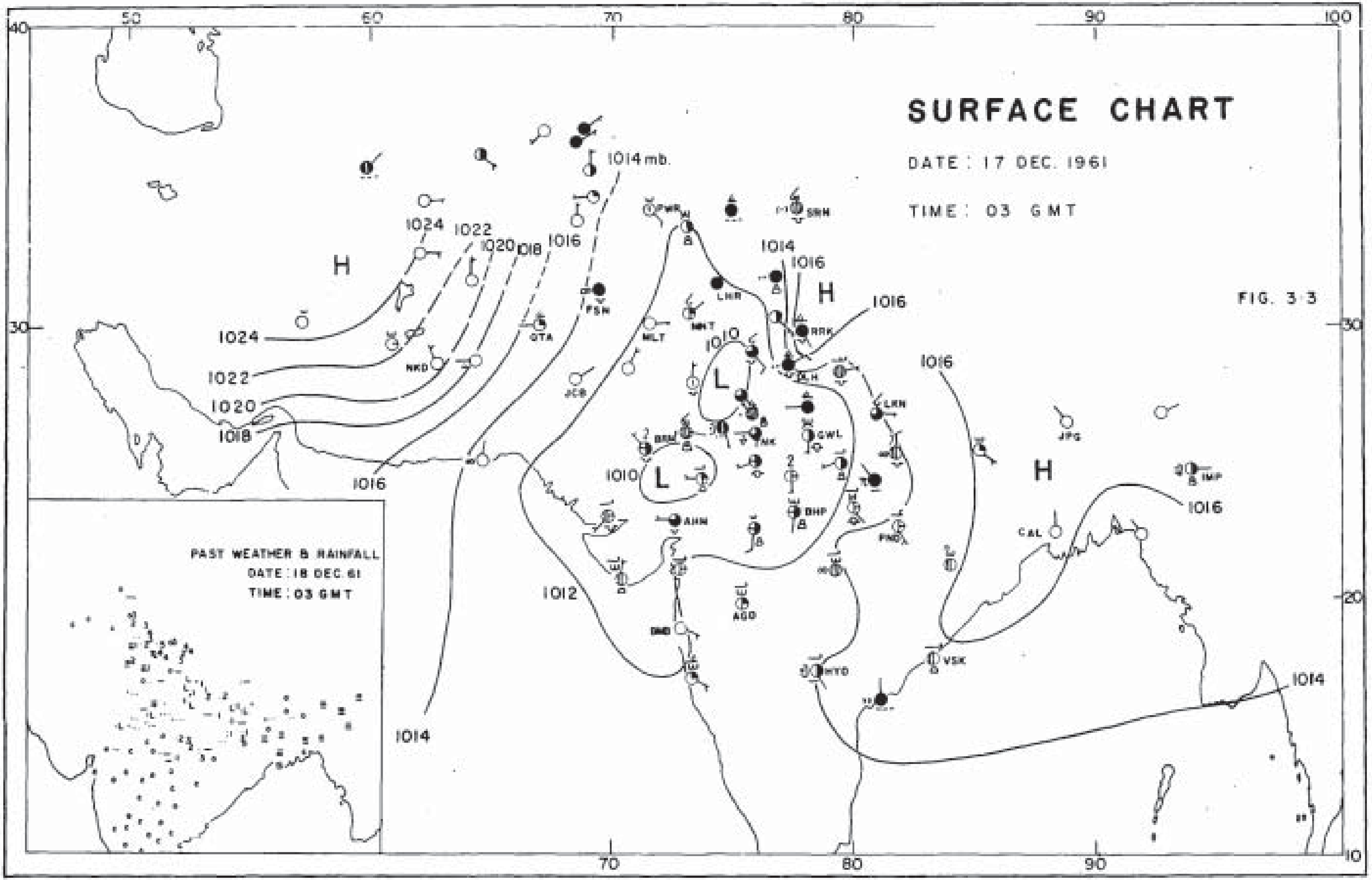
DDGF UOI No. W394/316-20 Poona-5, dated the 7 April, 1961.

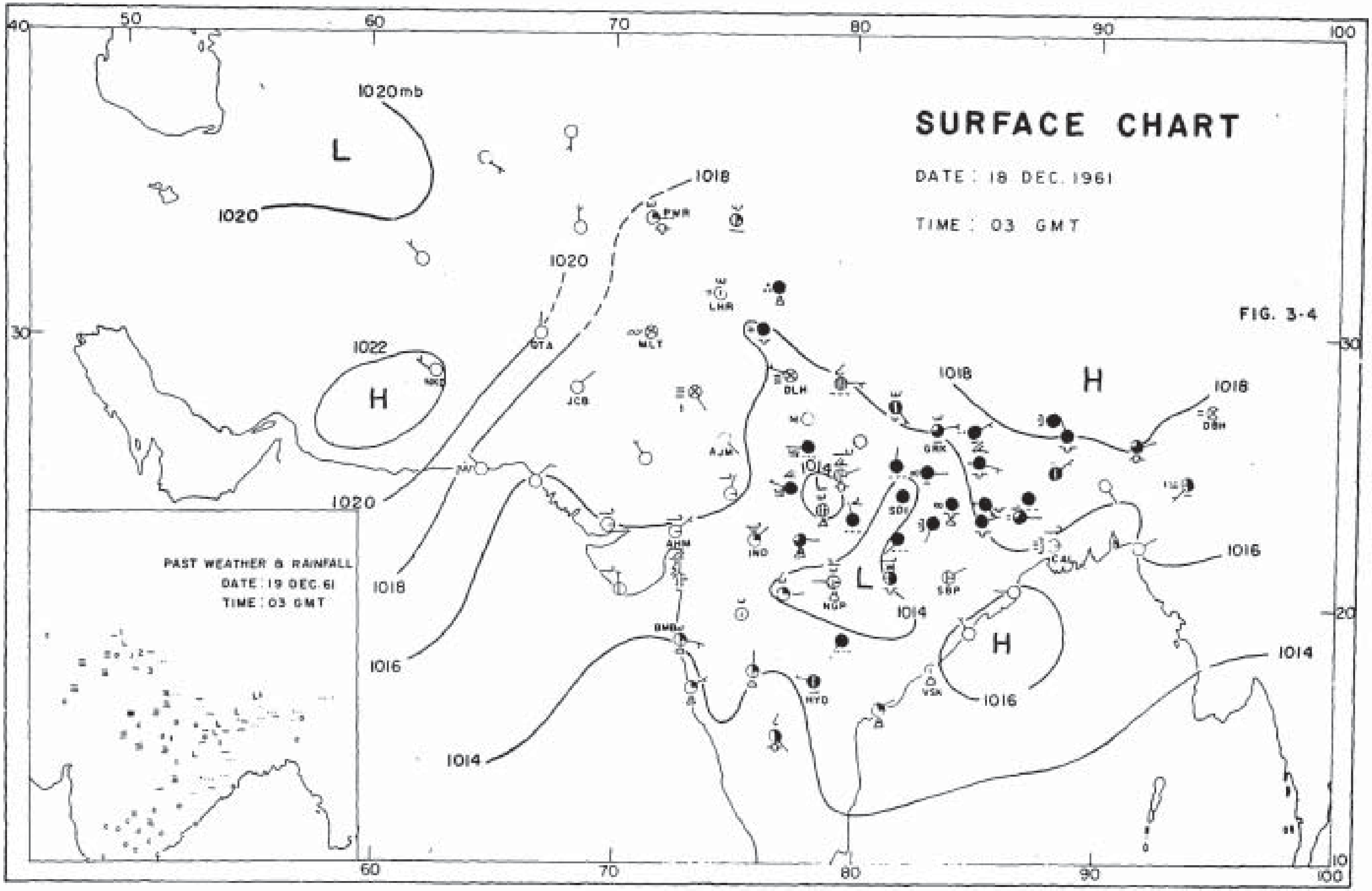
FIG. 2·1 AVERAGE NUMBER OF LOW PRESSURE CENTRES PER MONTH DURING WINTER (X-MAX., N-MIN)

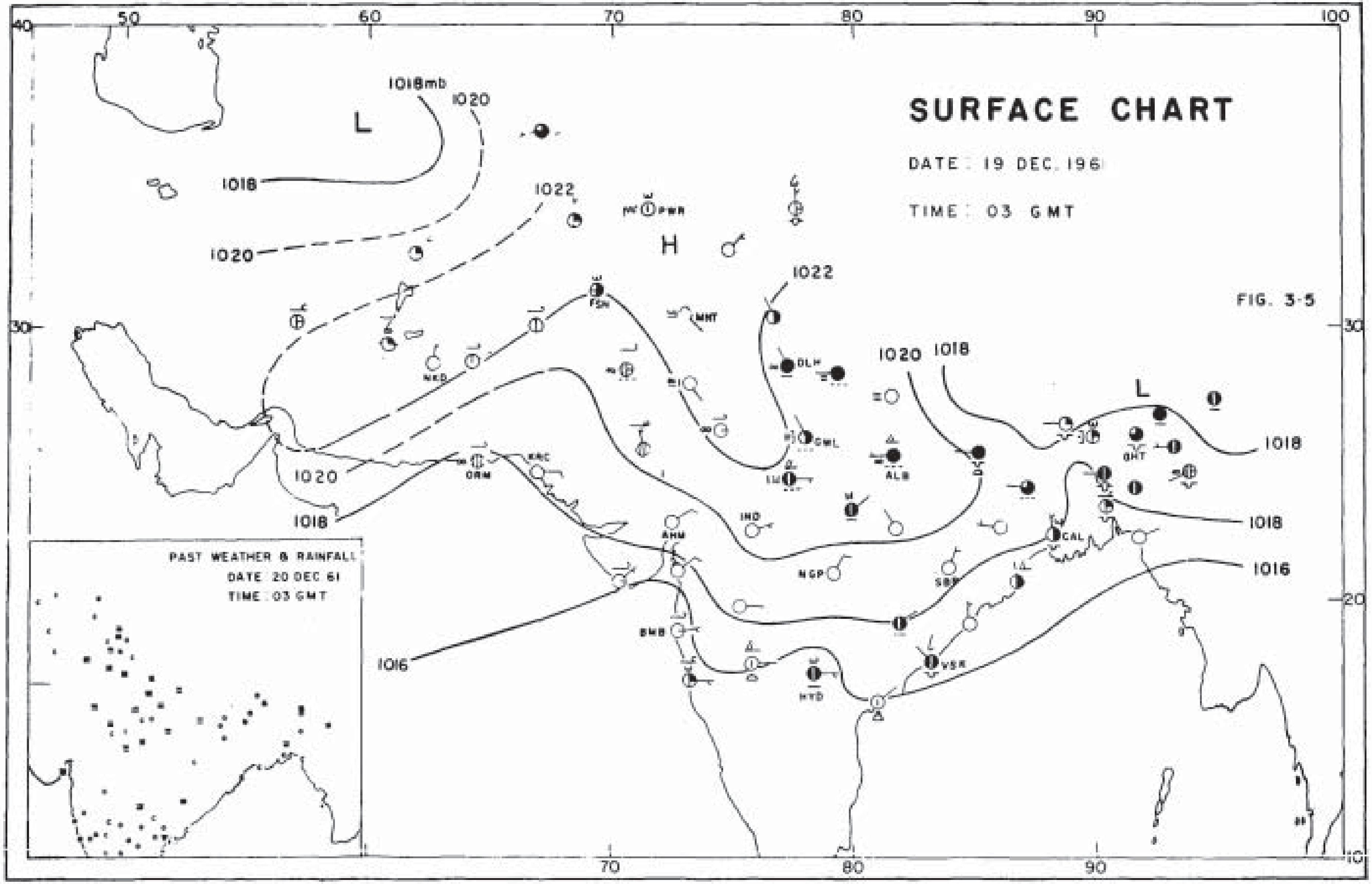



SURFACE CHART
DATE : 15 DEC. 1961
TIME : 03 GMT
FIG. 3·1
1010 mb.
1010
1012
1014
1016
1018
L
H
AMB
DLH
BRC
JPG
DHB
GWL
ALB
NNS
BRM
KHN
JCB
KRC
AHM
BHP
JGD
CAC
DWK
NGP
JGD
BMB
HYD
VSK
GDG
NKD
PWR
PAST WEATHER & RAINFALL
DATE : 16 DEC. 61
TIME : 03 GMT


SURFACE CHART
DATE: 16 DEC. 1961
TIME: 03 GMT
FIG. 3·2
PAST WEATHER & RAINFALL
DATE: 17 DEC. 61
TIME: 03 GMT
1014mb
1012
1014
1016
1018
L
H
PWR
SRN
DLH
QTA
KRM
NKD
MLT
JDP
KRC
AHM
IND
NGP
ALB
SBP
CAL
GHT
BMB
HYD
VSK
HRV
40
50
60
70
80
90
100
30
20
10


SURFACE CHART
DATE : 17 DEC. 1961
TIME : 03 GMT
FIG. 3.3
PAST WEATHER & RAINFALL
DATE : 18 DEC. 61
TIME : 03 GMT
1024
1022
1020
1018
1016
1014
1014 mb.
1012
1010
H
L
SRN
PWR
LHR
MNT
MLT
RRK
LKN
GWL
DHP
AHM
AGD
BMD
HYD
VSK
CAL
JPG
IMP
QTA
PSN
JCB
NKD
PND
50
60
70
80
90
100
40
30
20
10


SURFACE CHART
DATE : 18 DEC. 1961
TIME : 03 GMT
FIG. 3-4
1020mb
1020
1018
1022
1016
1014
L
H
PWR
LHR
MLT
QTA
JCB
DLH
AJM
AHM
BMB
IND
NGP
SDI
GRK
DBH
CAL
SBP
VSK
HYD
PAST WEATHER & RAINFALL
DATE : 19 DEC. 61
TIME : 03 GMT


SURFACE CHART
DATE : 19 DEC. 1961
TIME : 03 GMT
FIG. 3-5
1018mb
1020
1018
1022
L
H
PWR
FSN
LMHT
DLH
GWL
ALB
NKD
ORM
KRC
AHM
IND
NGP
SBP
CAL
GHT
BMB
HYD
VSK
1016
PAST WEATHER & RAINFALL
DATE : 20 DEC 61
TIME : 03 GMT
40
50
60
70
80
90
100
30
20
10

PRESSURE CHANGES (mb) AT 03 GMT

FIG. 3·6

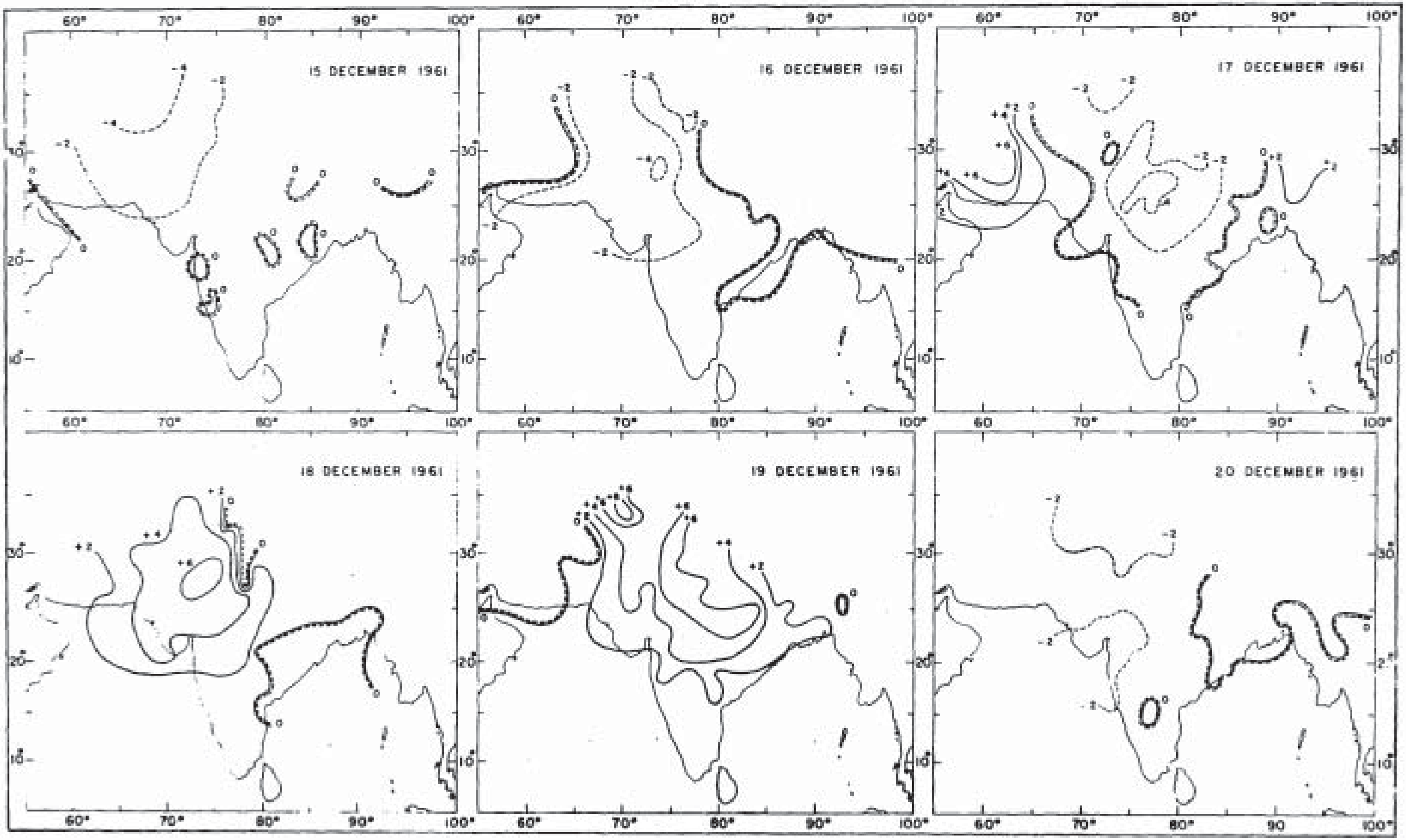
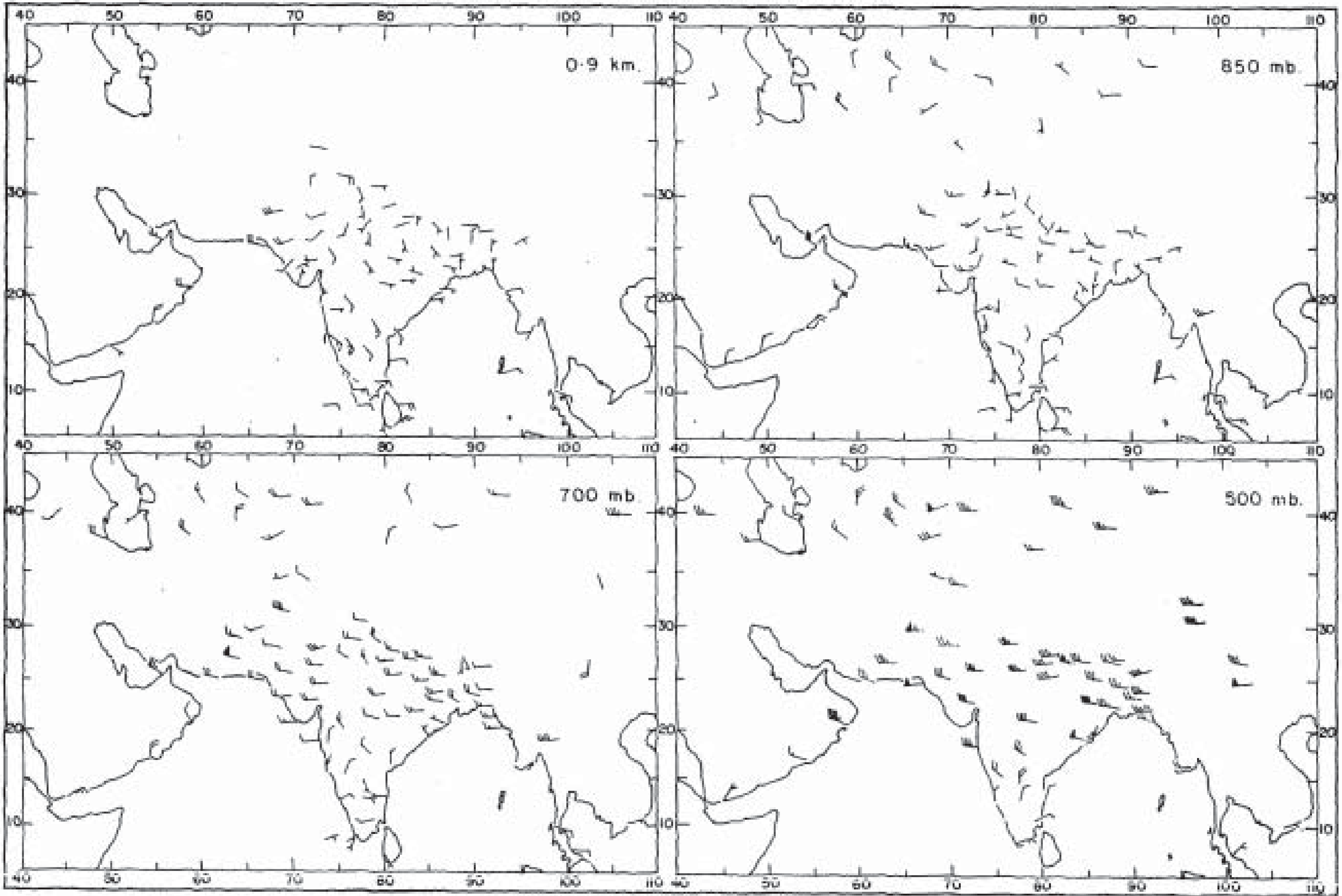
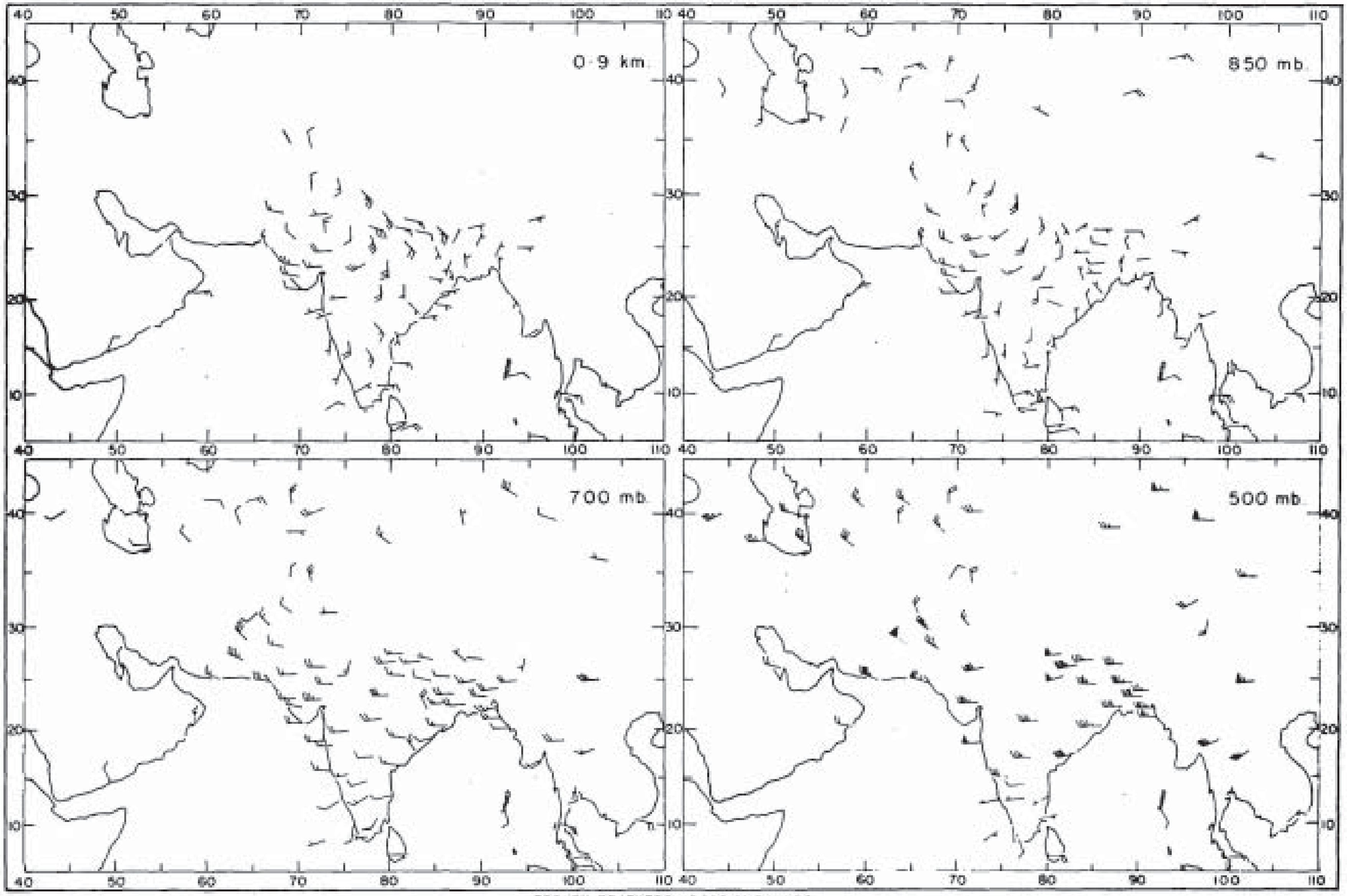


FIG. 3·7. UPPER WINDS DATE : 16 DEC. 61 TIME : 00 GMT



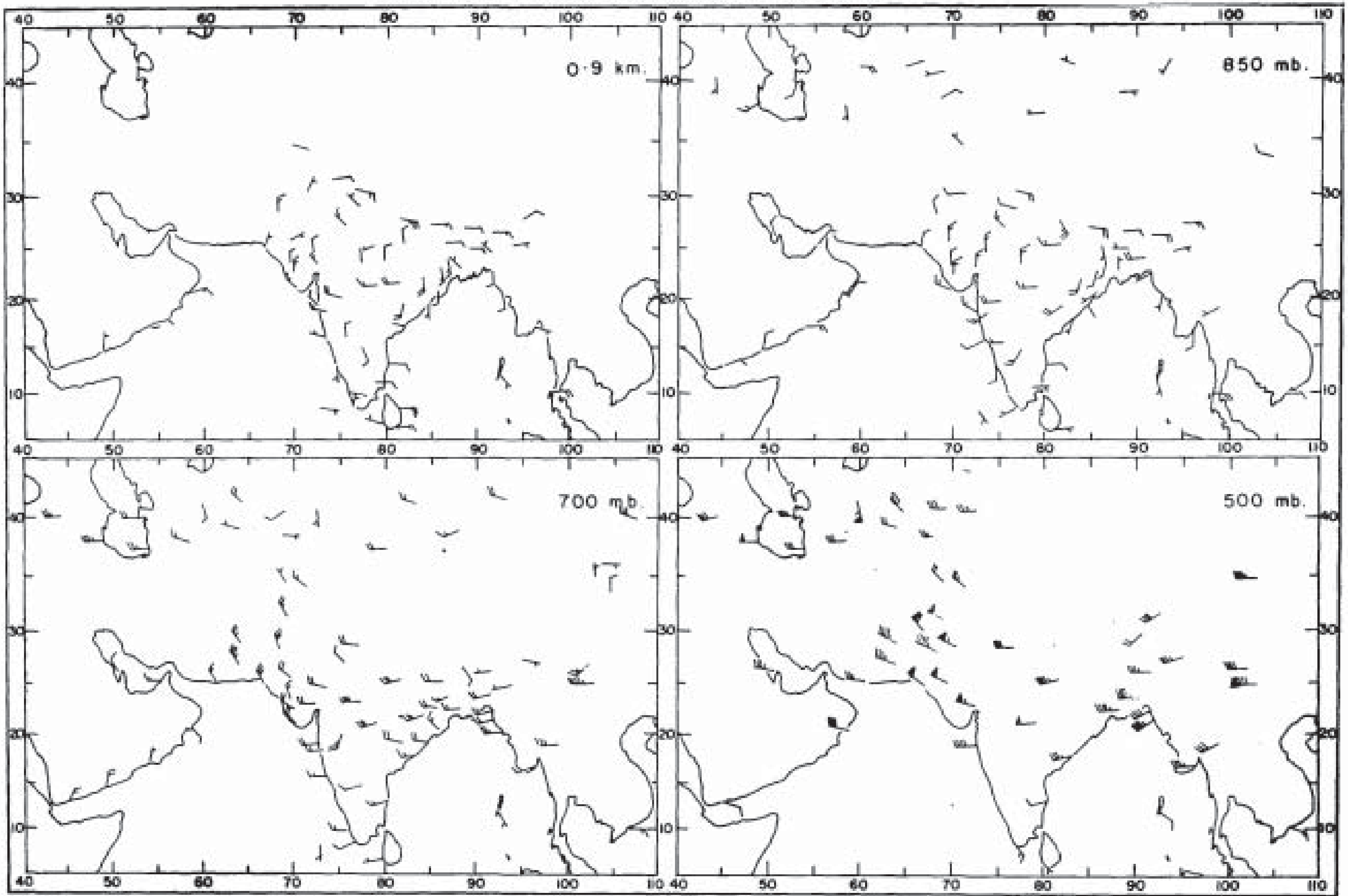
BROKEN FEATHERS — 0600 GMT WINDS

FIG. 3-8. UPPER WINDS DATE: 17 DEC. 61 TIME: 00 GMT



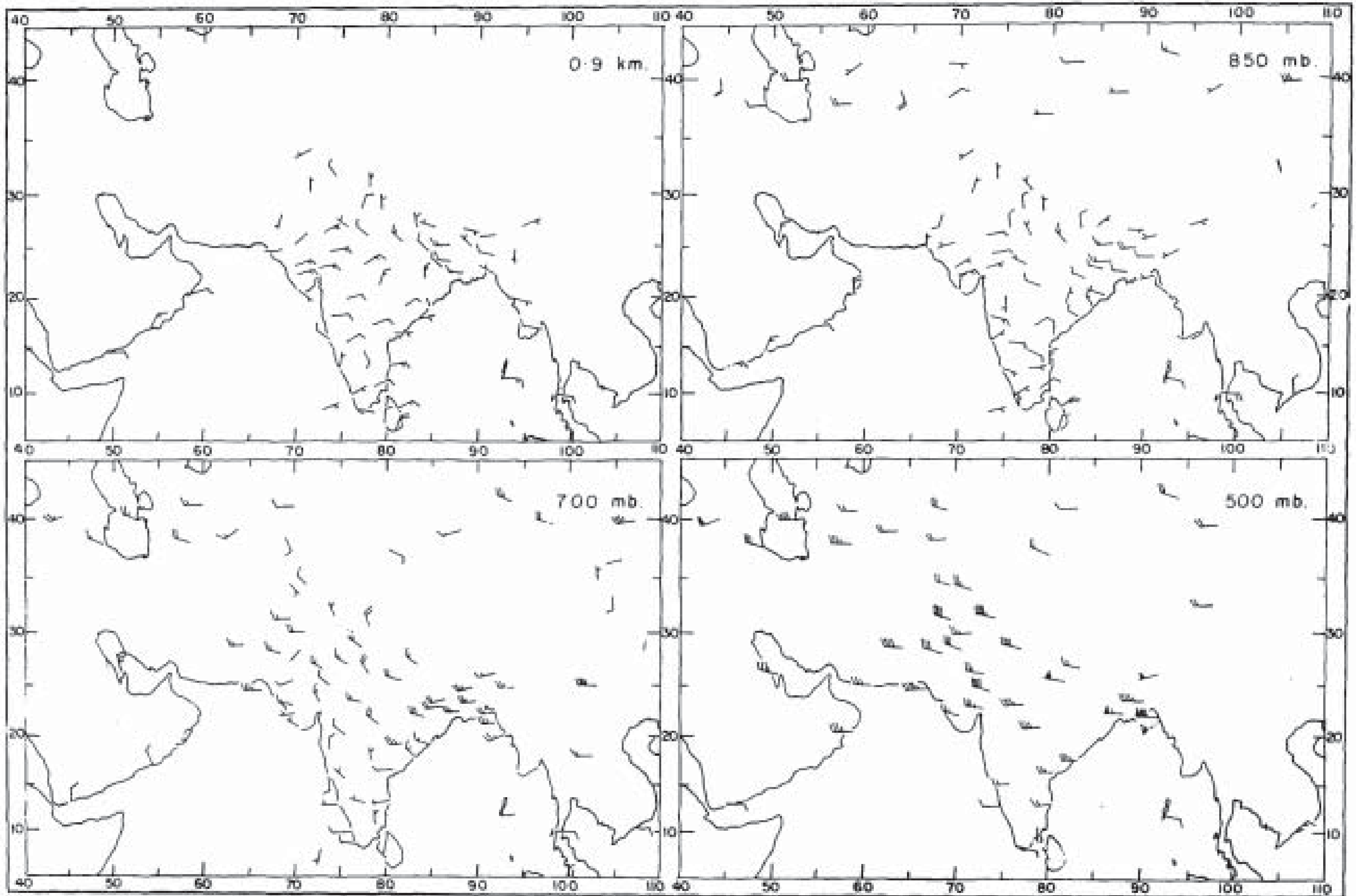
BROKEN FEATHERS - 0600 GMT WINDS

FIG 3-9 UPPER WINDS DATE: 18 DEC. 61 TIME: 00 GMT

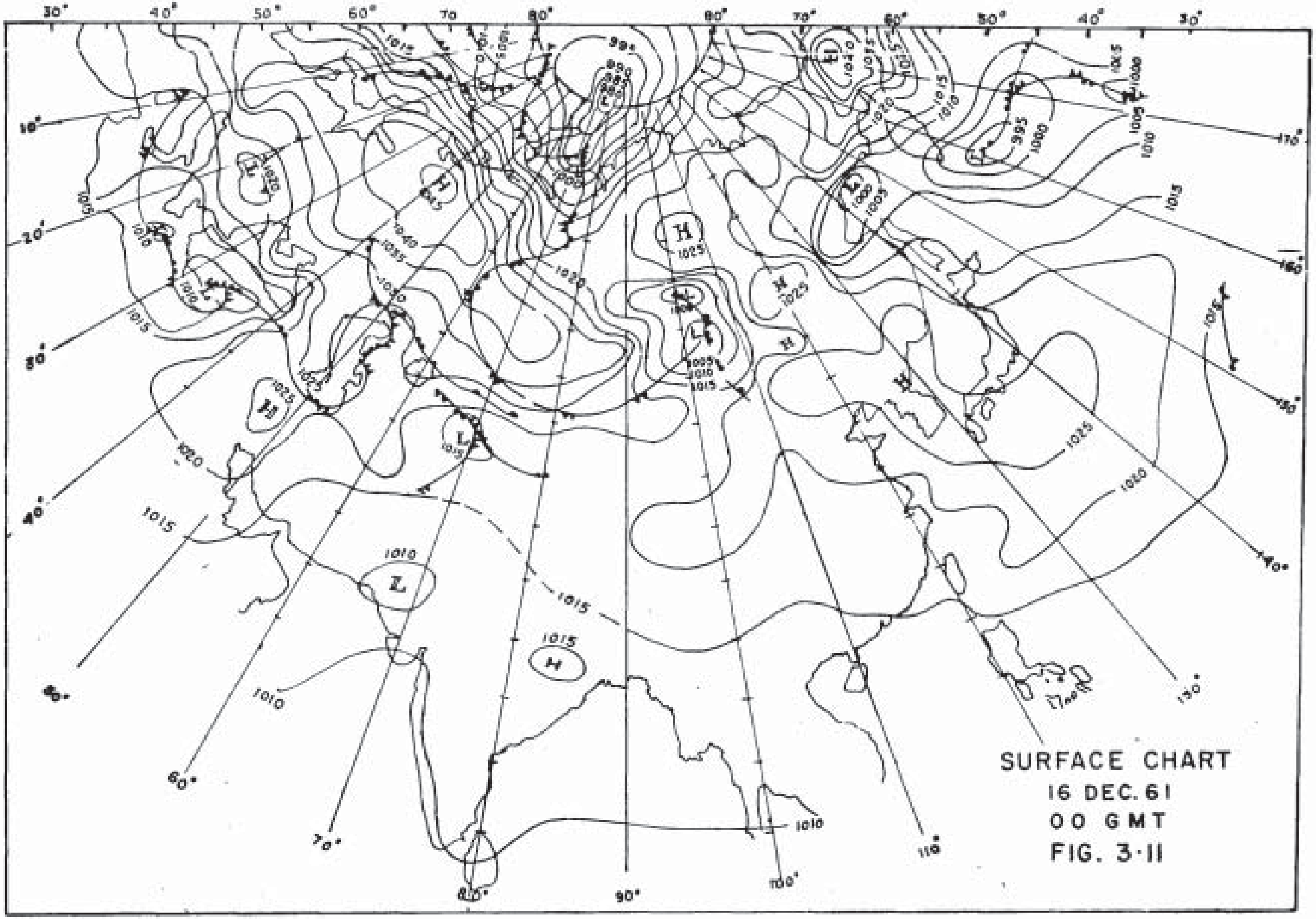


BROKEN FEATHERS - 0600 GMT WINDS

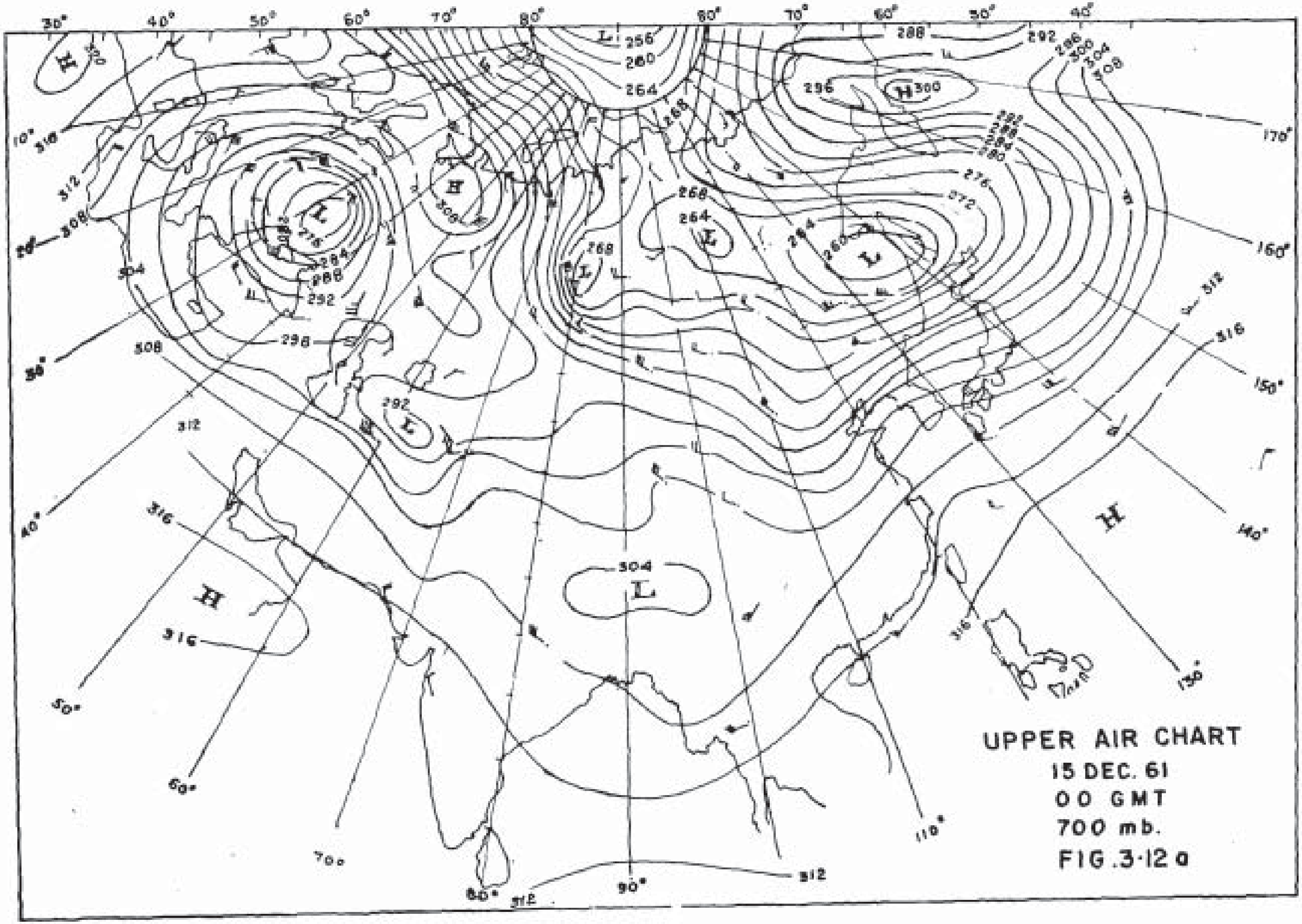
FIG. 3·10. UPPER WINDS DATE: 19 DEC. 61 TIME: 00 GMT



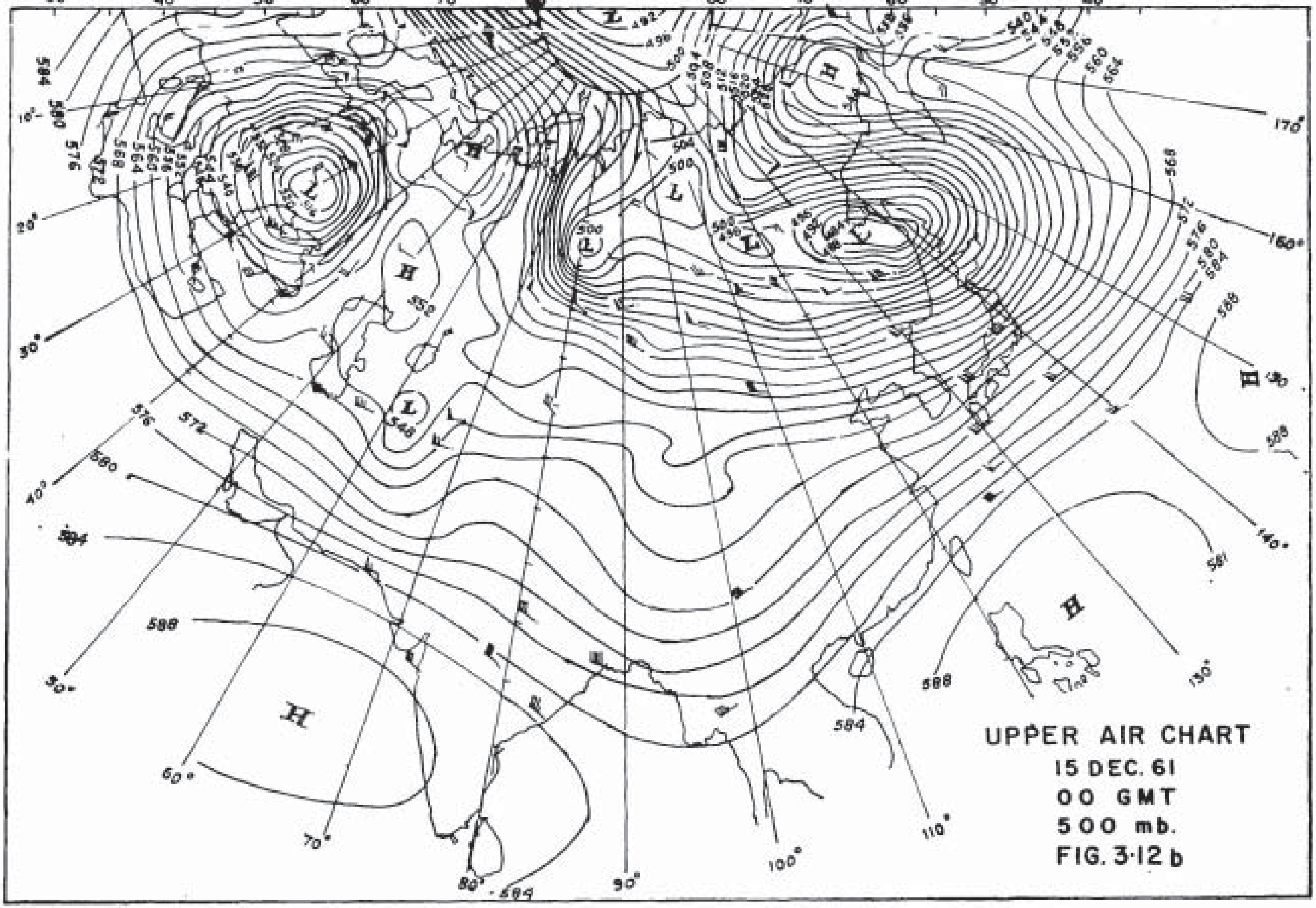
BROKEN FEATHERS - 0600 GMT WINDS



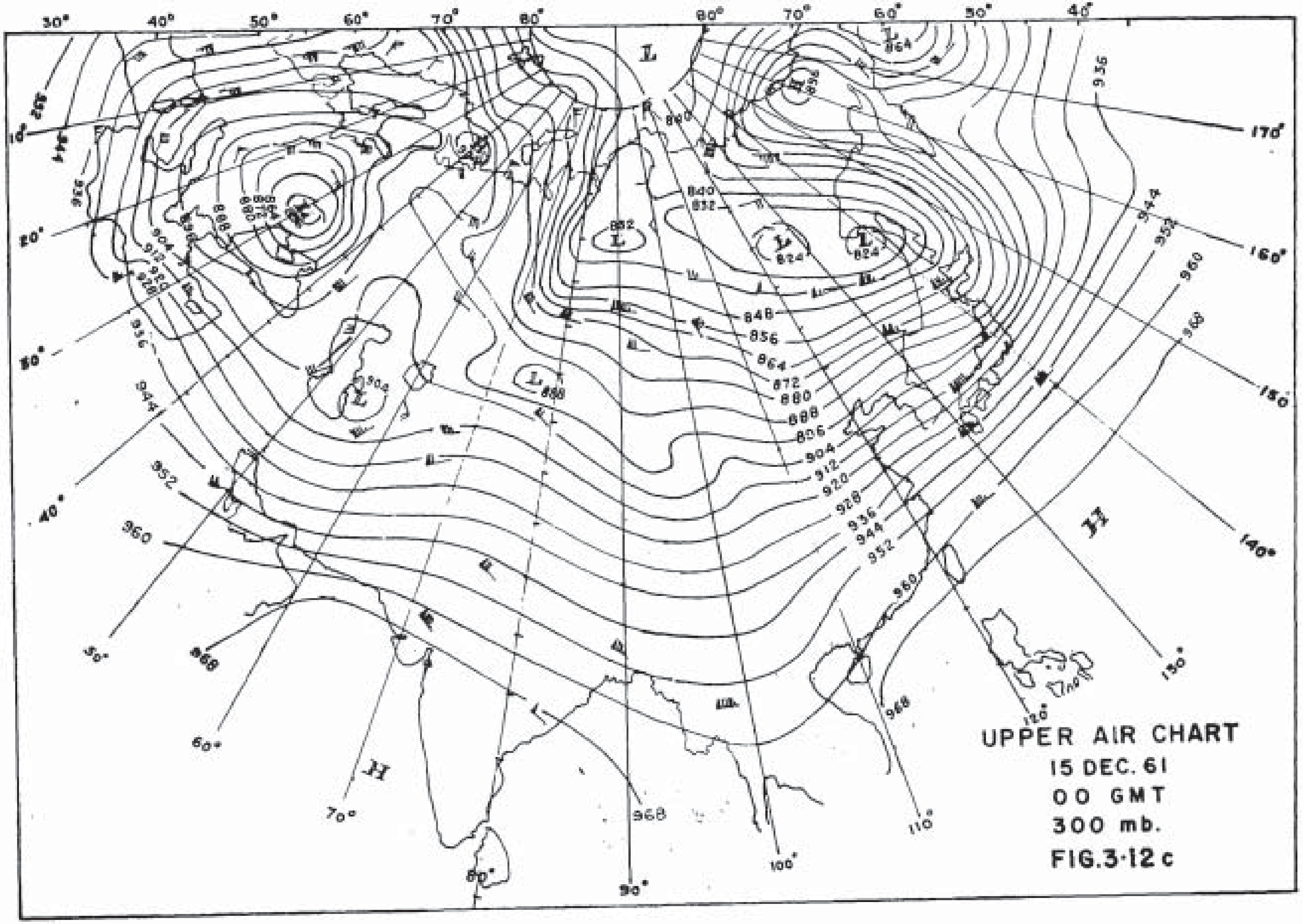
SURFACE CHART
16 DEC. 61
00 GMT
FIG. 3·11



UPPER AIR CHART
15 DEC. 61
00 GMT
700 mb.
FIG. 3·12 a



UPPER AIR CHART
15 DEC. 61
00 GMT
500 mb.
FIG. 3·12 b



UPPER AIR CHART
15 DEC. 61
00 GMT
300 mb.
FIG. 3·12 c

FIG. 3·13. SEQUENCE OF WEATHER OVER DELHI (PALAM)

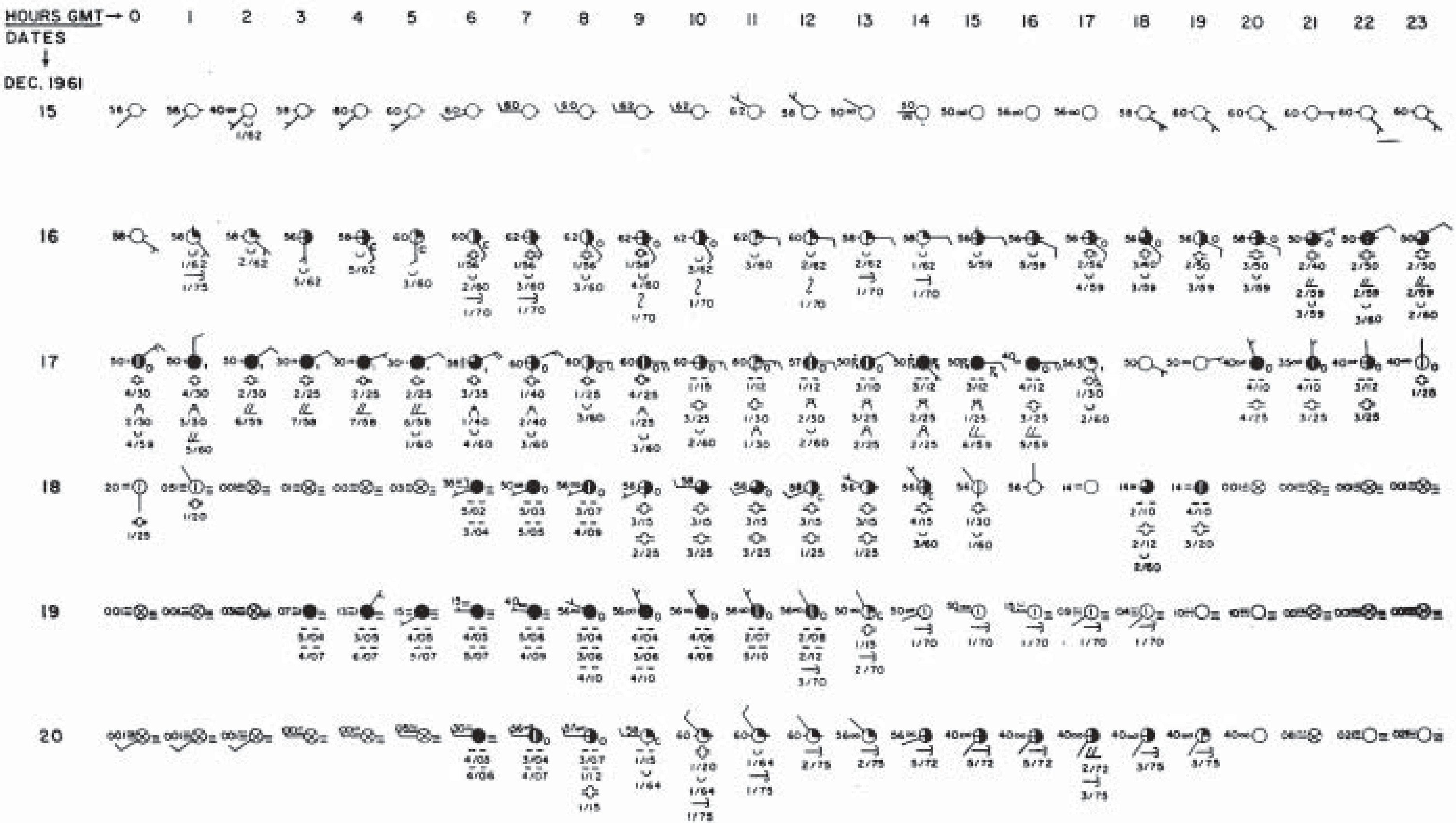


FIG. 3·14. VERTICAL TIME SECTION: DELHI (15 - 20 DEC. 1961)

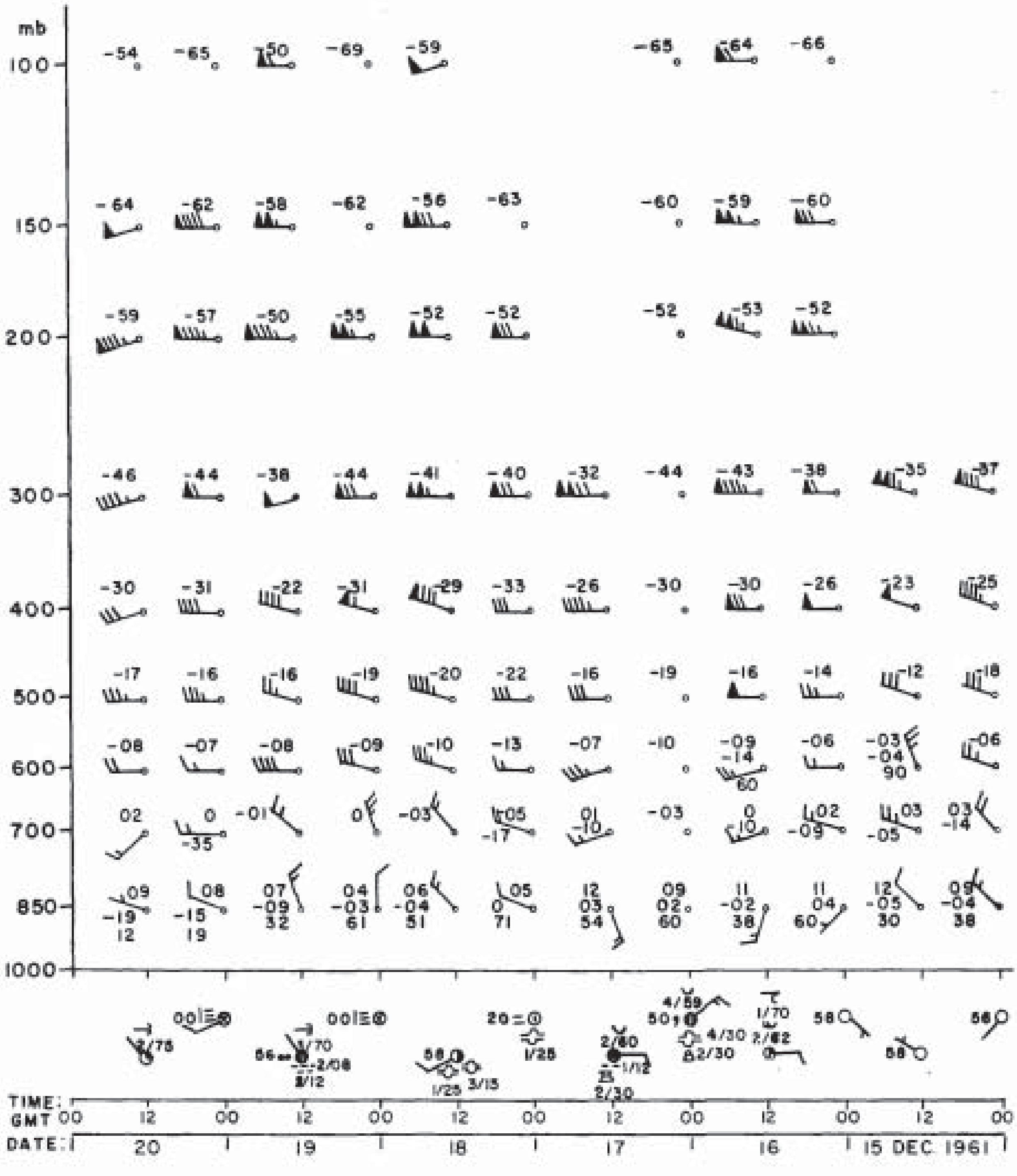
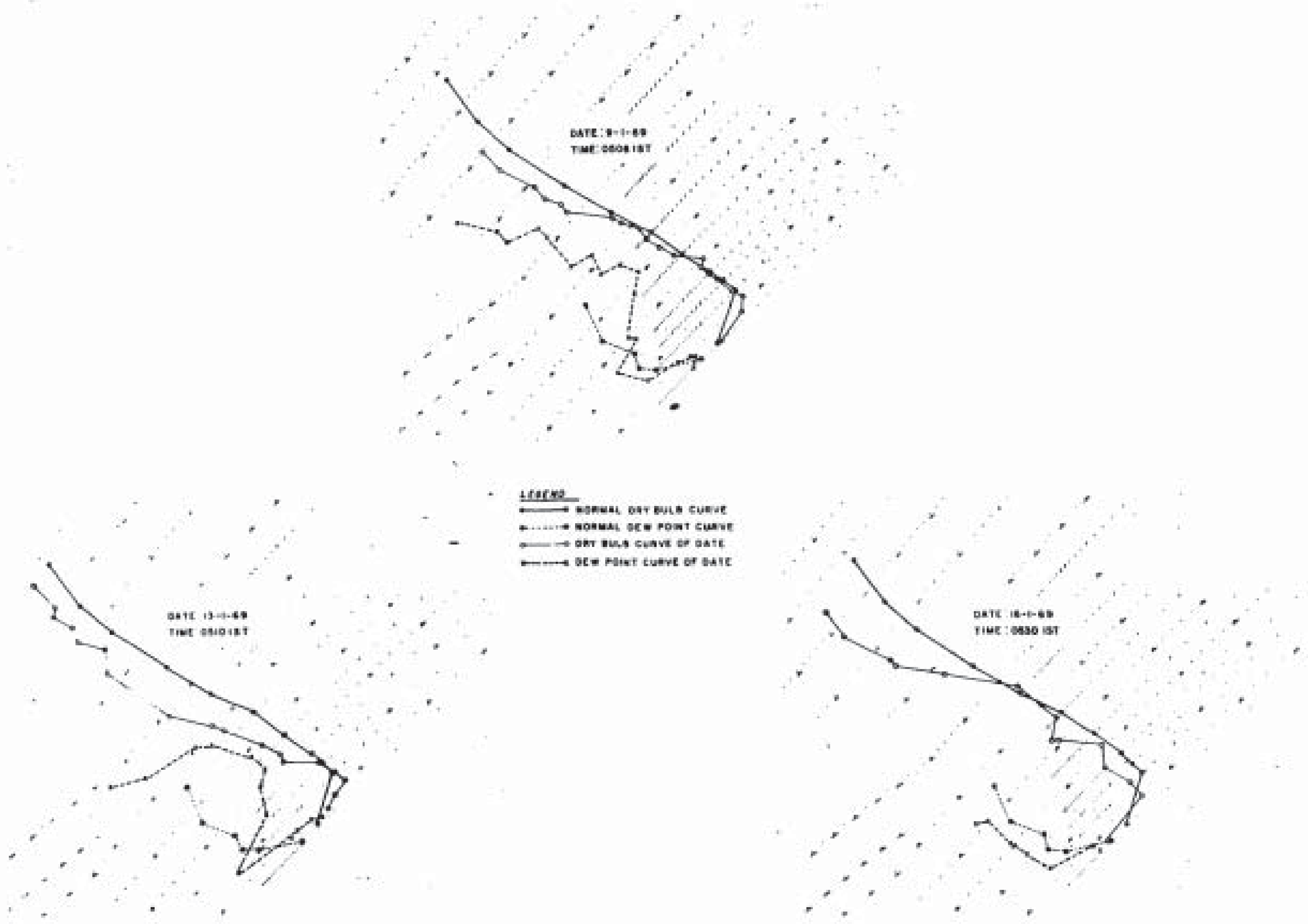
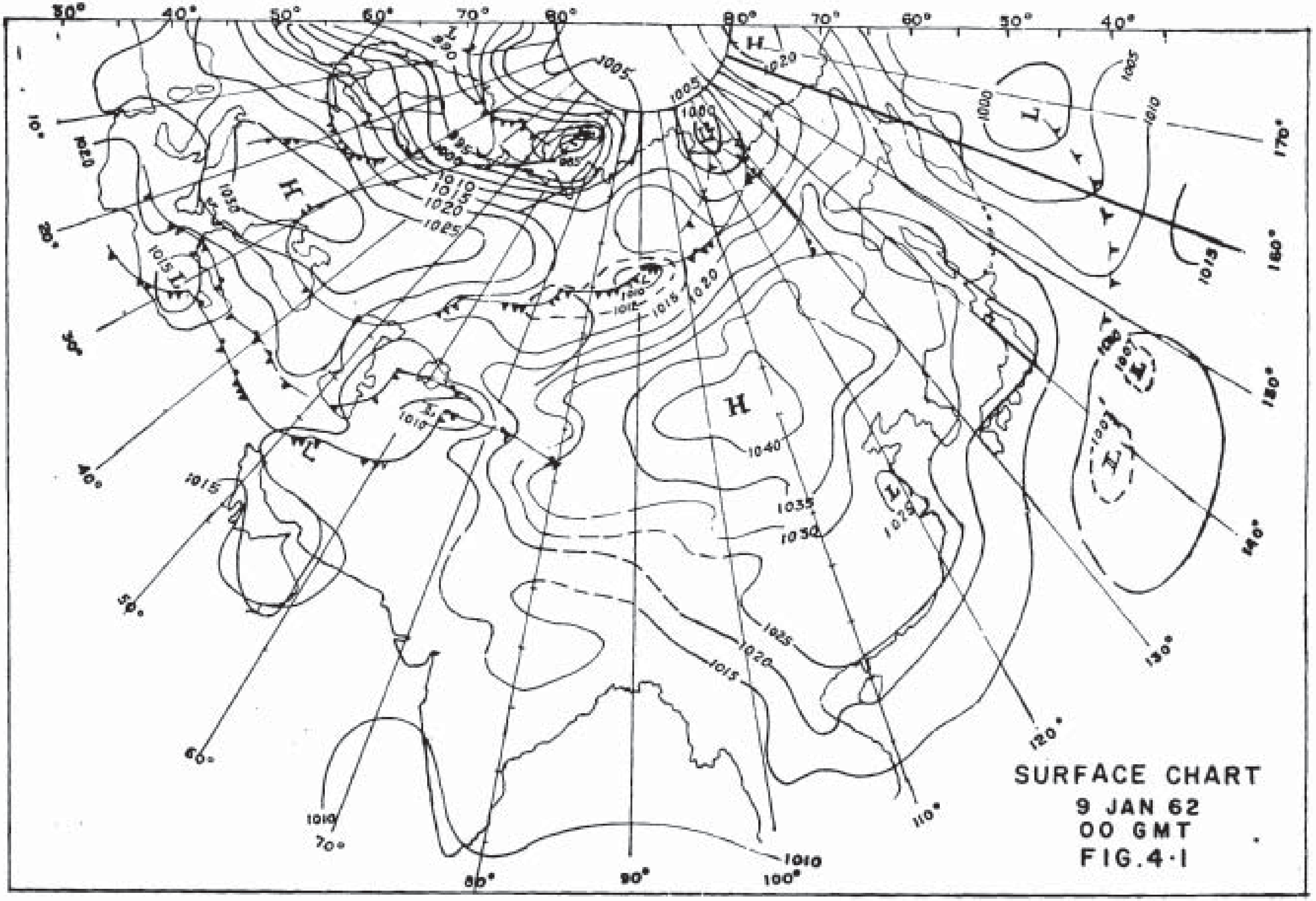
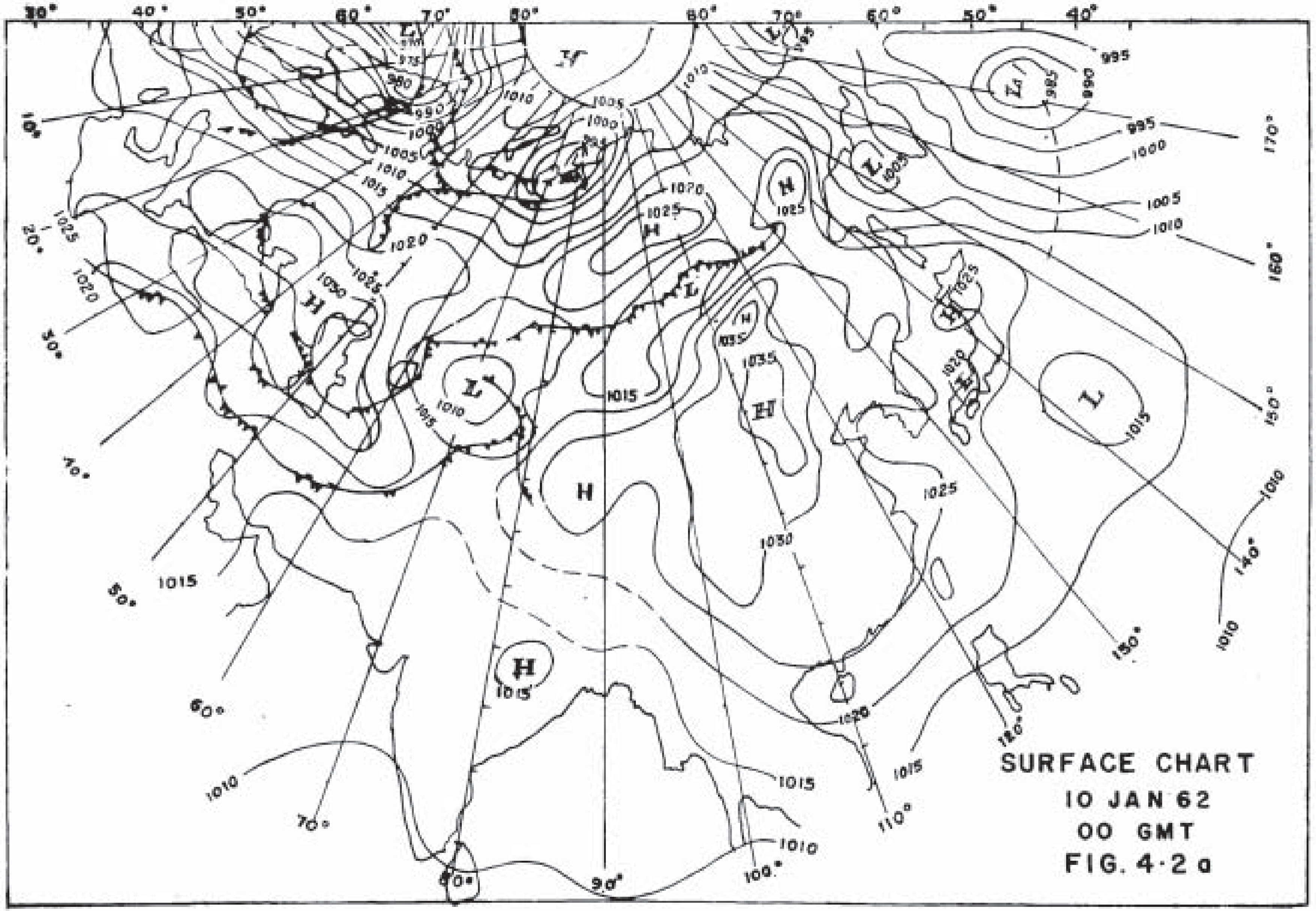


FIG. 3-15 RADIOSONDE ASCENT AT NEW DELHI

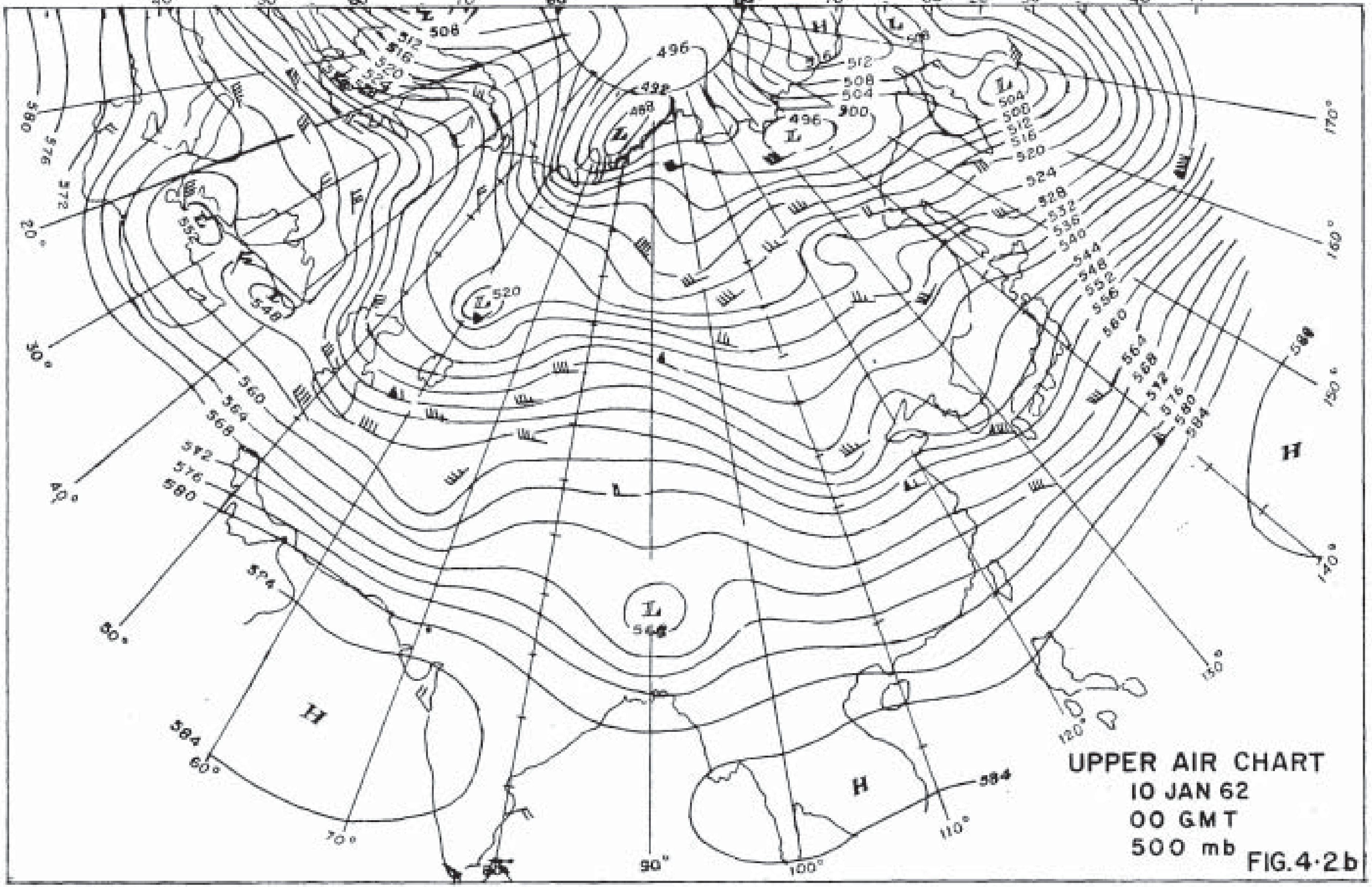




SURFACE CHART
9 JAN 62
00 GMT
FIG. 4·1



SURFACE CHART
10 JAN 62
00 GMT
FIG. 4·2 a



UPPER AIR CHART
10 JAN 62
00 GMT
500 mb
FIG.4·2b

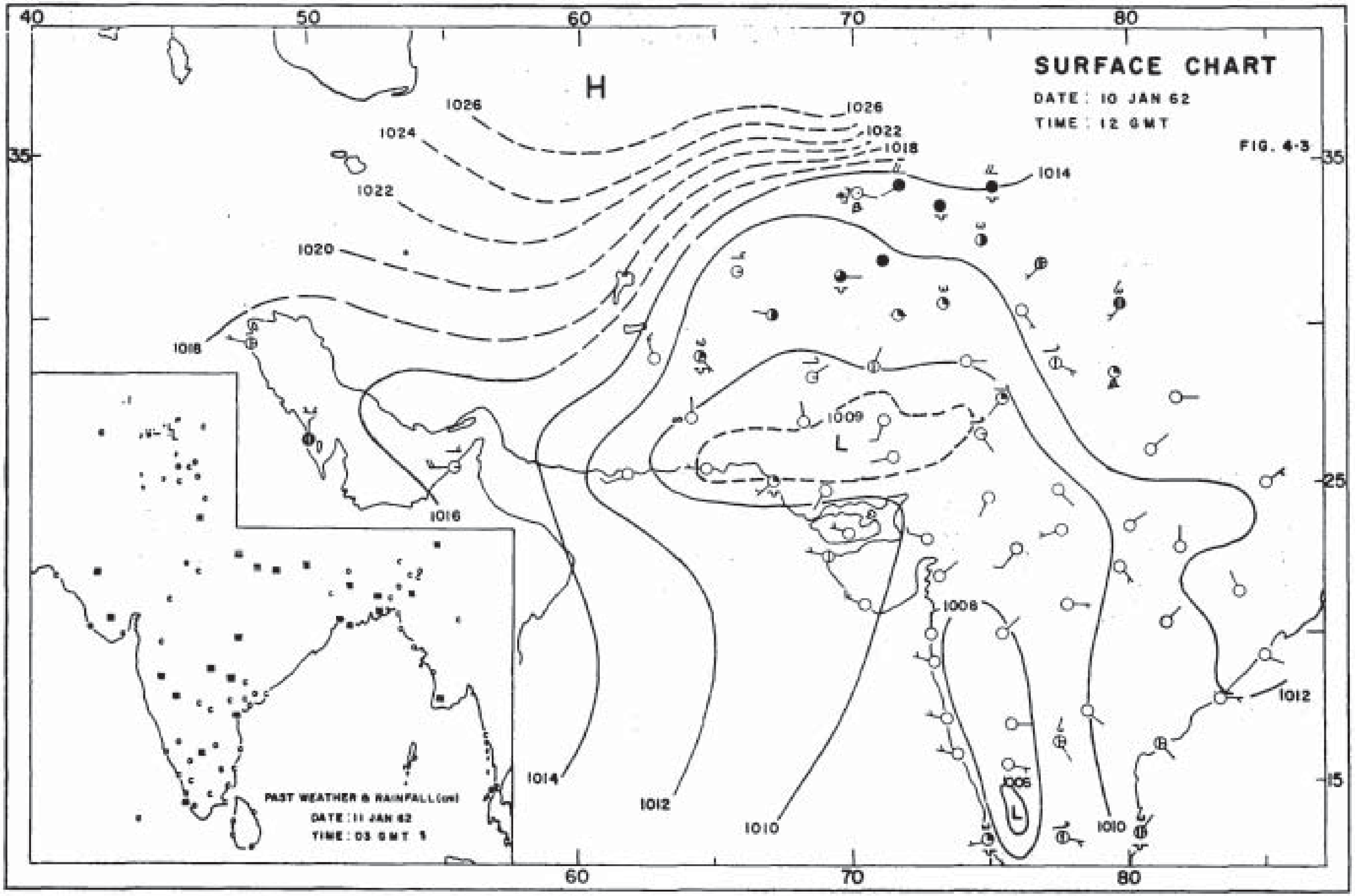

SURFACE CHART
DATE : 10 JAN 62
TIME : 12 GMT
FIG. 4-3
H
L
1026
1024
1022
1020
1018
1016
1014
1012
1010
1009
1008
1006
40
50
60
70
80
35
25
15
PAST WEATHER & RAINFALL (cm)
DATE : 11 JAN 62
TIME : 03 GMT

FIG. 4·4

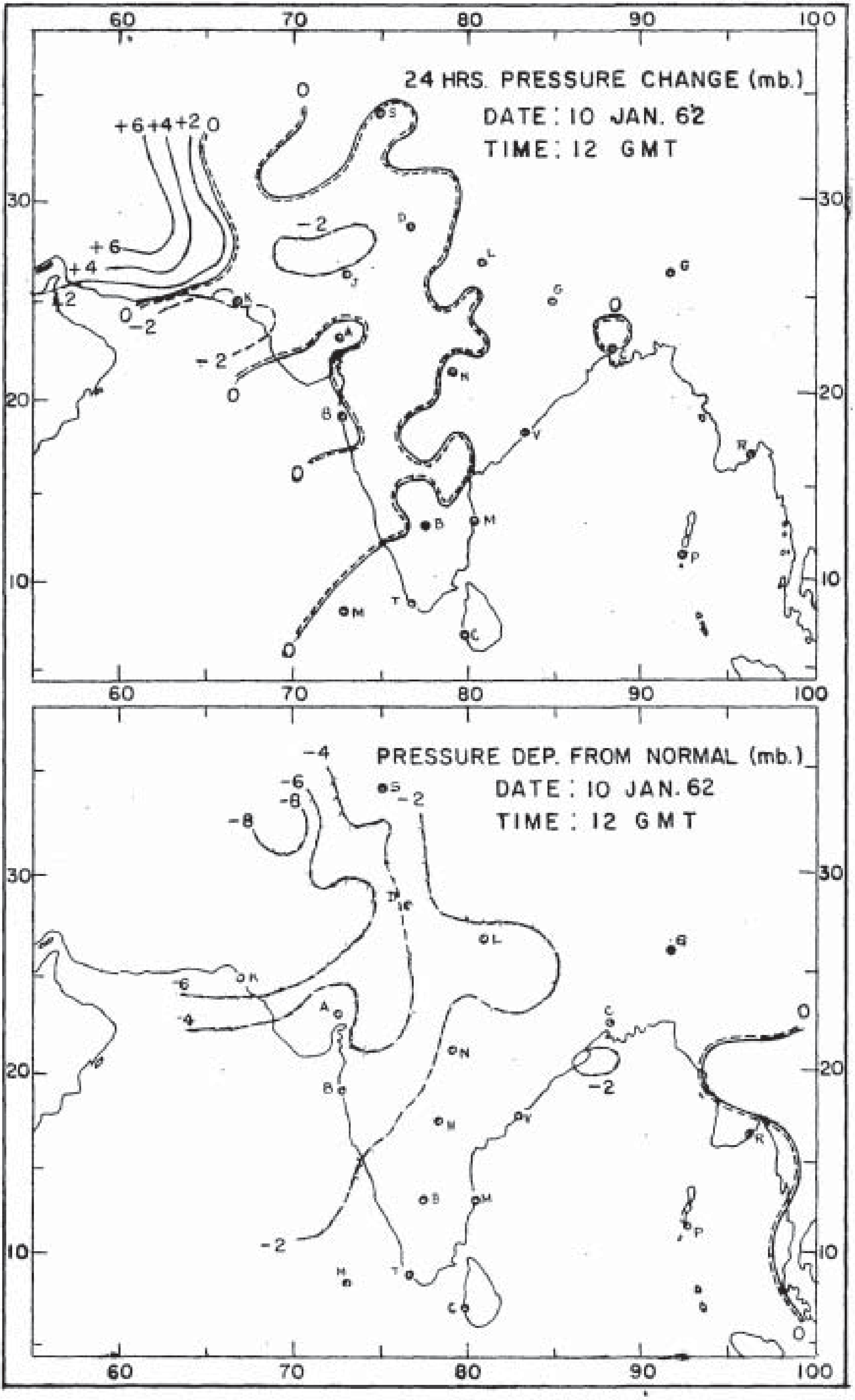
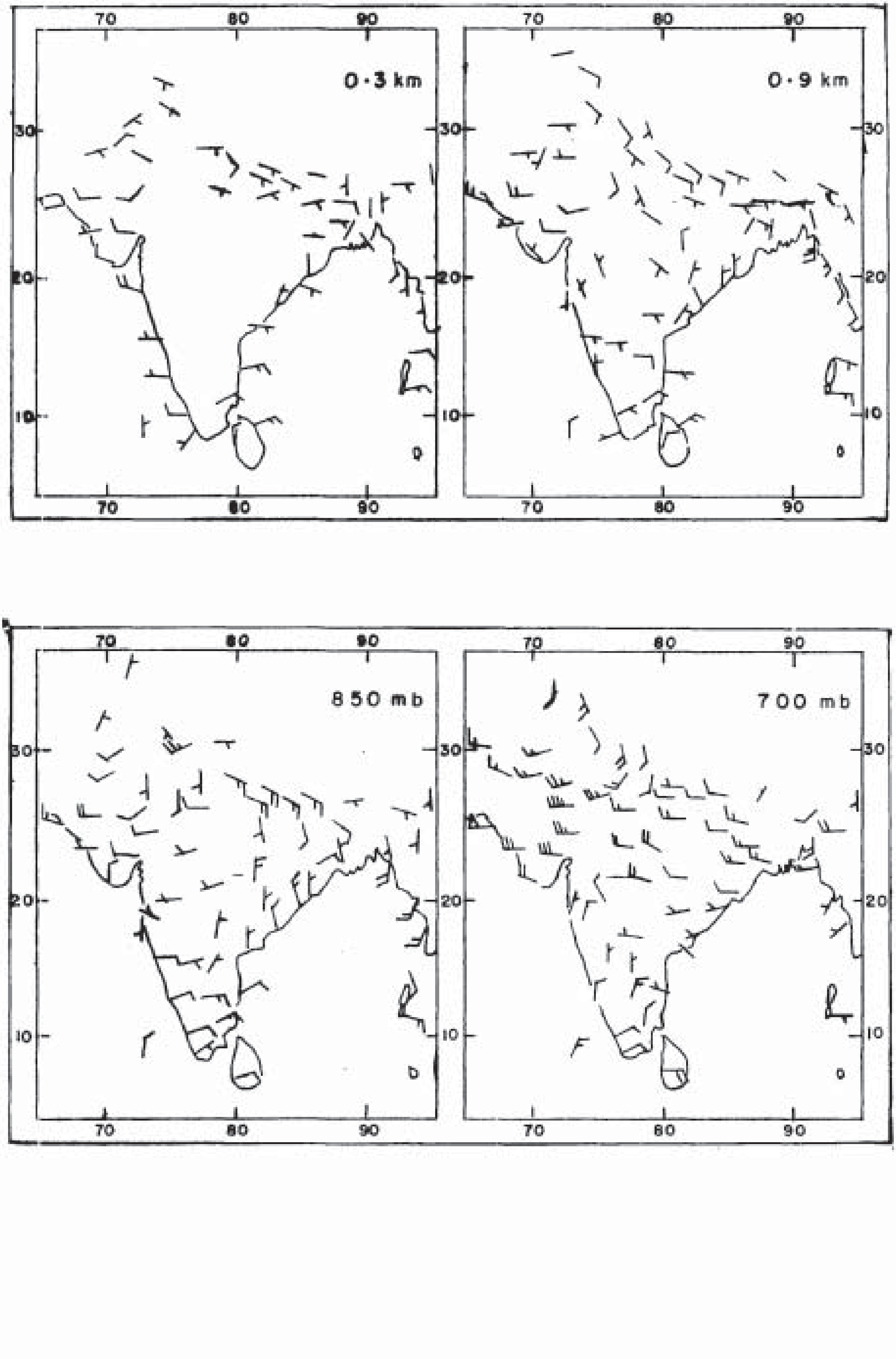
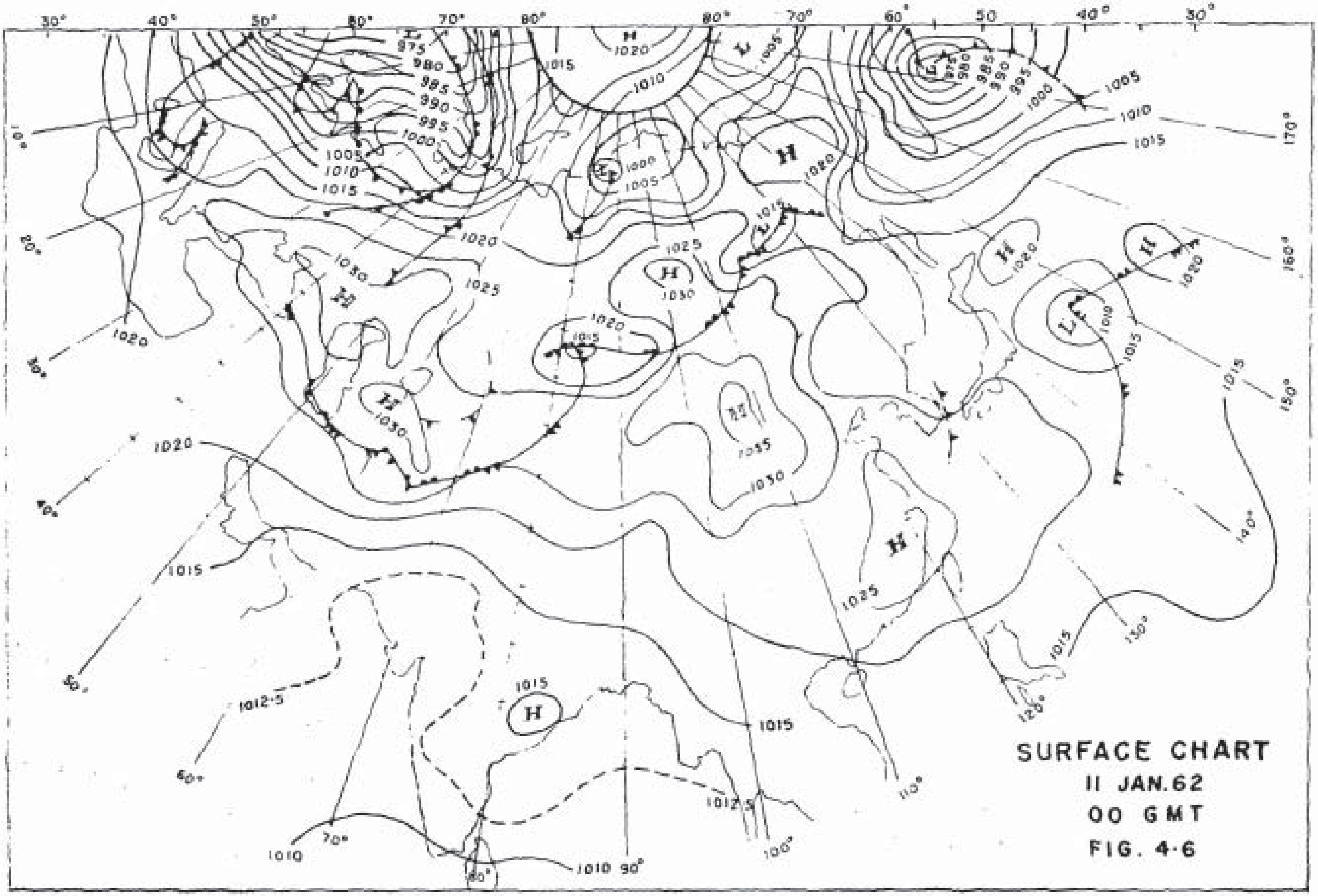
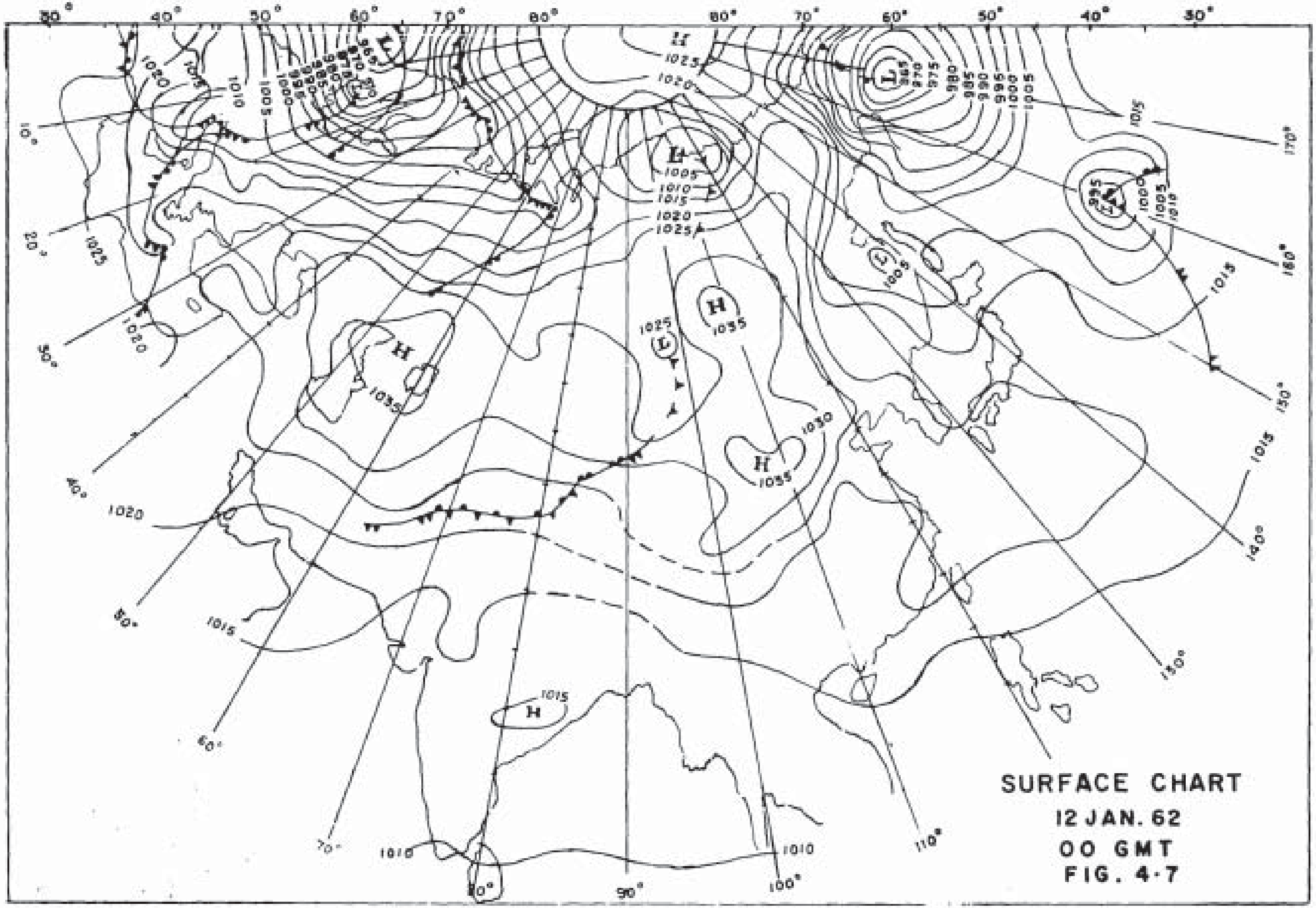

24 HRS. PRESSURE CHANGE (mb.)
DATE: 10 JAN. 62
TIME: 12 GMT
PRESSURE DEP. FROM NORMAL (mb.)
DATE: 10 JAN. 62
TIME: 12 GMT
60
70
80
90
100
10
20
30

FIG. 4·5 UPPER WINDS. DATE : 10 JAN. 62. TIME 12 GMT





SURFACE CHART
11 JAN. 62
00 GMT
FIG. 4·6



SURFACE CHART
12 JAN. 62
00 GMT
FIG. 4·7

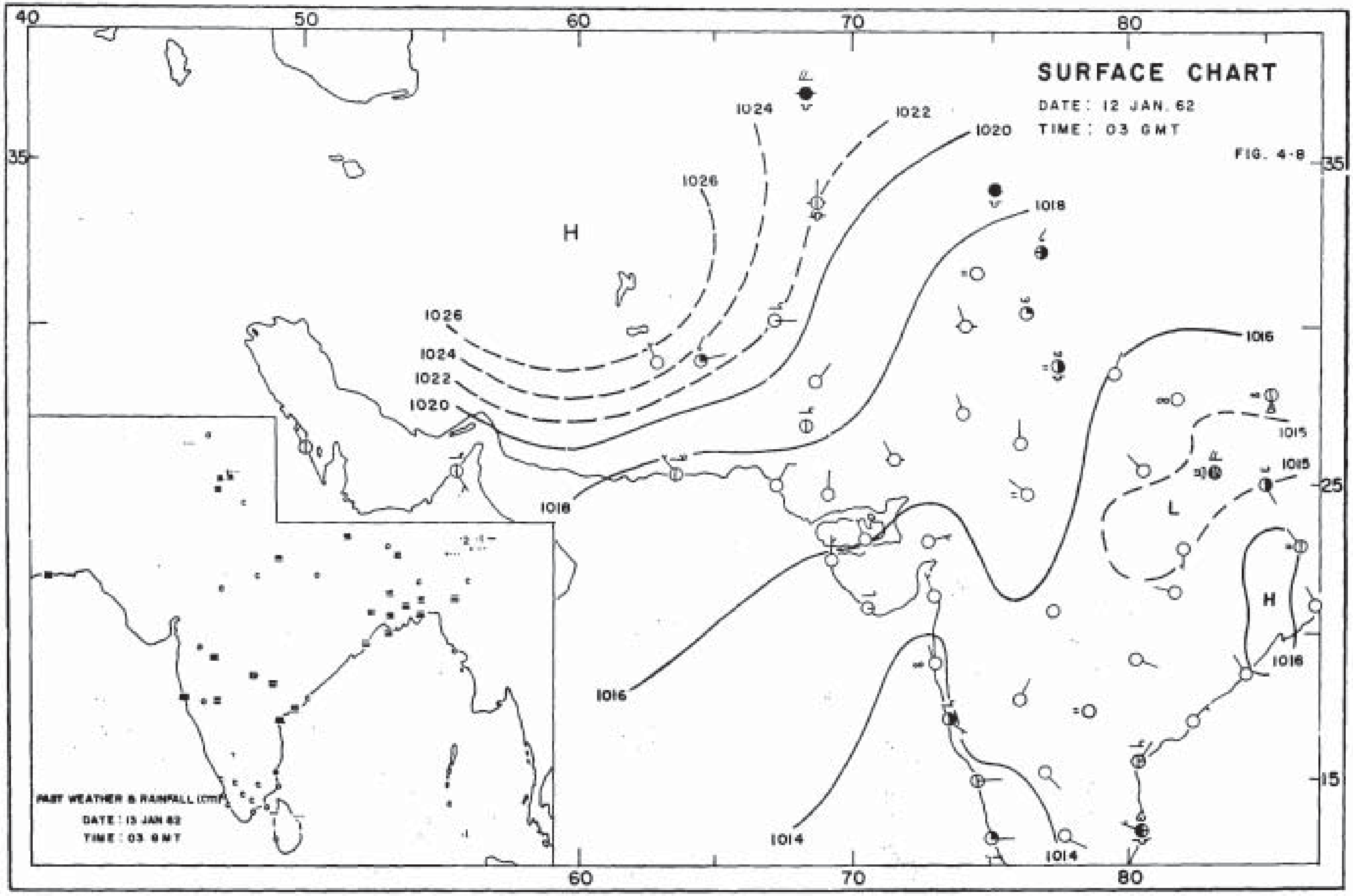
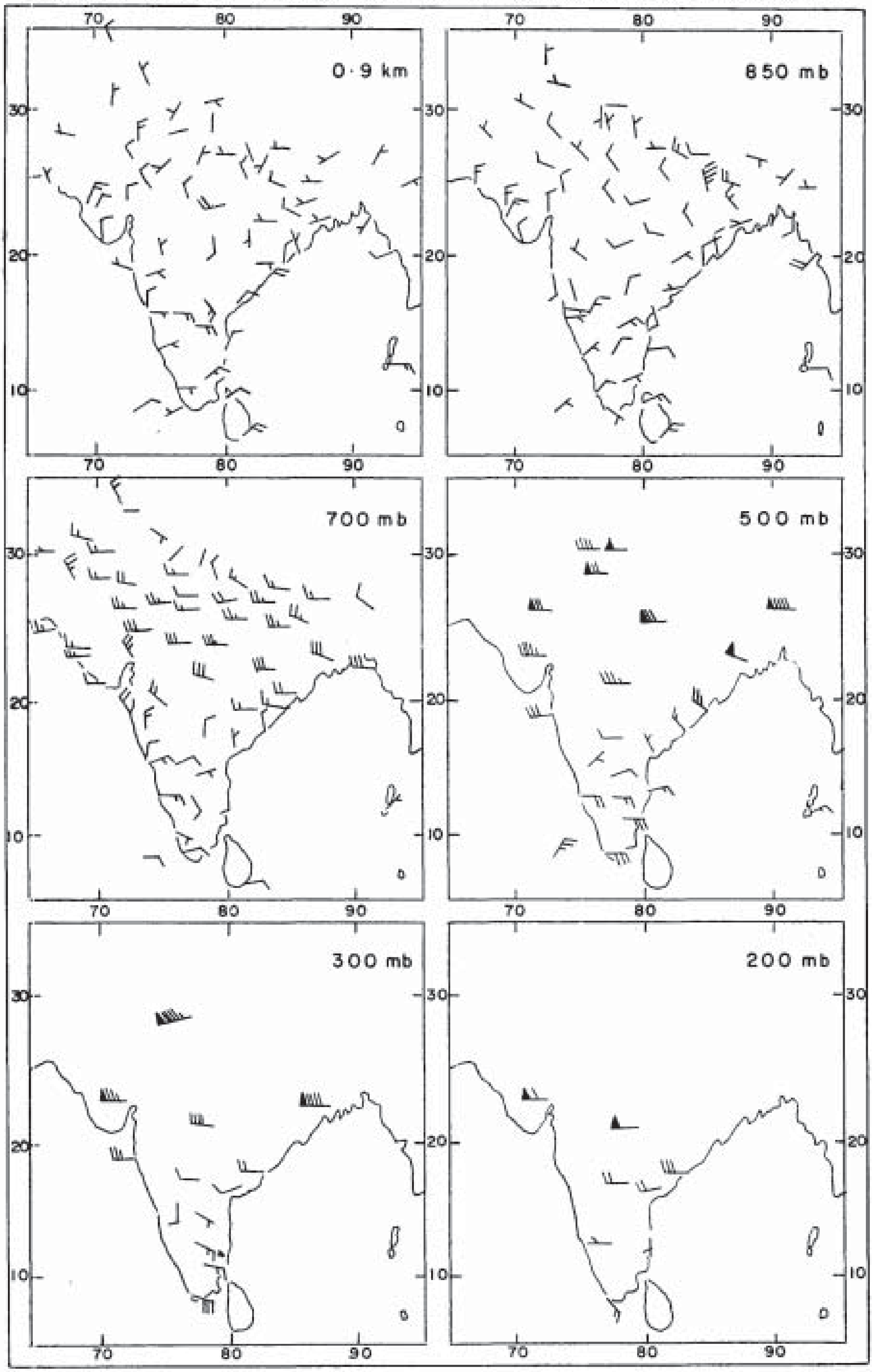

SURFACE CHART
DATE : 12 JAN. 62
TIME : 03 GMT
FIG. 4·8
PAST WEATHER & RAINFALL (CM)
DATE : 13 JAN 62
TIME : 03 GMT
1026
1024
1022
1020
1018
1016
1015
1014
H
L
40
50
60
70
80
35
25
15

FIG. 4·9 UPPER WINDS. DATE: 12 JAN. 62. TIME: 00 GMT



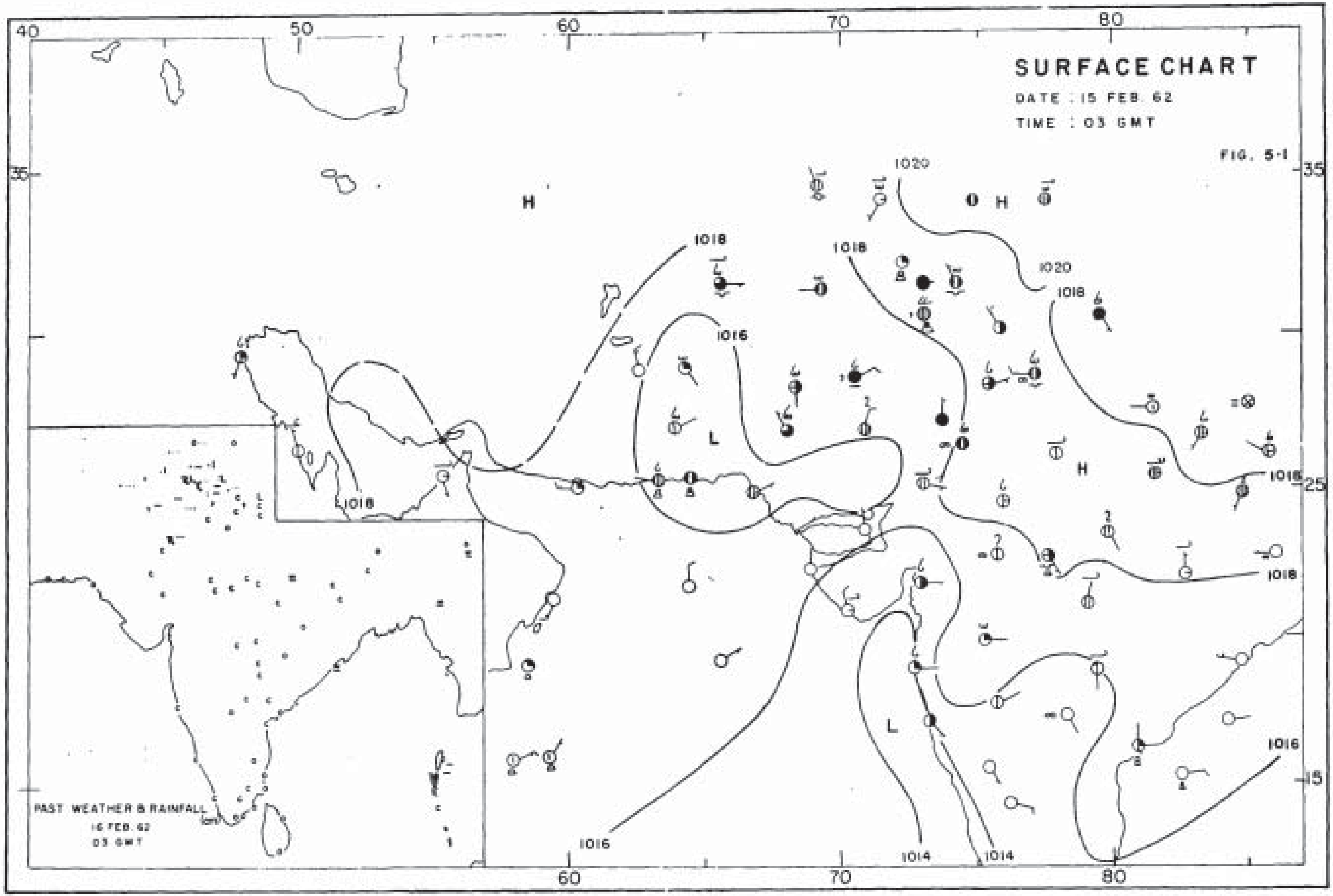
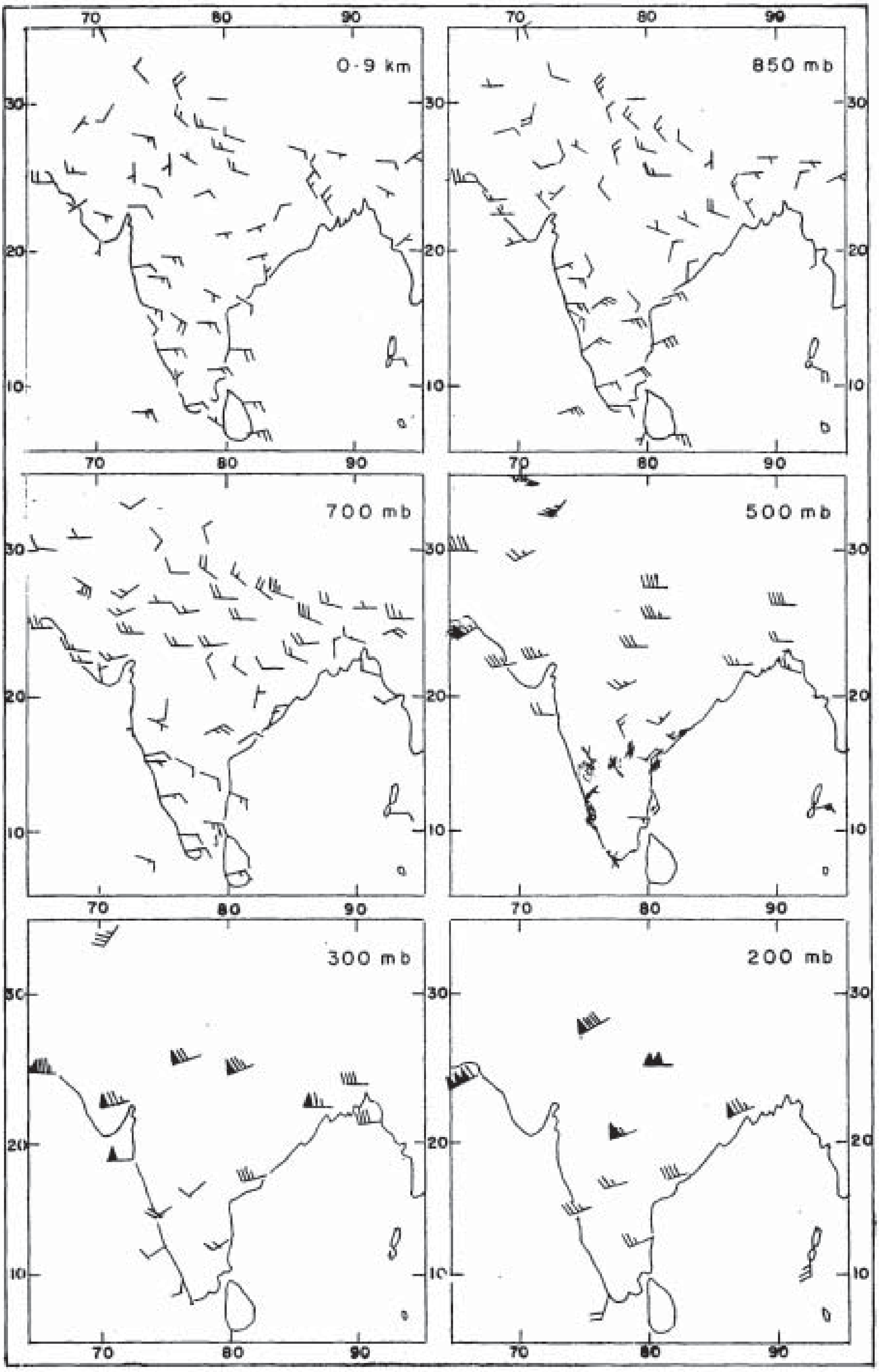
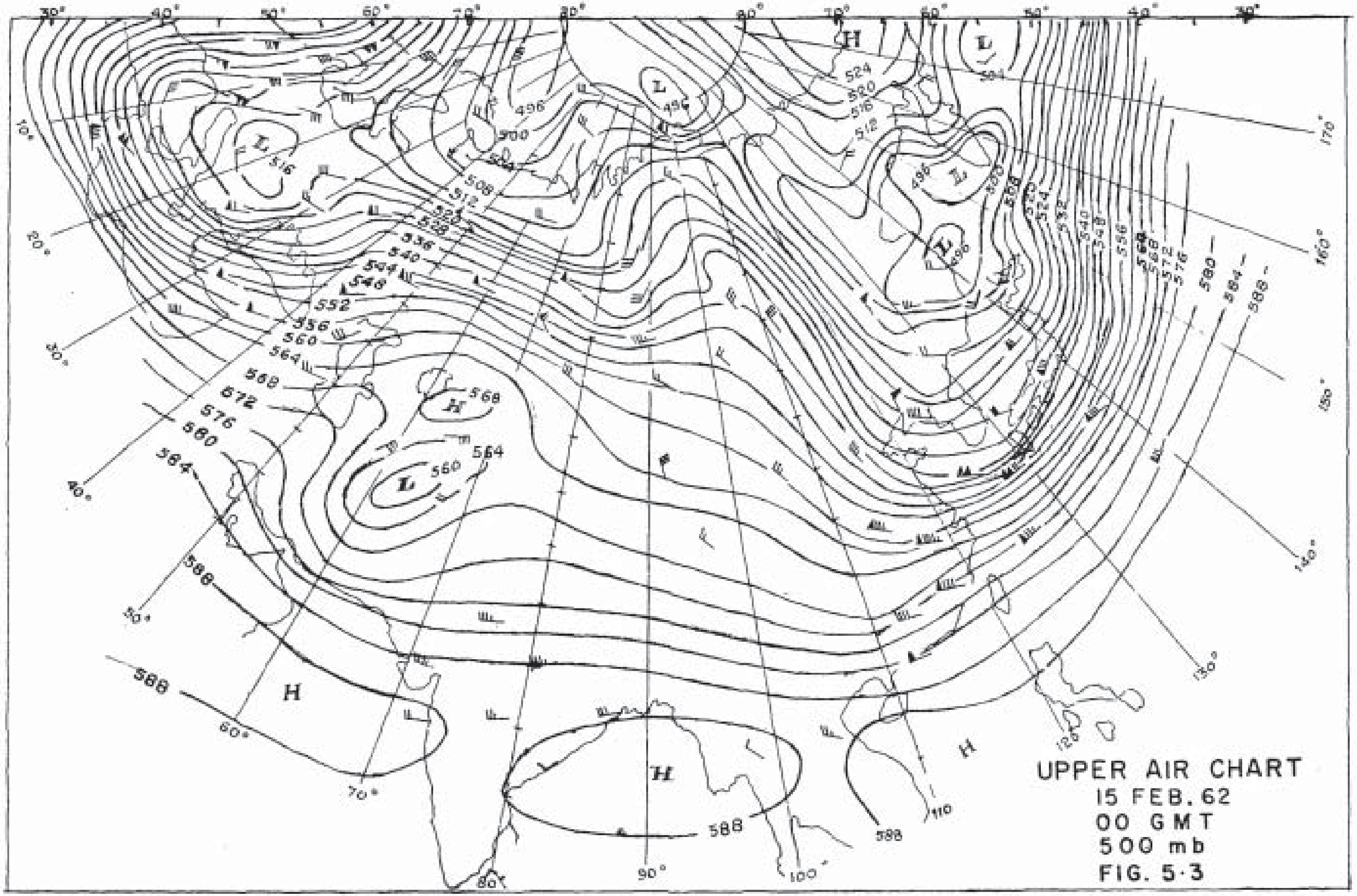

SURFACE CHART
DATE : 15 FEB. 62
TIME : 03 GMT
FIG. 5-1
1020
1018
1016
1014
H
L
40
50
60
70
80
35
25
15
PAST WEATHER & RAINFALL
16 FEB. 62
03 GMT

FIG. 5·2 UPPER WINDS. DATE: 15 FEB. 62. TIME: 00 GMT





UPPER AIR CHART
15 FEB. 62
00 GMT
500 mb
FIG. 5·3

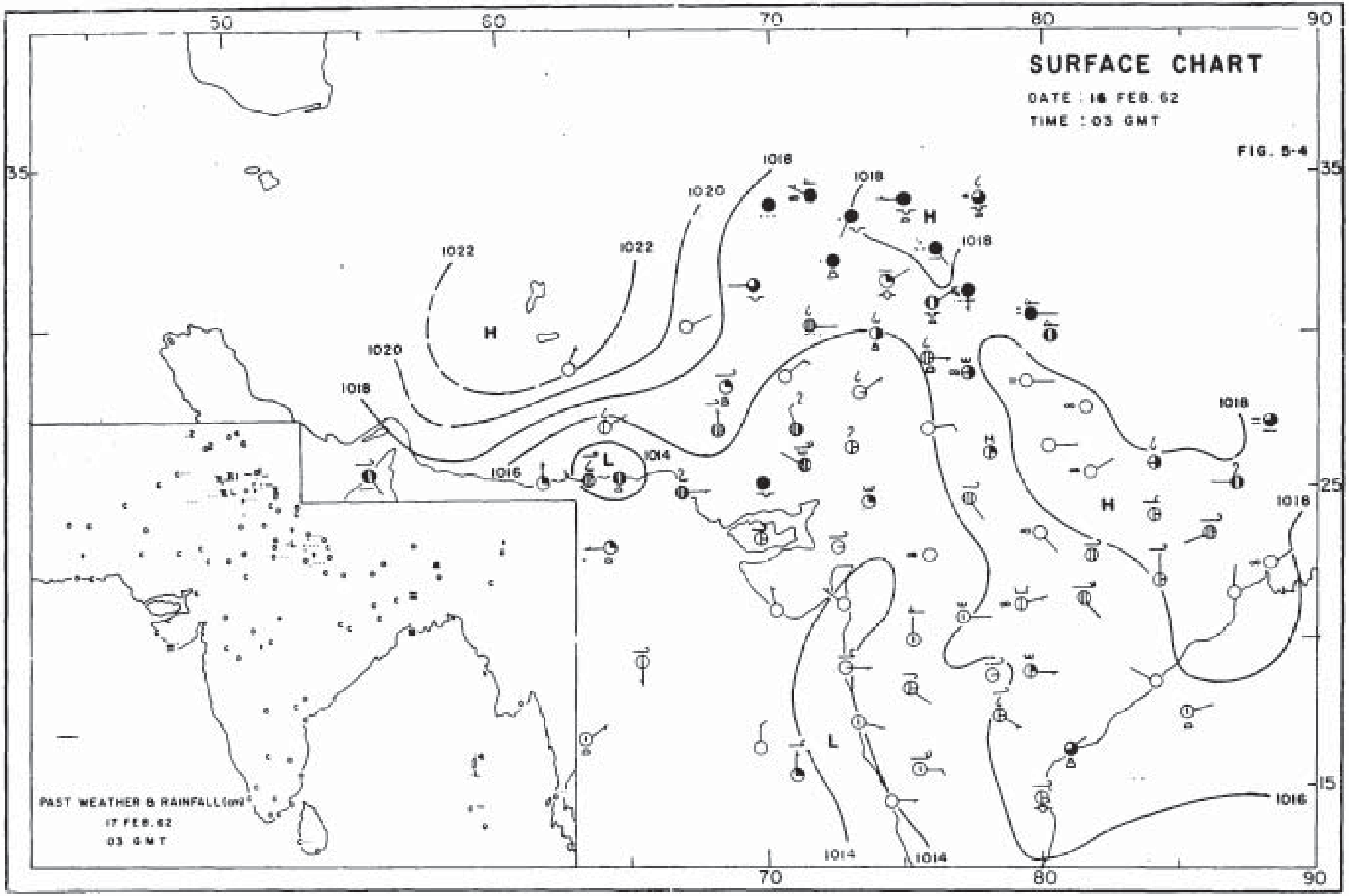
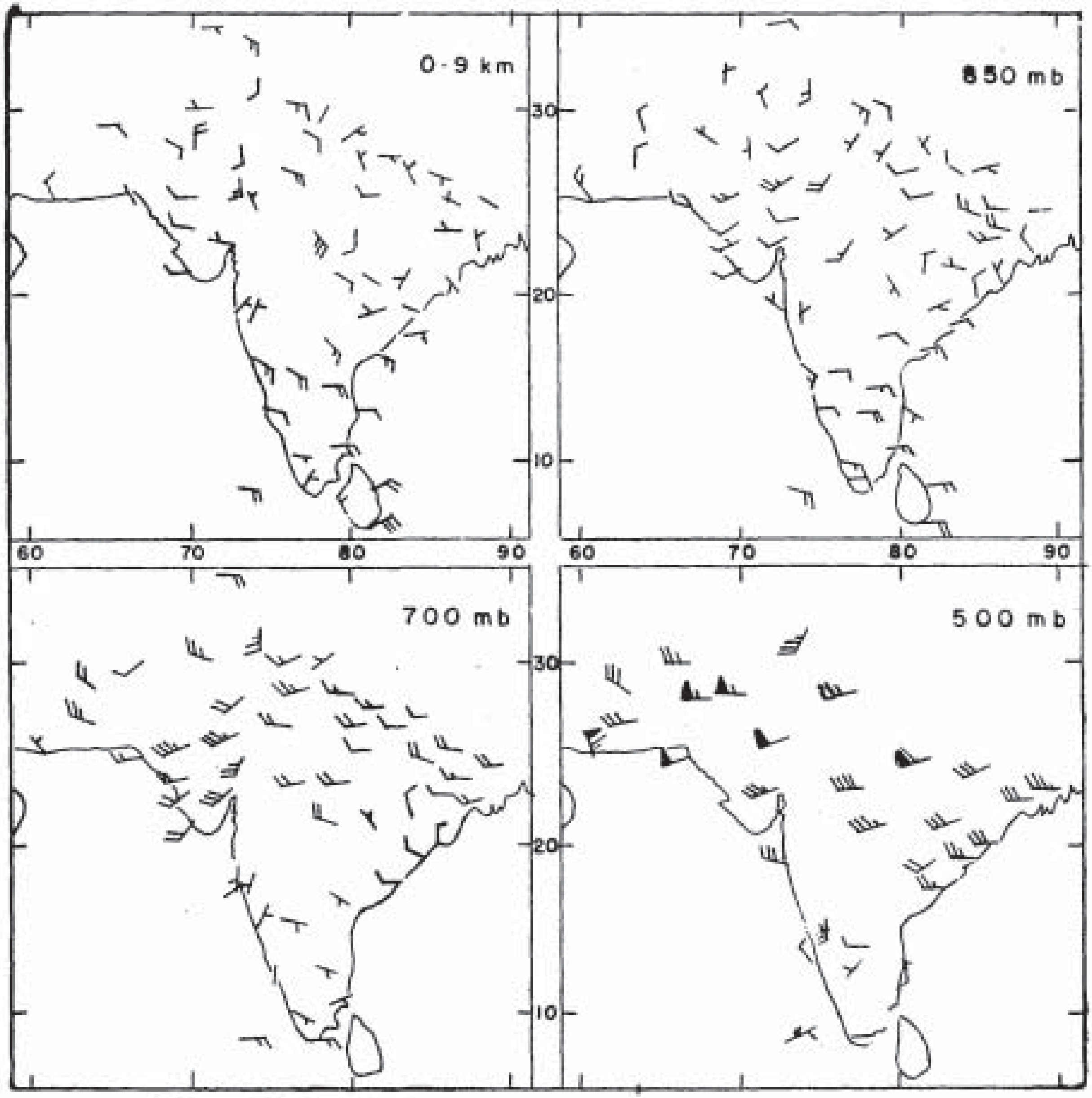

SURFACE CHART
DATE : 16 FEB. 62
TIME : 03 GMT
FIG. 5-4
1022
1022
1020
1020
1018
1018
1018
1018
1018
1018
1016
1016
1014
1014
1014
H
H
H
H
L
L
50
60
70
80
90
35
25
15
PAST WEATHER & RAINFALL (cm)
17 FEB. 62
03 GMT

FIG. 5·5 UPPER WINDS. DATE: 16 FEB. 62. TIME: 00 GMT



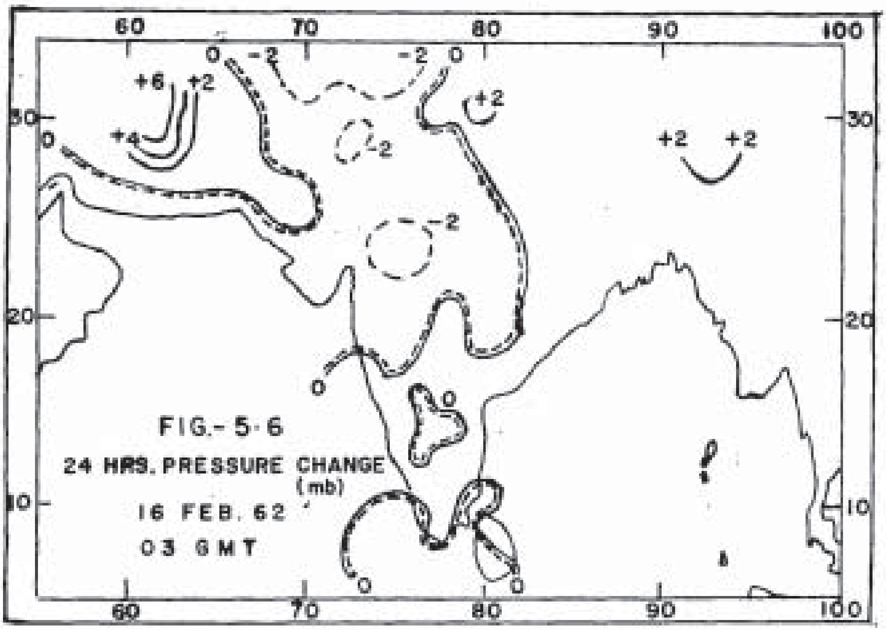


FIG.- 5·6

24 HRS. PRESSURE CHANGE (mb)

16 FEB. 62

03 GMT

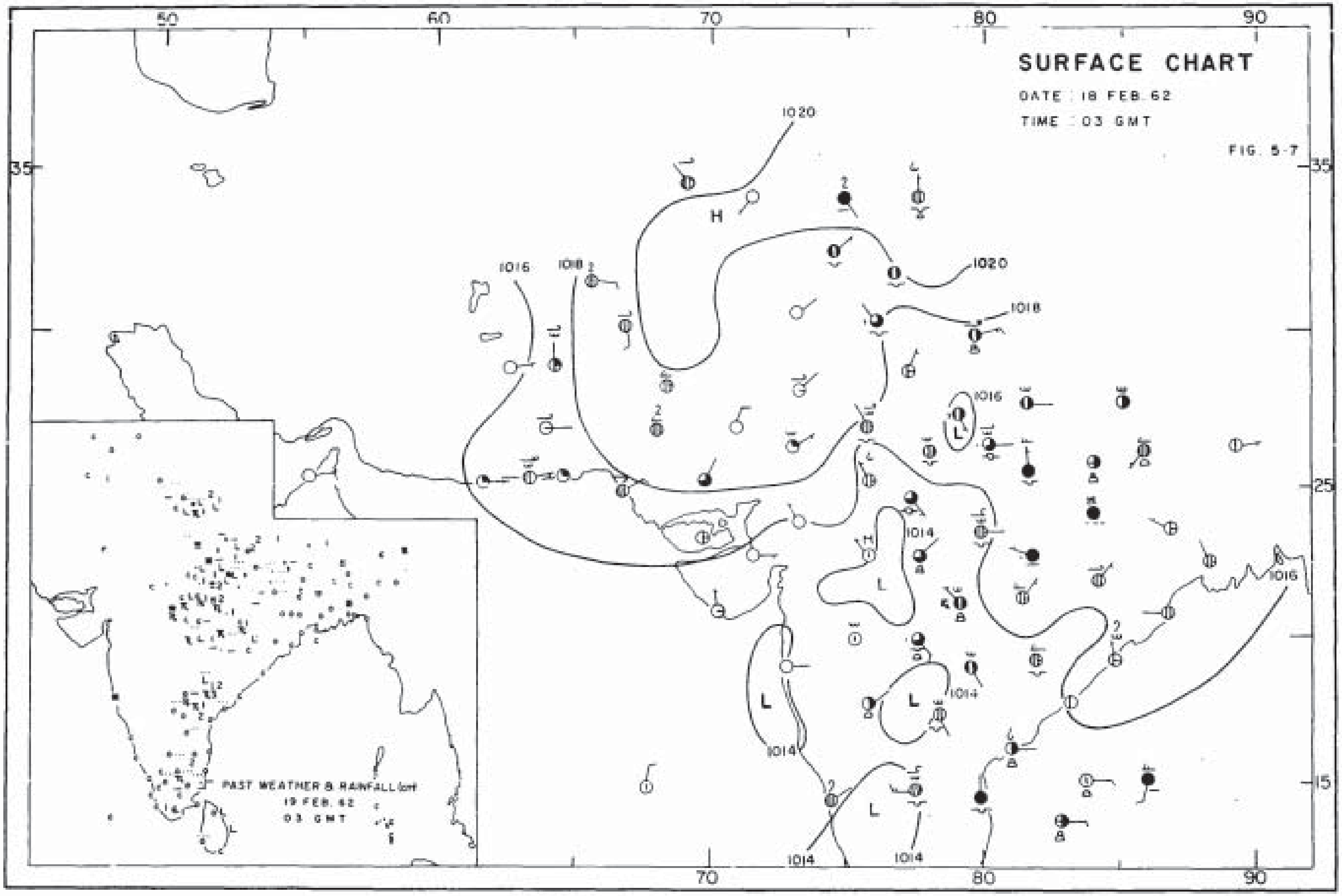

SURFACE CHART
DATE : 18 FEB. 62
TIME : 03 GMT
FIG. 5·7
1020
1018
1016
1014
H
L
PAST WEATHER & RAINFALL (cm)
19 FEB. 62
03 GMT
50
60
70
80
90
35
25
15

FIG. 5·8 UPPER WINDS. DATE: 18 FEB. 62. TIME: 00 GMT

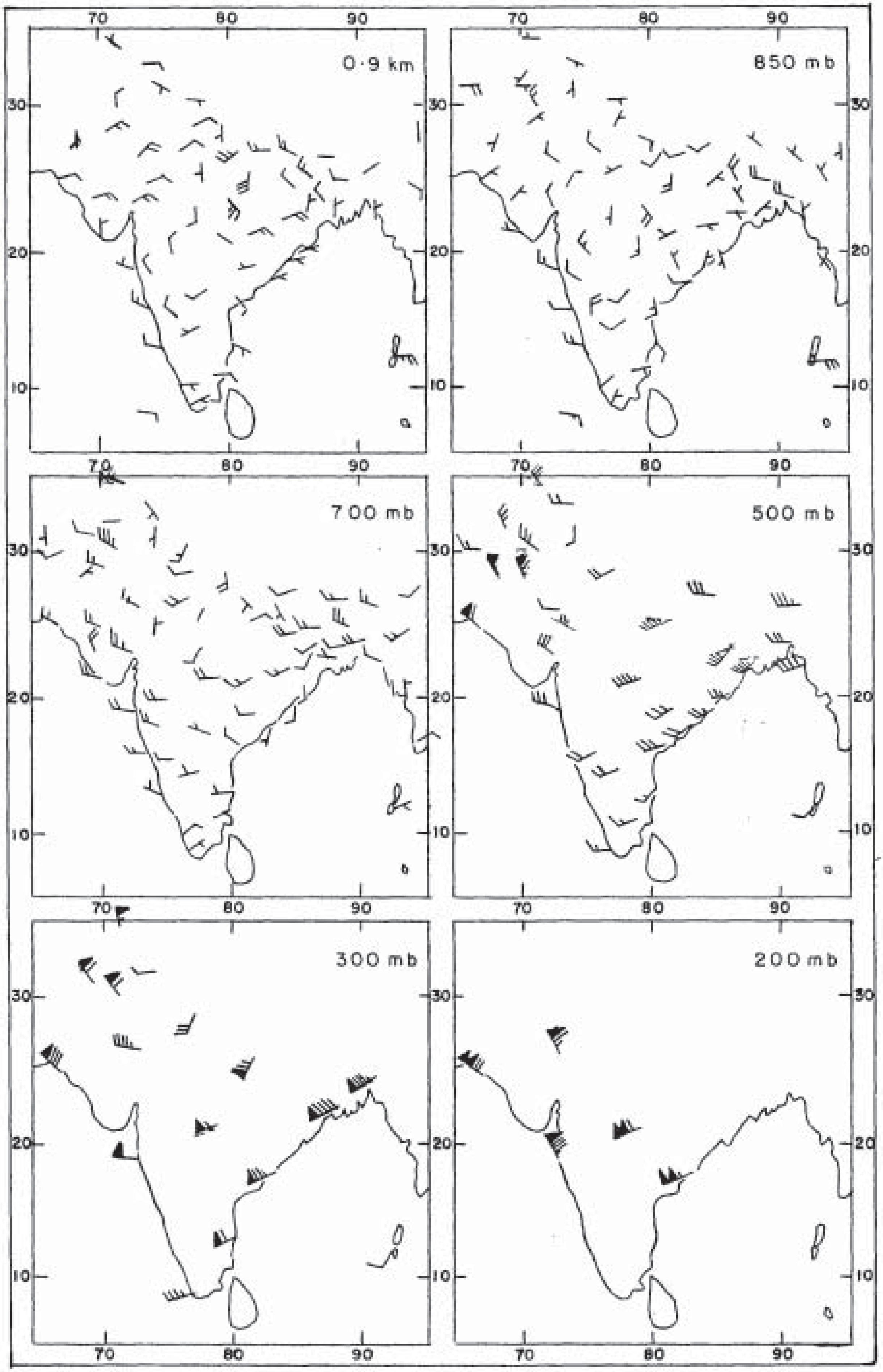
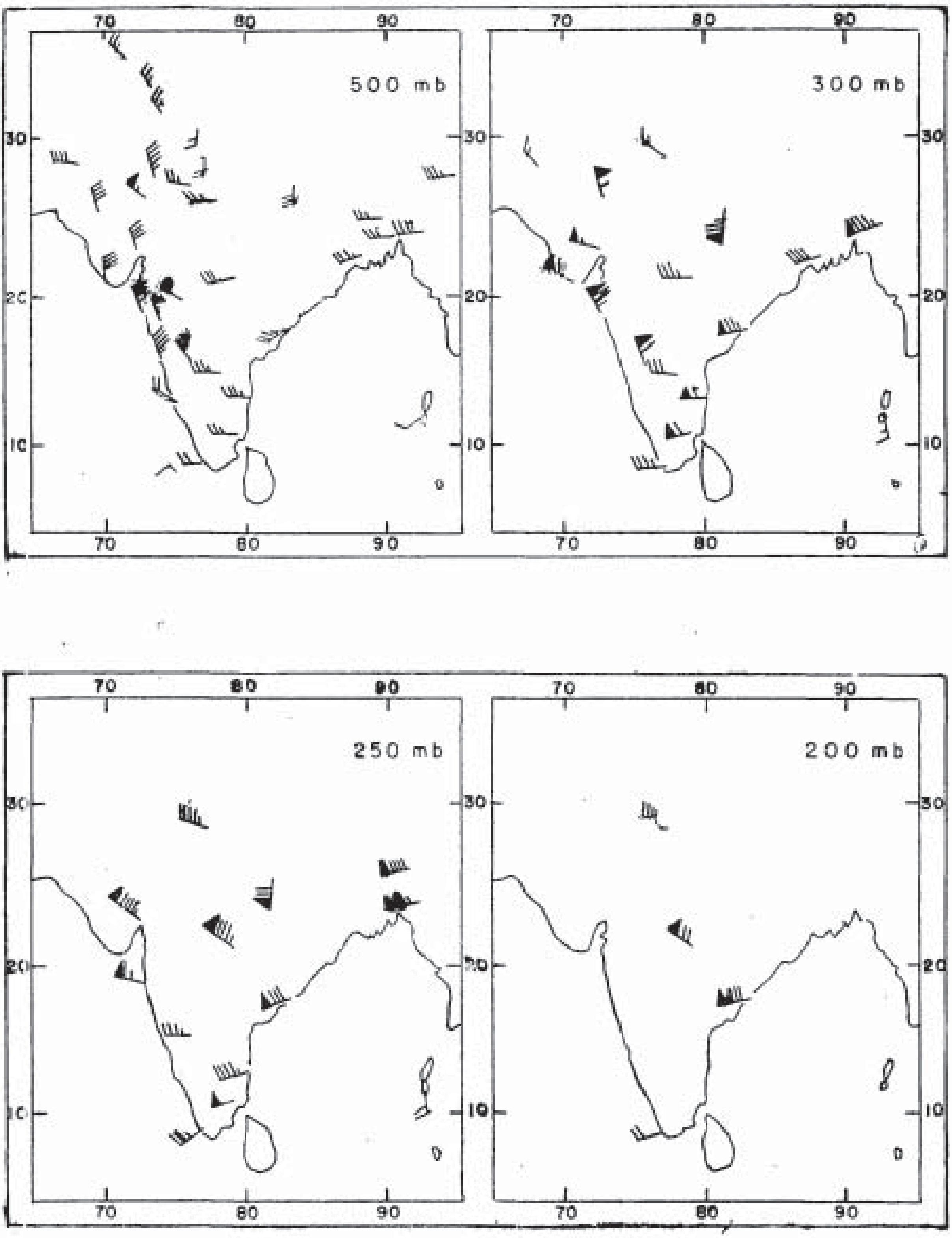


FIG.5·9 UPPER WINDS. DATE: 18 FEB. 62. TIME: 12 GMT



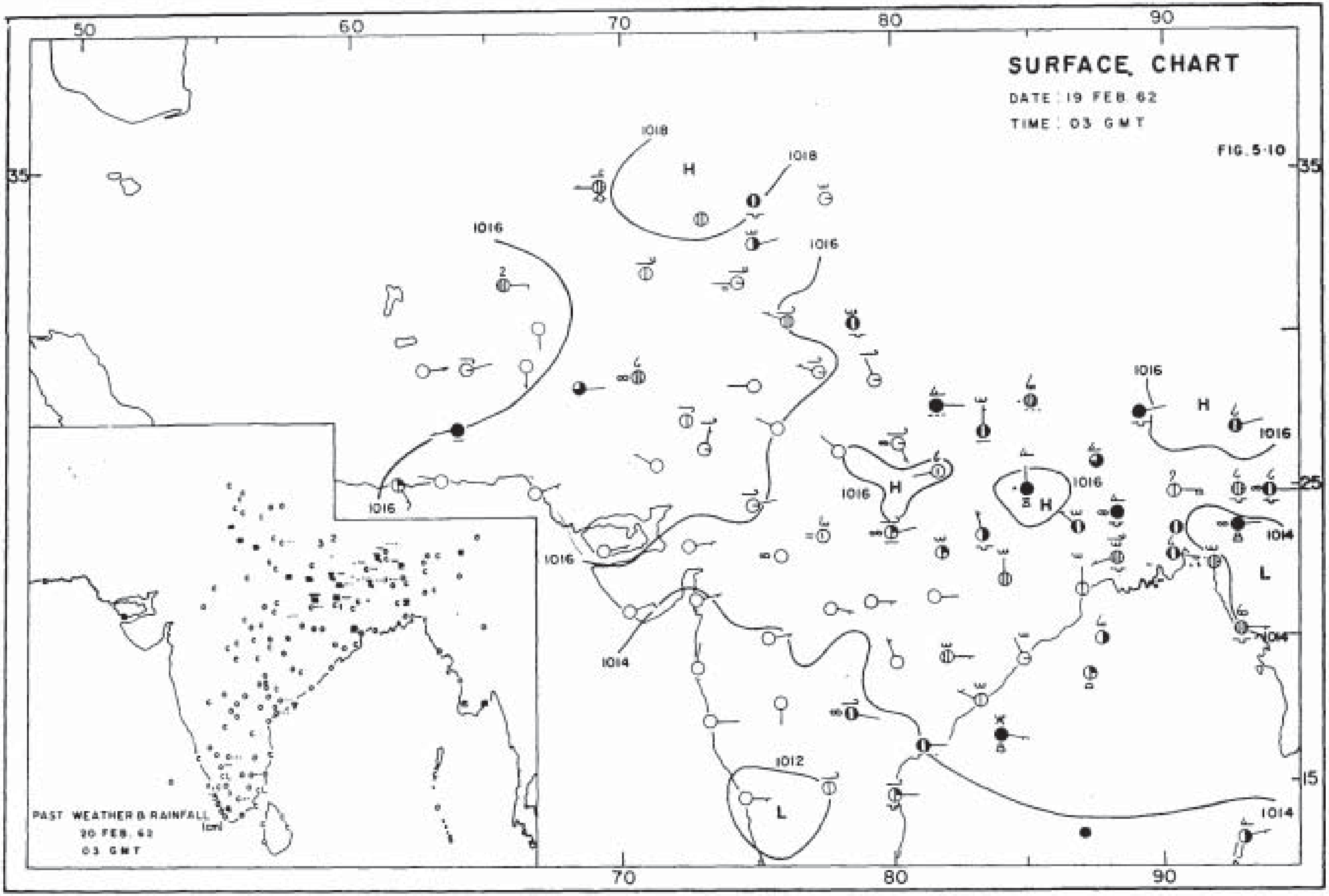

SURFACE CHART
DATE : 19 FEB 62
TIME : 03 GMT
FIG. 5·10
PAST WEATHER & RAINFALL
20 FEB. 62
03 GMT
50
60
70
80
90
35
25
15
1018
1016
1014
1012
H
L

FIG. 5·II UPPER WINDS. DATE : 19 FEB. 62. TIME : 00 GMT

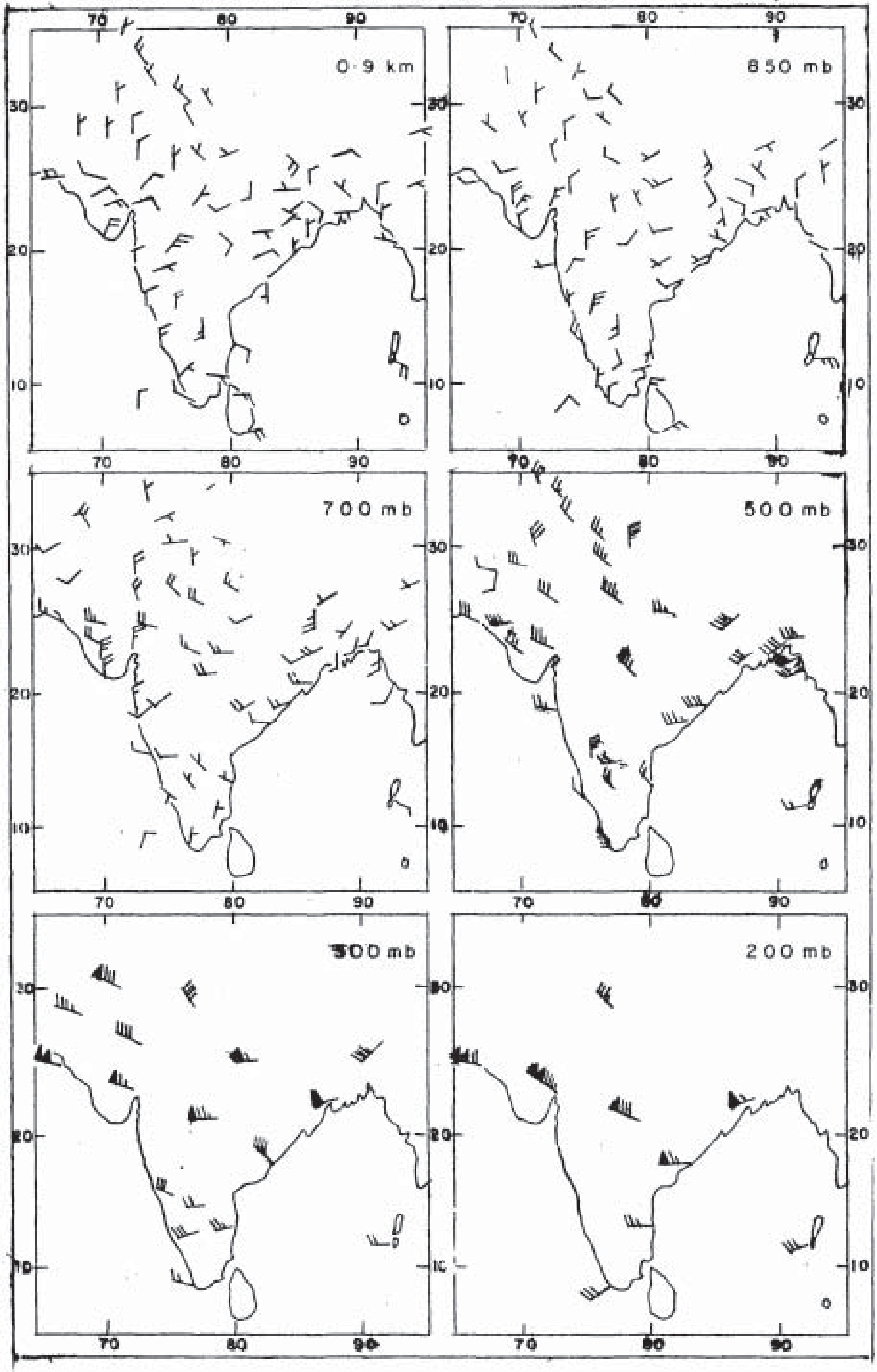
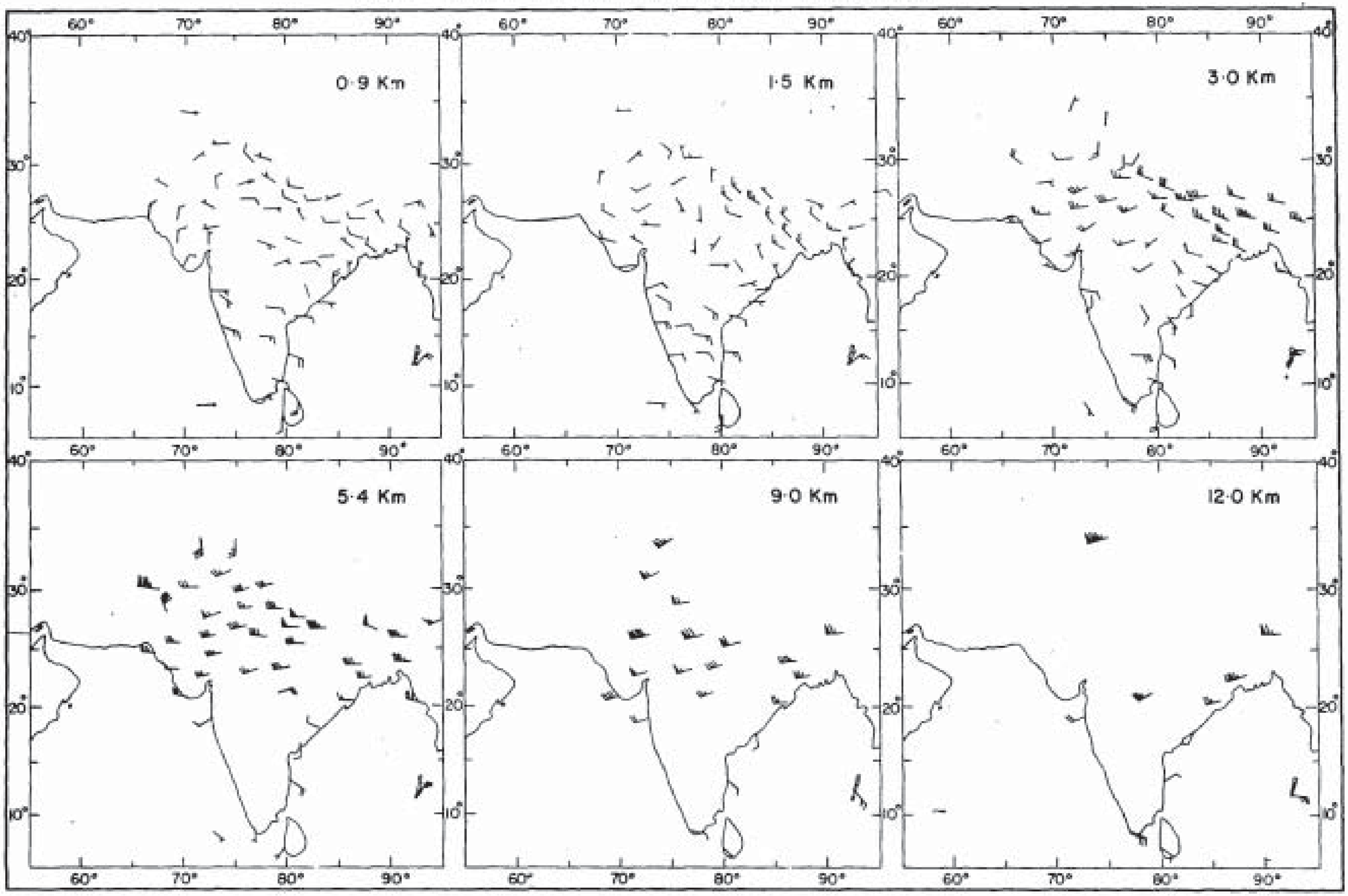
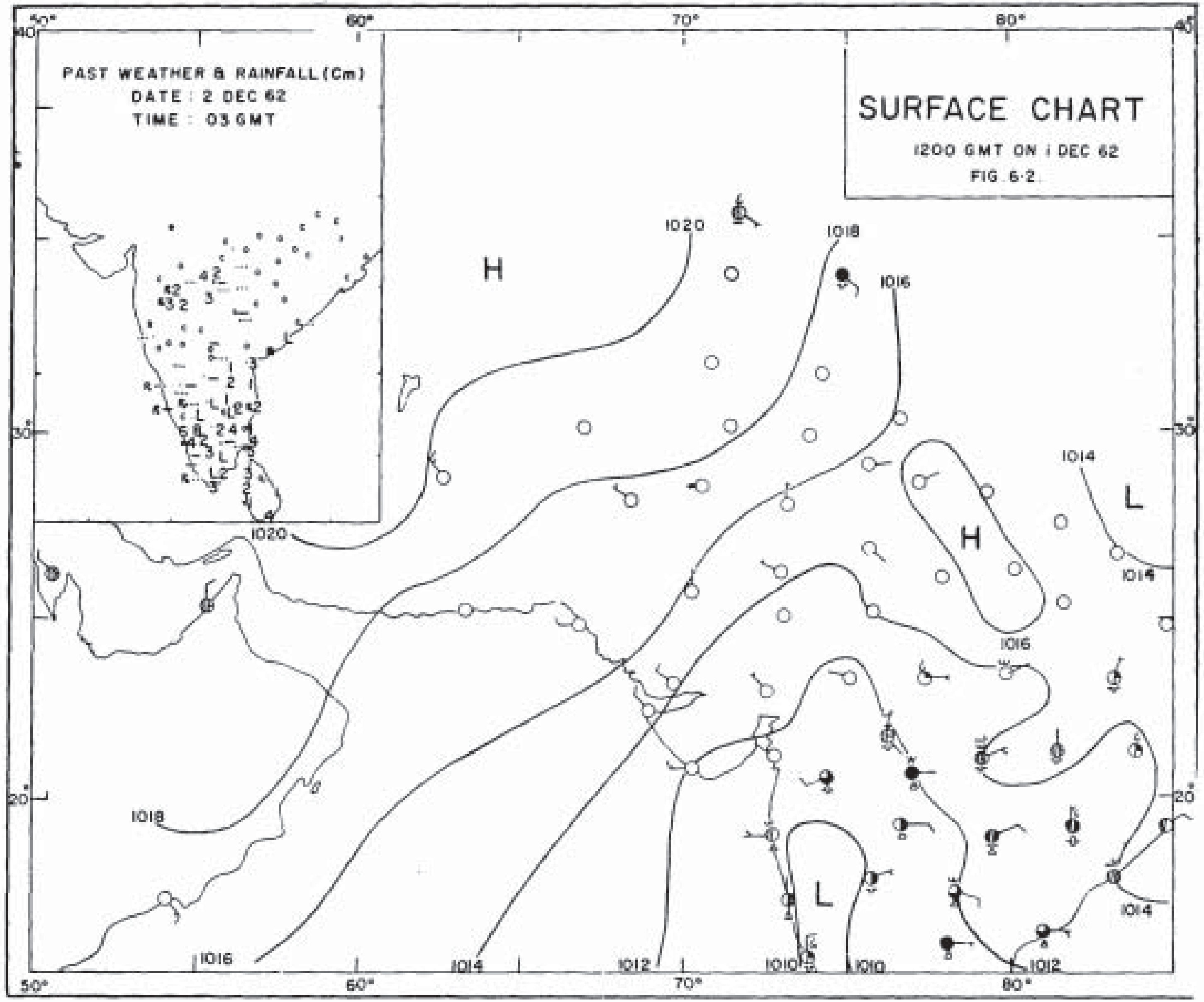
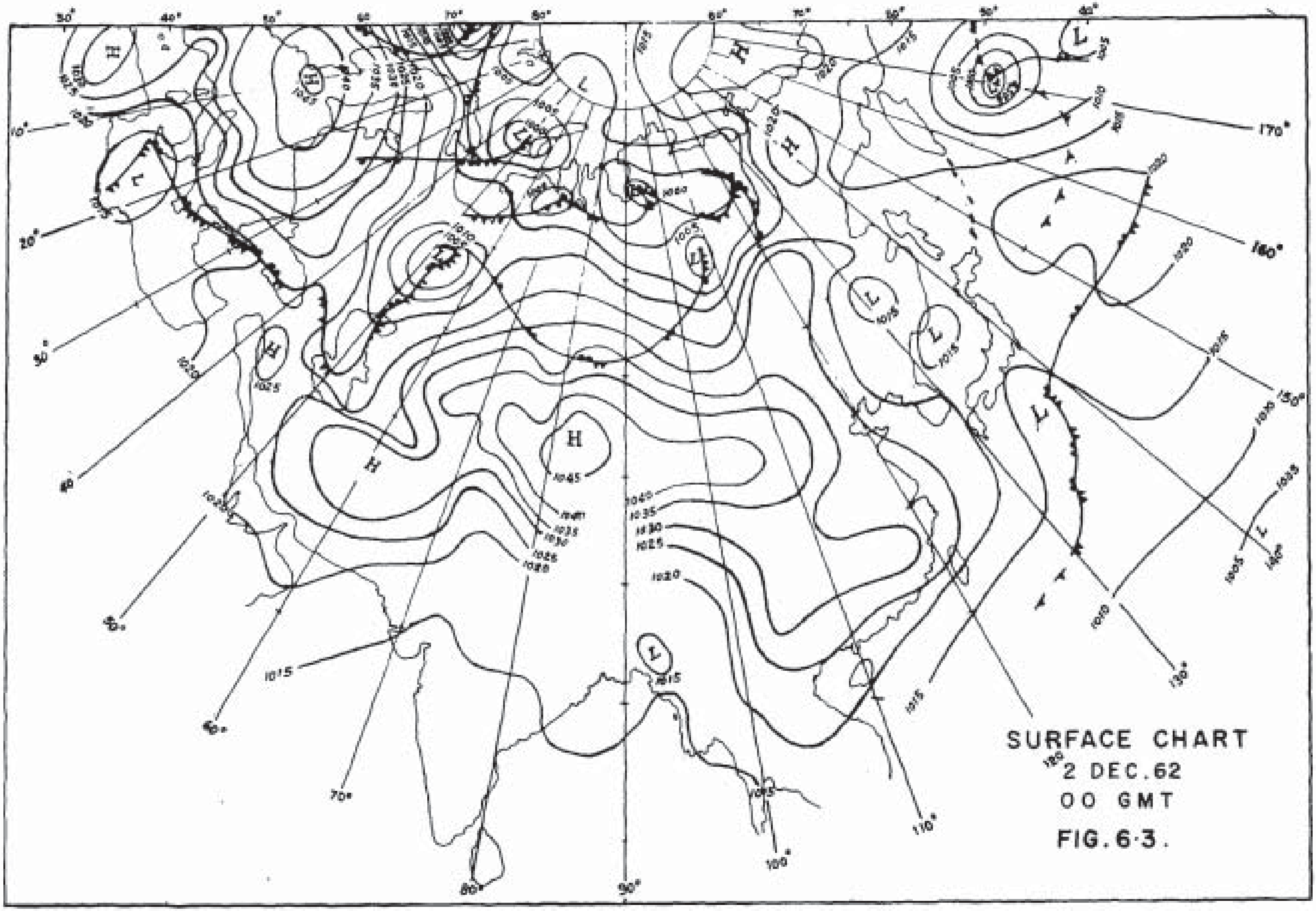


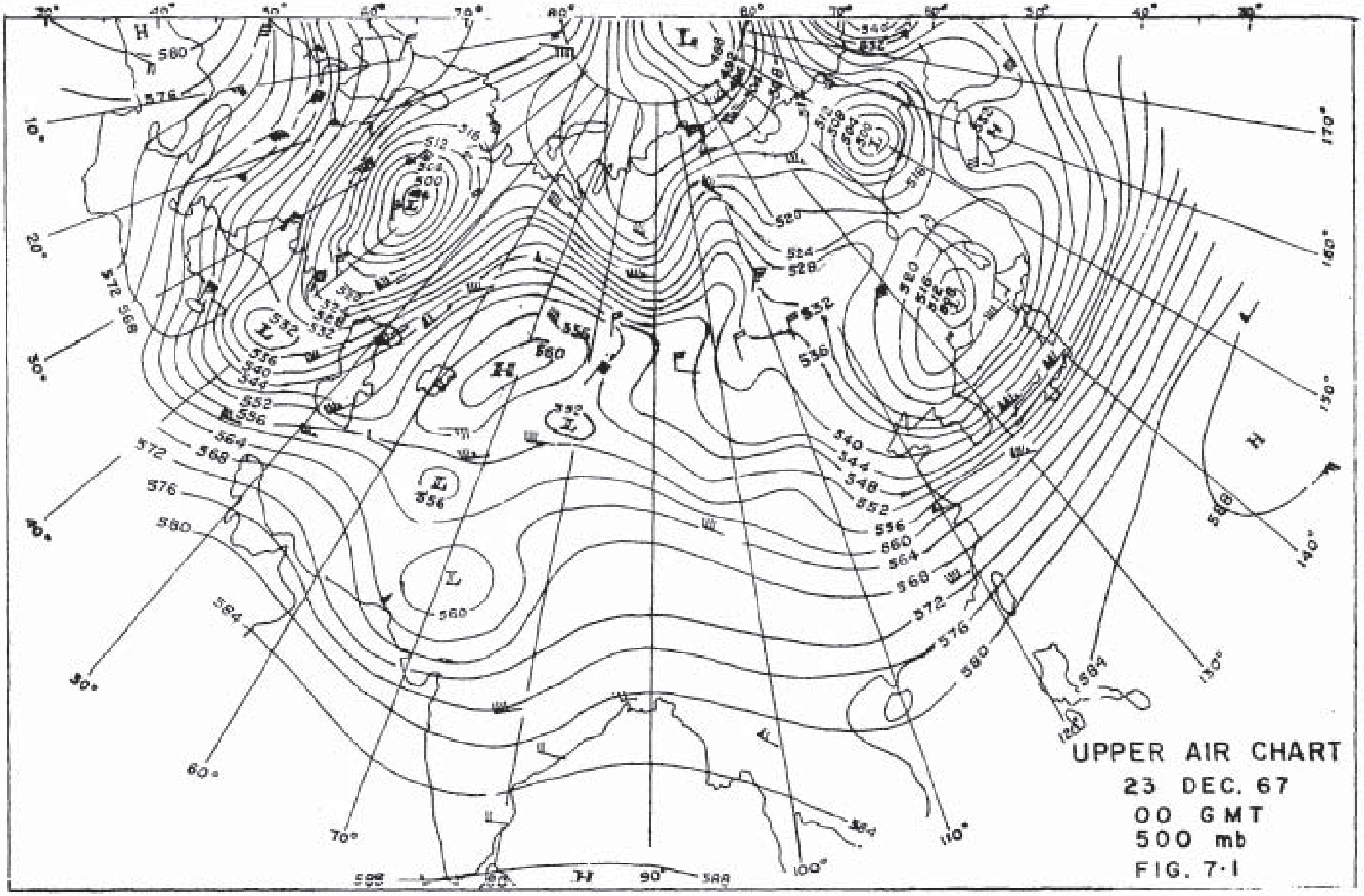
FIG. 6·1. UPPER WINDS DATE : 1 DEC. 62 TIME : 12 GMT



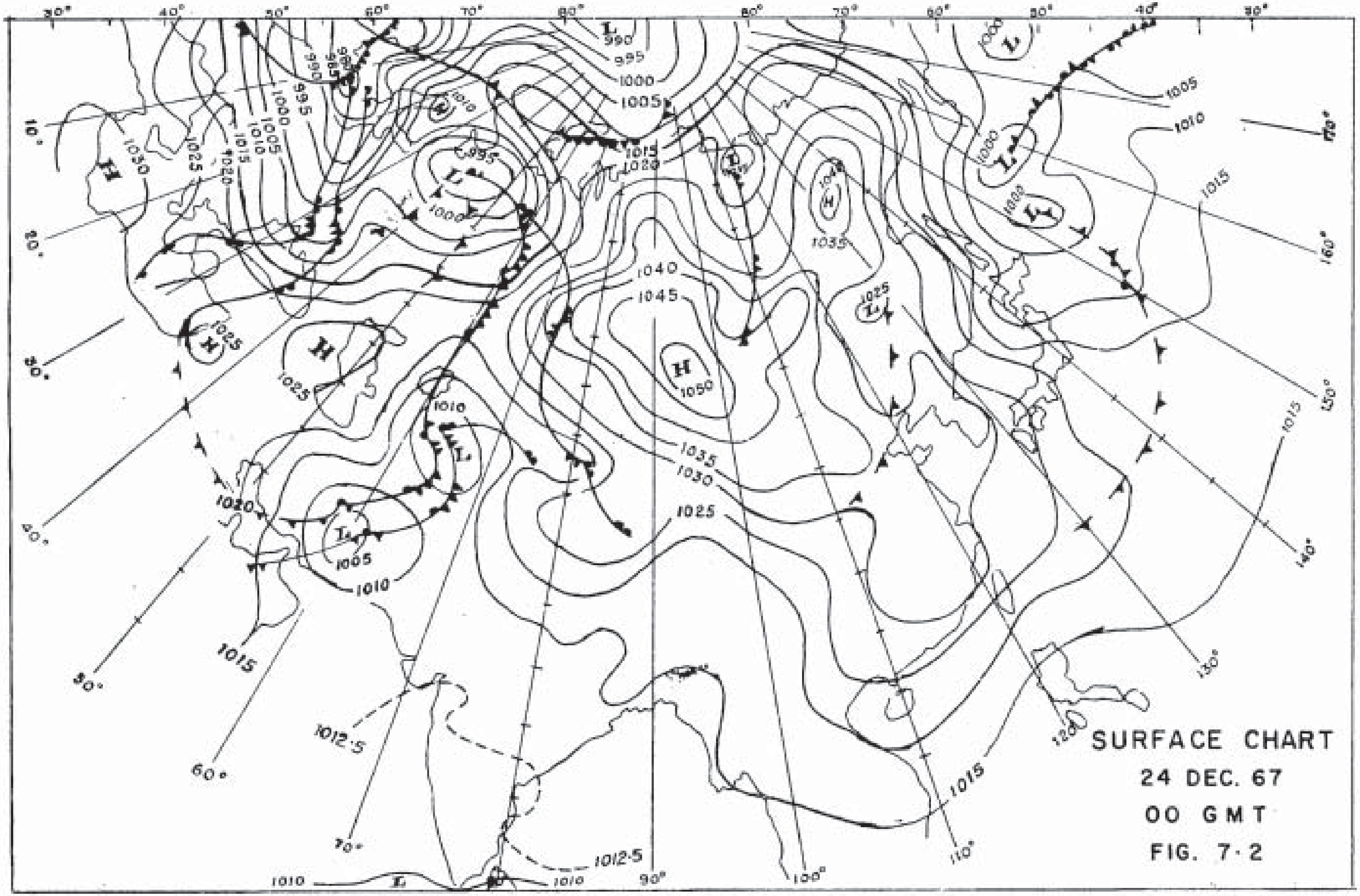

SURFACE CHART
1200 GMT ON 1 DEC 62
FIG. 6·2.
PAST WEATHER & RAINFALL (Cm)
DATE : 2 DEC 62
TIME : 03 GMT
H
H
L
L
1020
1018
1016
1014
1012
1010
50°
60°
70°
80°
40°
30°
20°



SURFACE CHART
18Z 2 DEC. 62
00 GMT
FIG. 6·3.



UPPER AIR CHART
23 DEC. 67
00 GMT
500 mb
FIG. 7·1



SURFACE CHART
24 DEC. 67
00 GMT
FIG. 7·2

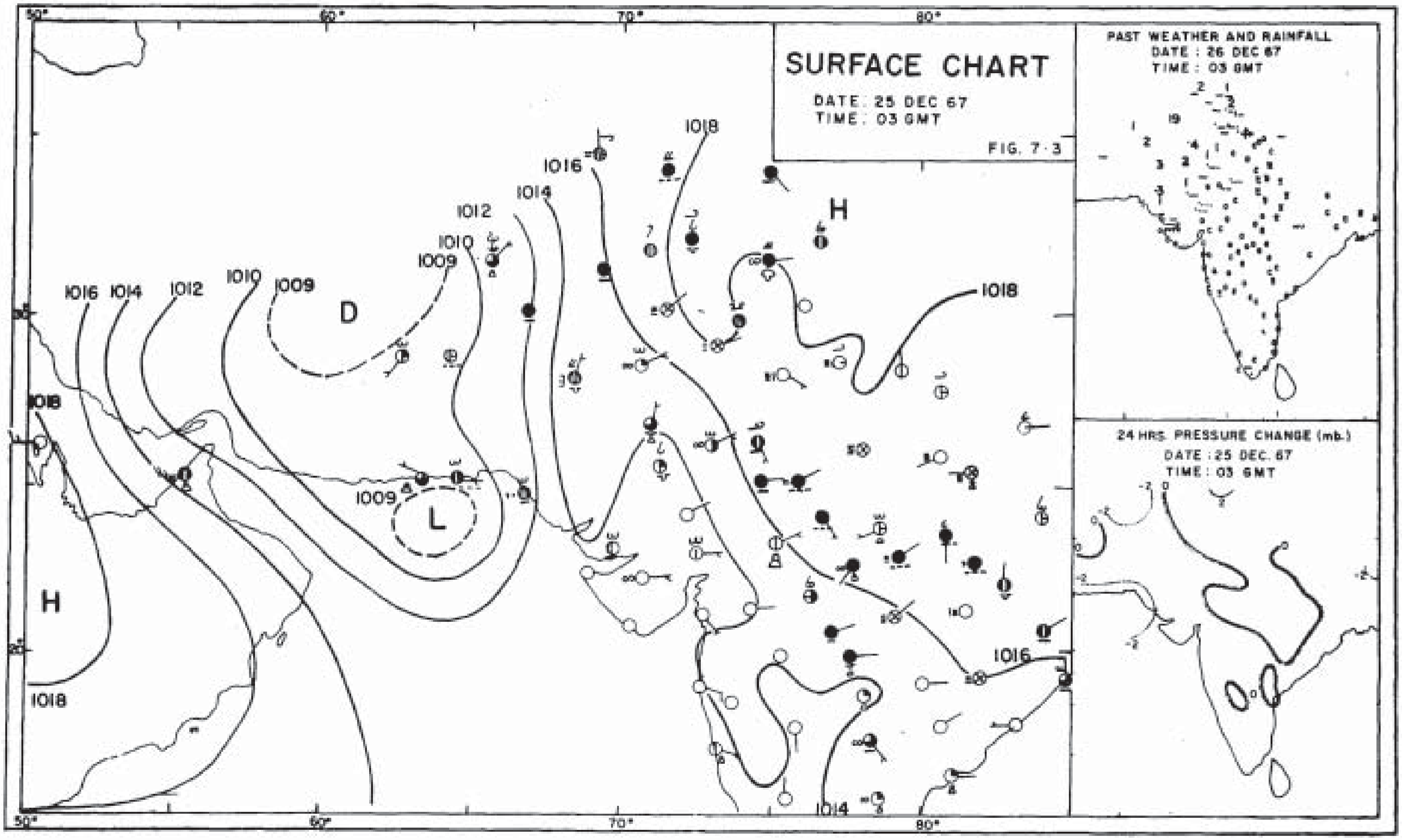
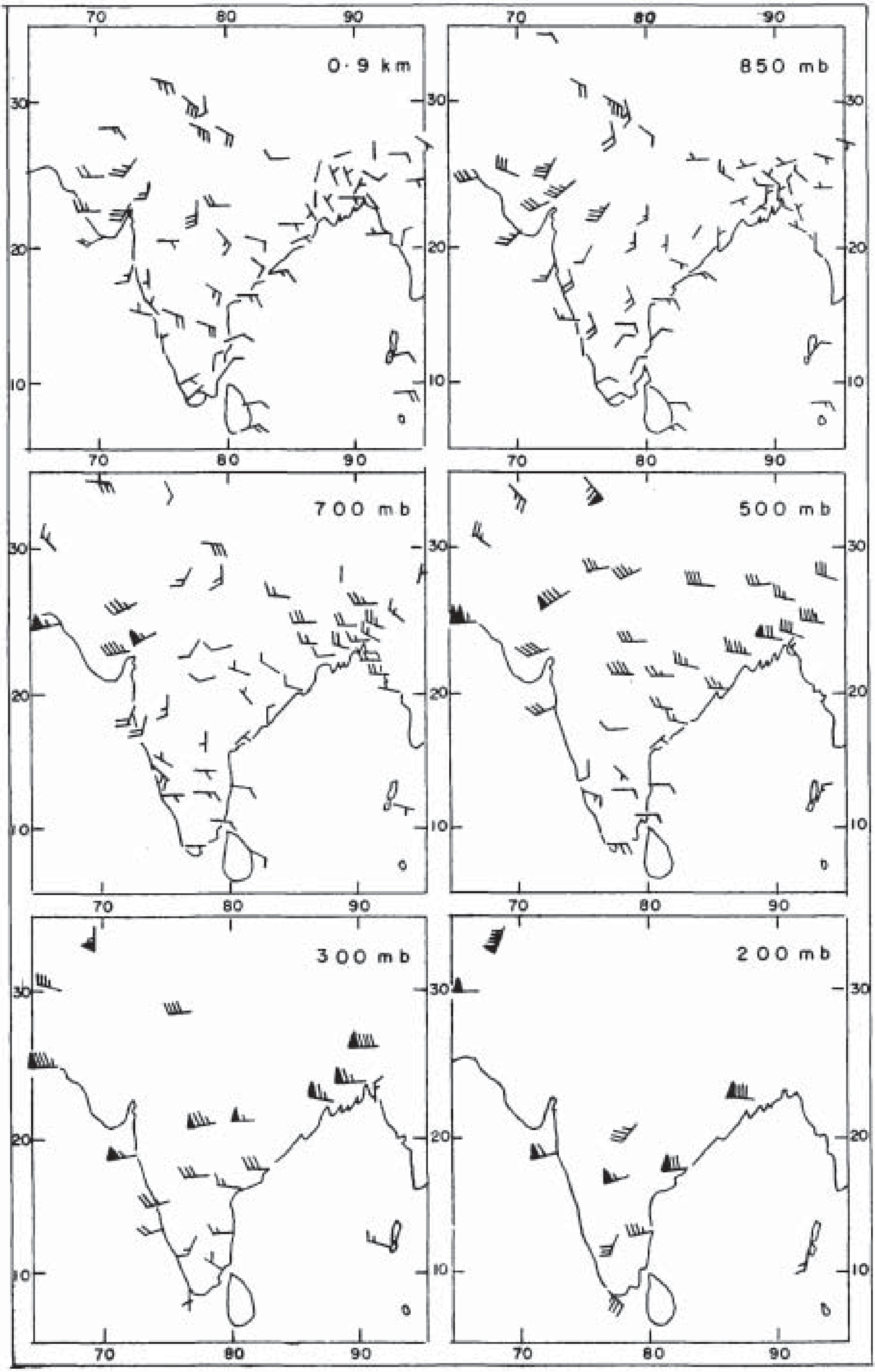
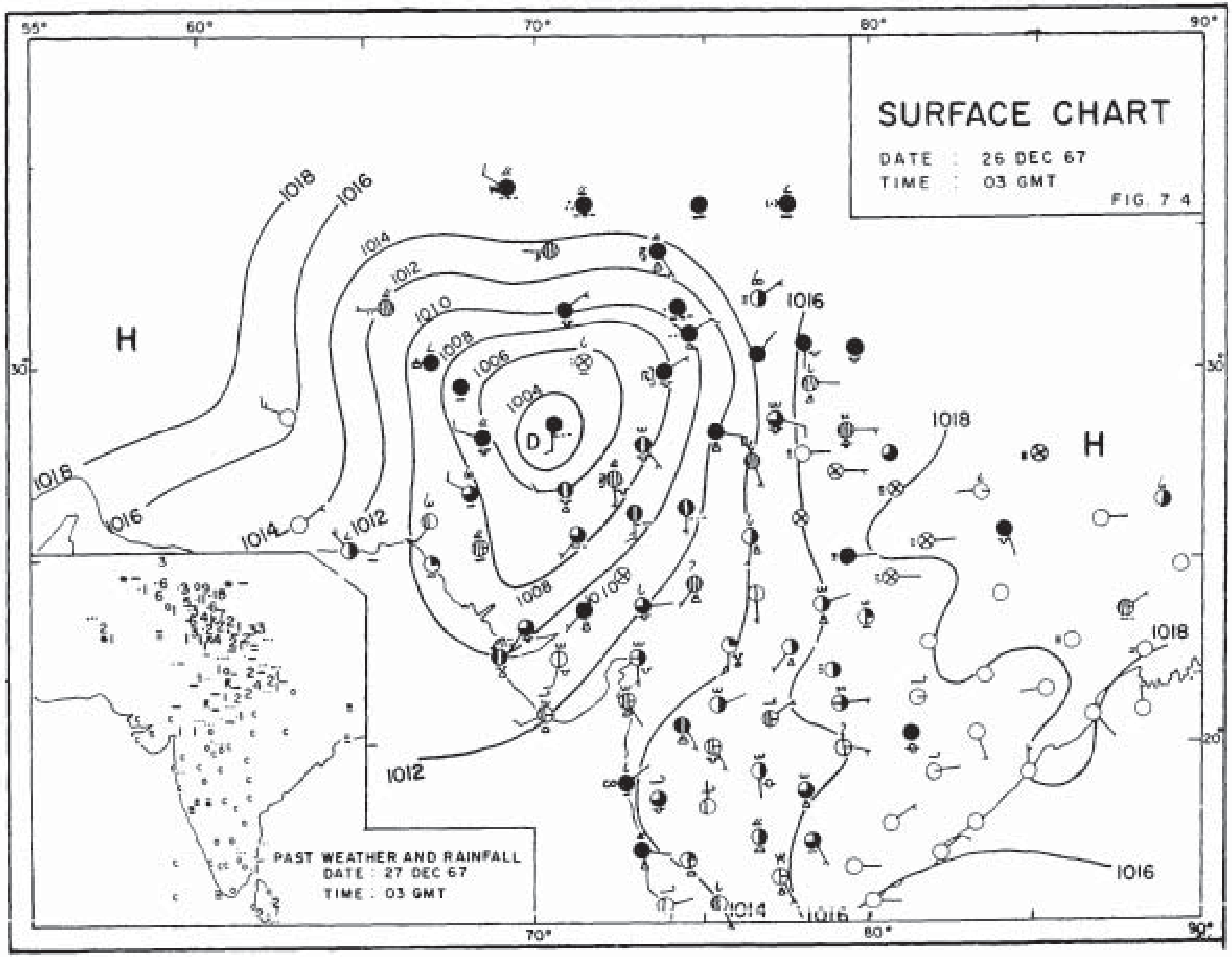
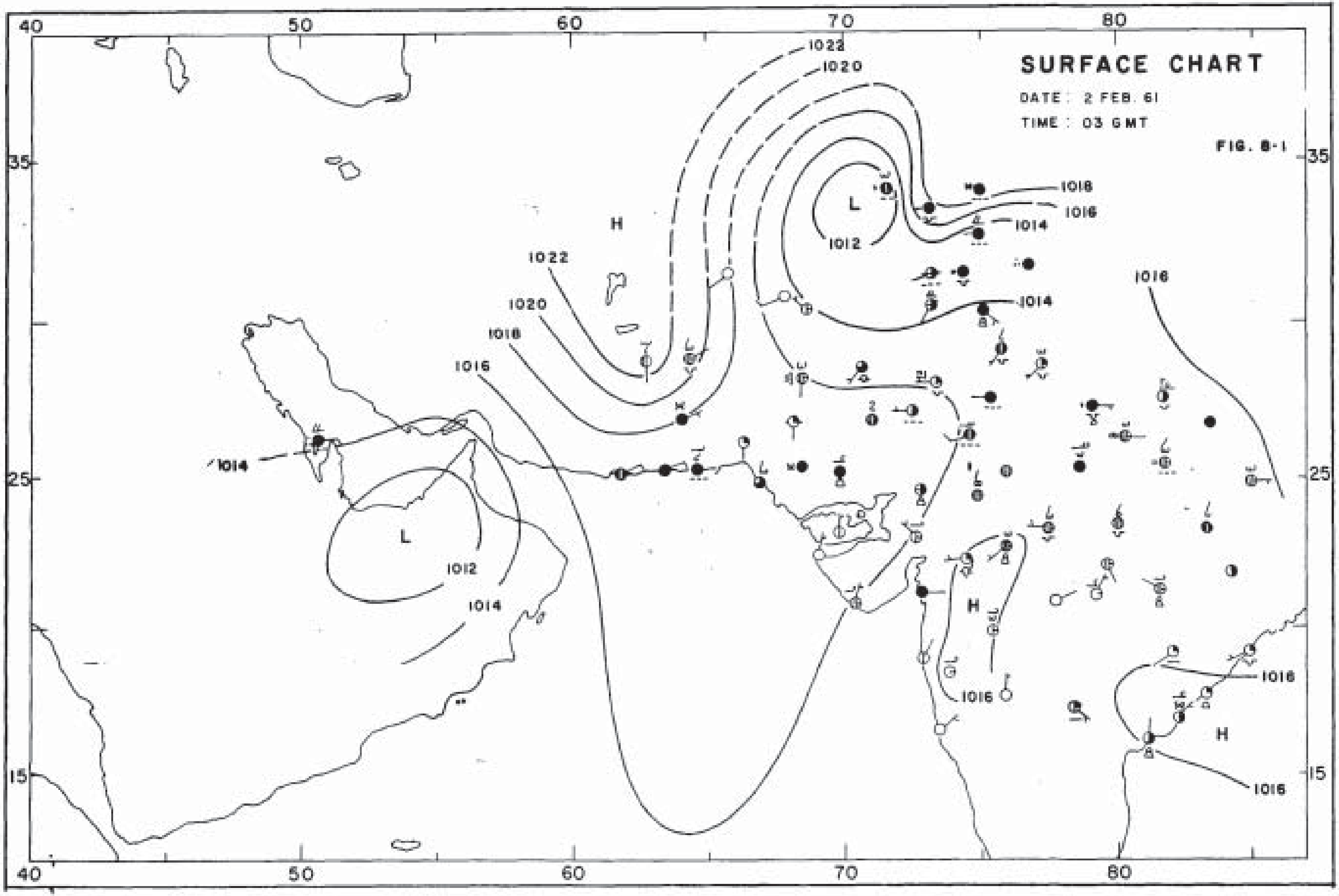

SURFACE CHART
DATE: 25 DEC 67
TIME: 03 GMT
FIG. 7·3
PAST WEATHER AND RAINFALL
DATE : 26 DEC 67
TIME : 03 GMT
24 HRS. PRESSURE CHANGE (mb.)
DATE : 25 DEC. 67
TIME : 03 GMT
1009
1010
1012
1014
1016
1018
H
D
L
50°
60°
70°
80°

FIG. 7·5 UPPER WINDS. DATE : 26 DEC. 67. TIME : 00 GMT

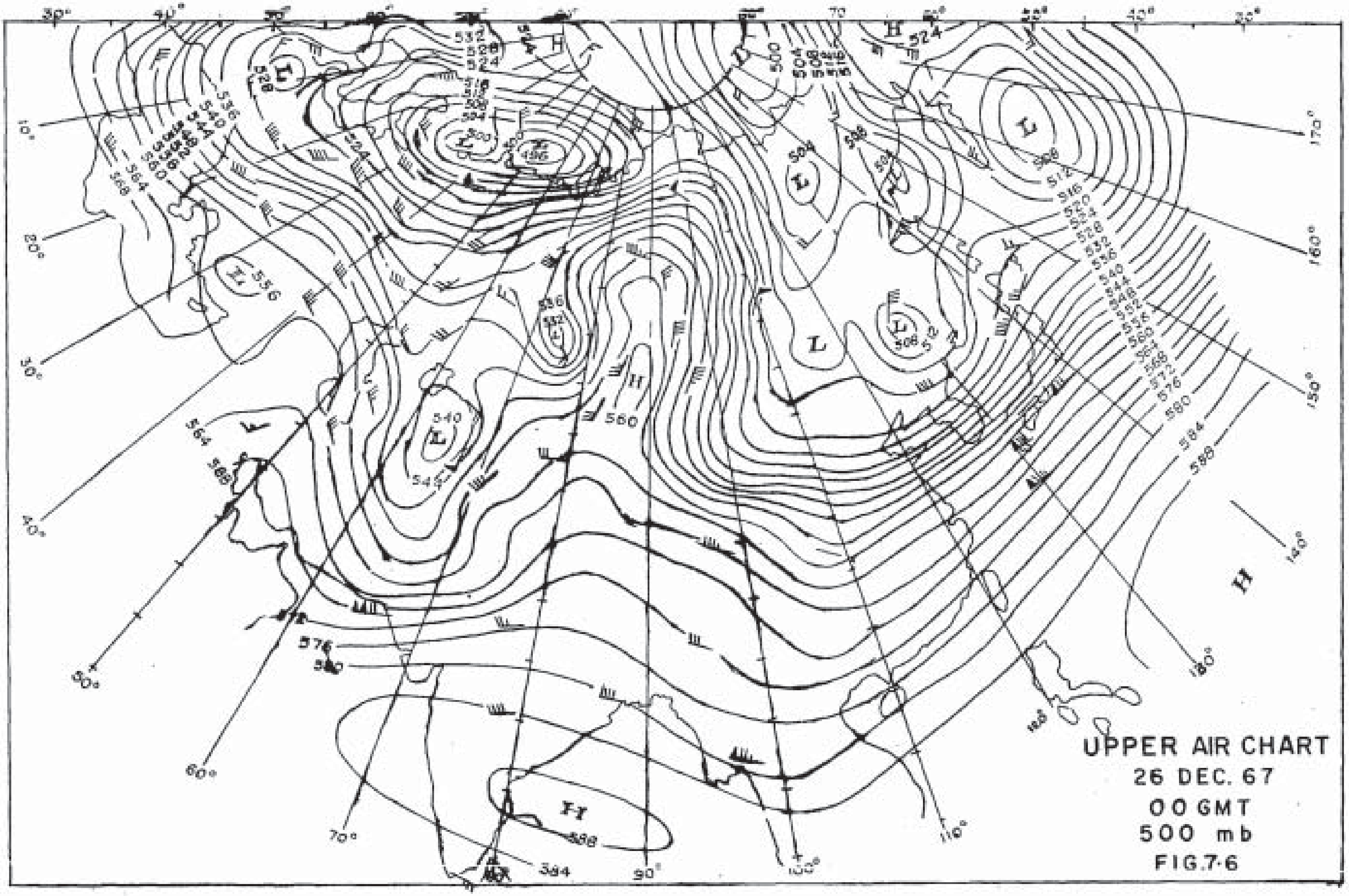



SURFACE CHART
DATE : 26 DEC 67
TIME : 03 GMT
FIG. 7.4
PAST WEATHER AND RAINFALL
DATE : 27 DEC 67
TIME : 03 GMT
55°
60°
70°
80°
90°
30°
20°
H
D
1004
1006
1008
1010
1012
1014
1016
1018



SURFACE CHART
DATE : 2 FEB. 61
TIME : 03 GMT
1022
1020
1018
1016
1014
1012
H
L
40
50
60
70
80
35
25
15

FIG. 8-1



UPPER AIR CHART
26 DEC. 67
00 GMT
500 mb
FIG.7·6

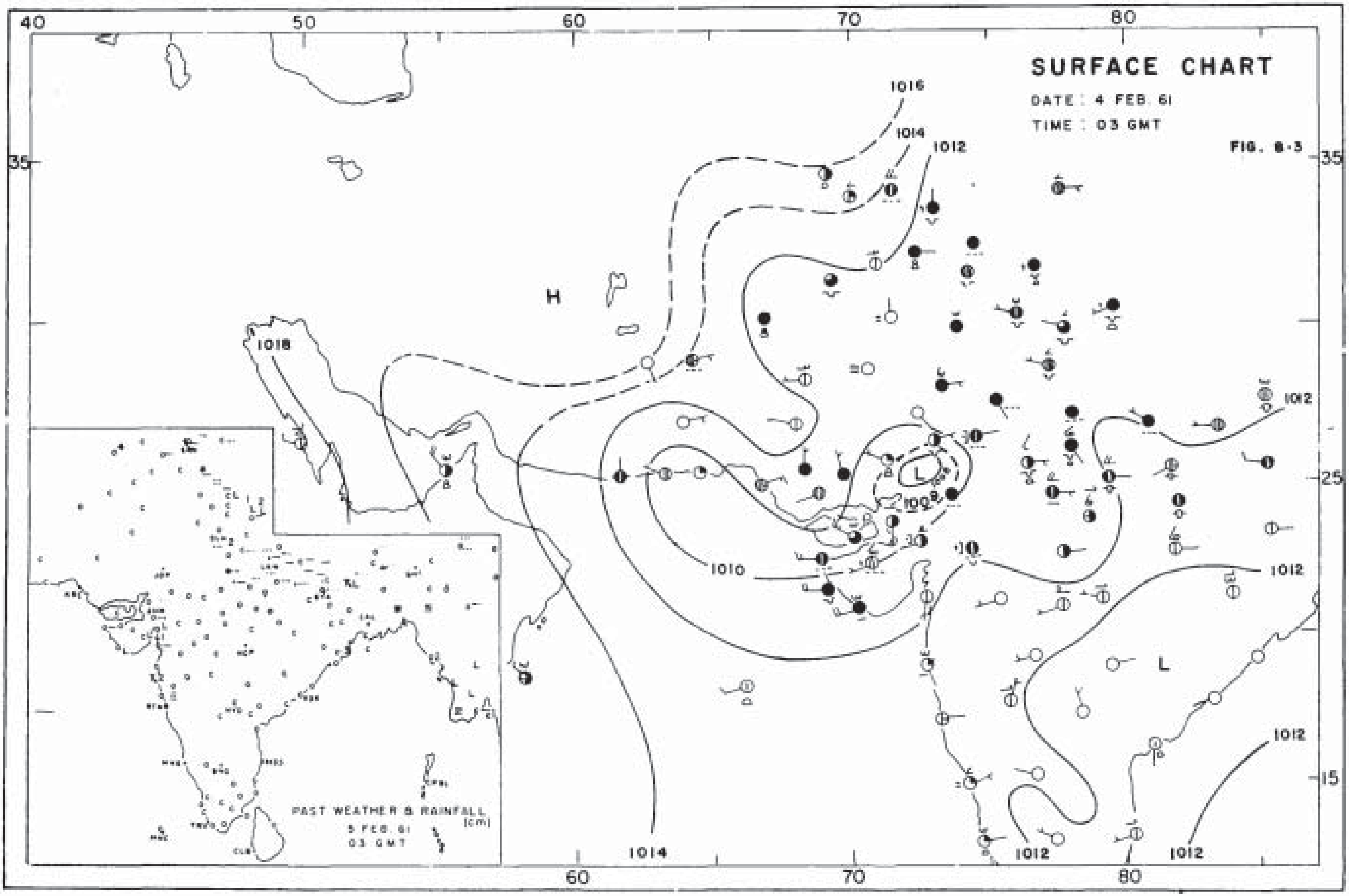

SURFACE CHART
DATE : 4 FEB. 61
TIME : 03 GMT
40
50
60
70
80
35
25
15
1016
1014
1012
1018
1010
1008
H
L
PAST WEATHER & RAINFALL (cm)
5 FEB. 61
03 GMT

FIG. 8·3

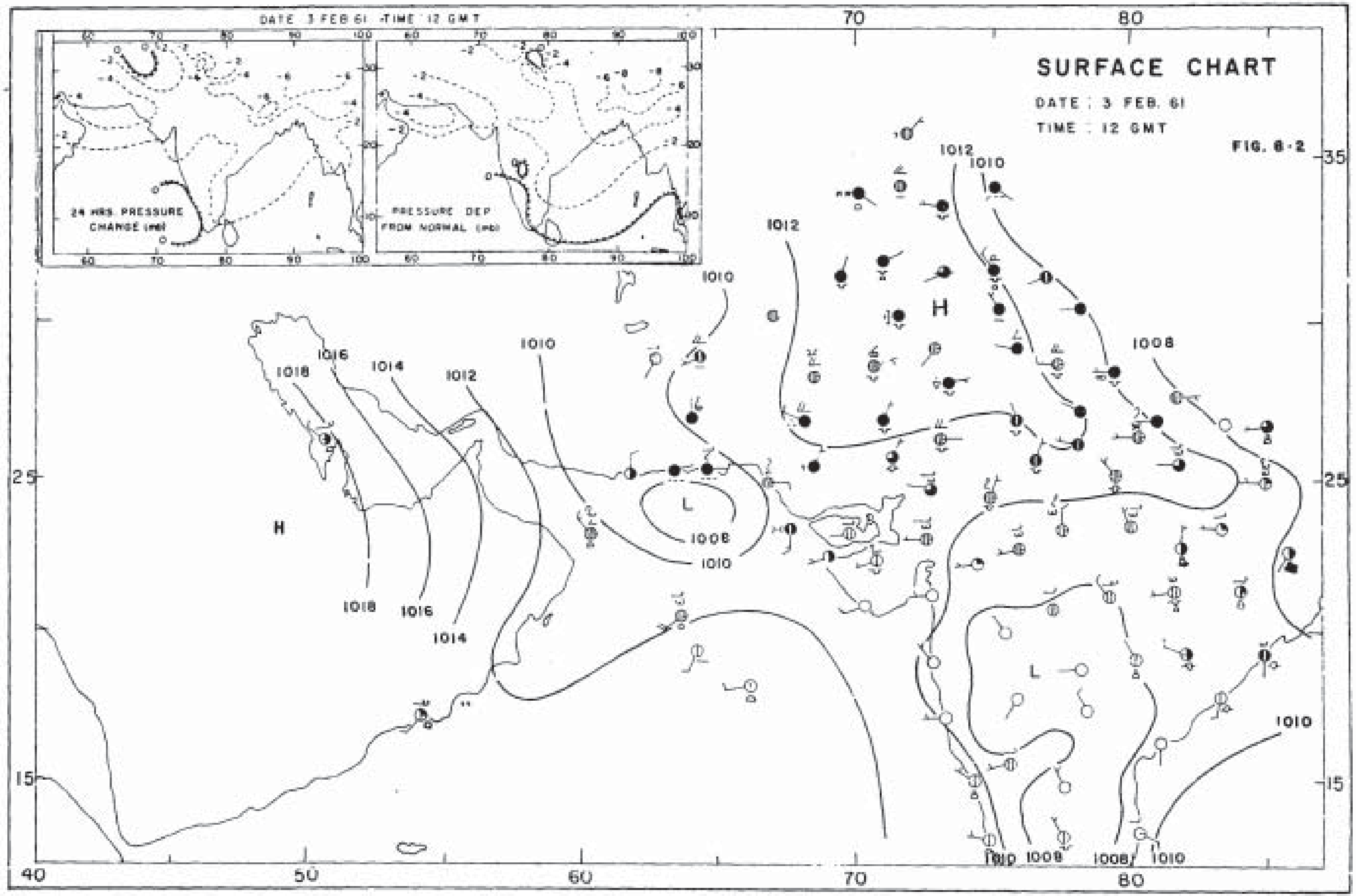
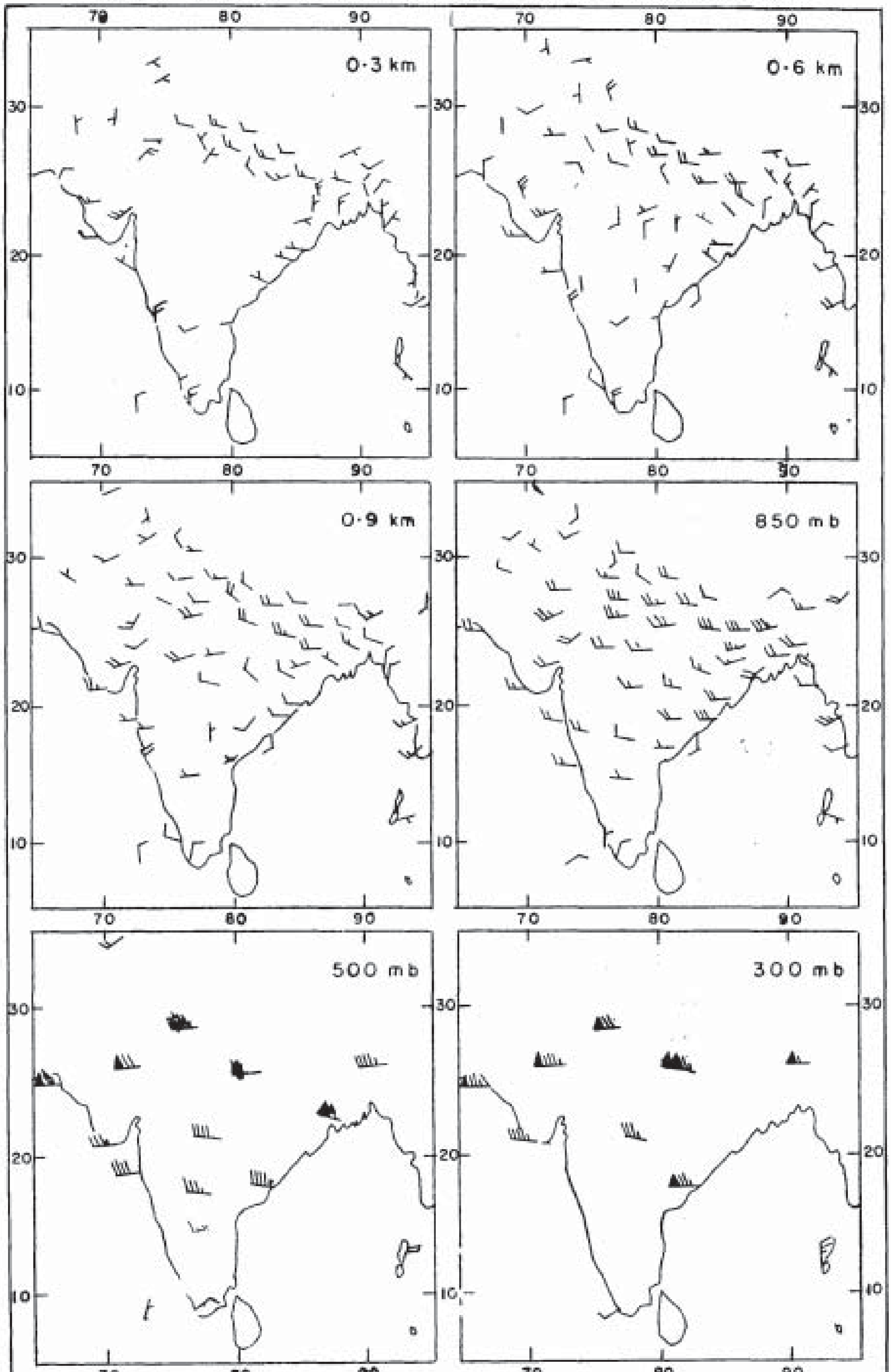

SURFACE CHART
DATE : 3 FEB. 61
TIME : 12 GMT
DATE 3 FEB 61 -TIME 12 GMT
24 HRS. PRESSURE CHANGE (mb)
PRESSURE DEP FROM NORMAL (mb)
1018
1016
1014
1012
1010
1008
H
L

FIG. 8·2

FIG. 8·5 UPPER WINDS. DATE : 4 FEB. 61. TIME : 00 GMT



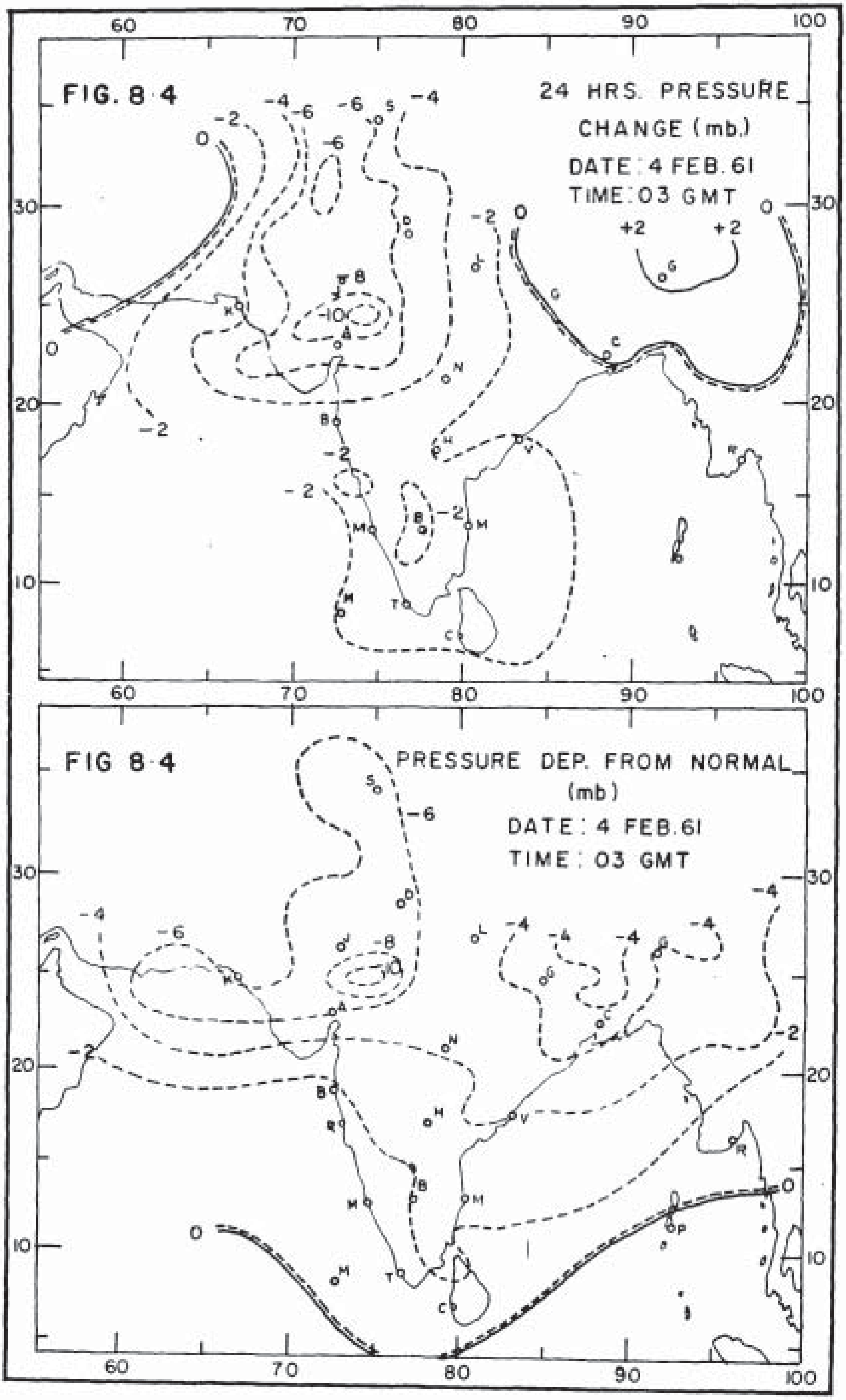
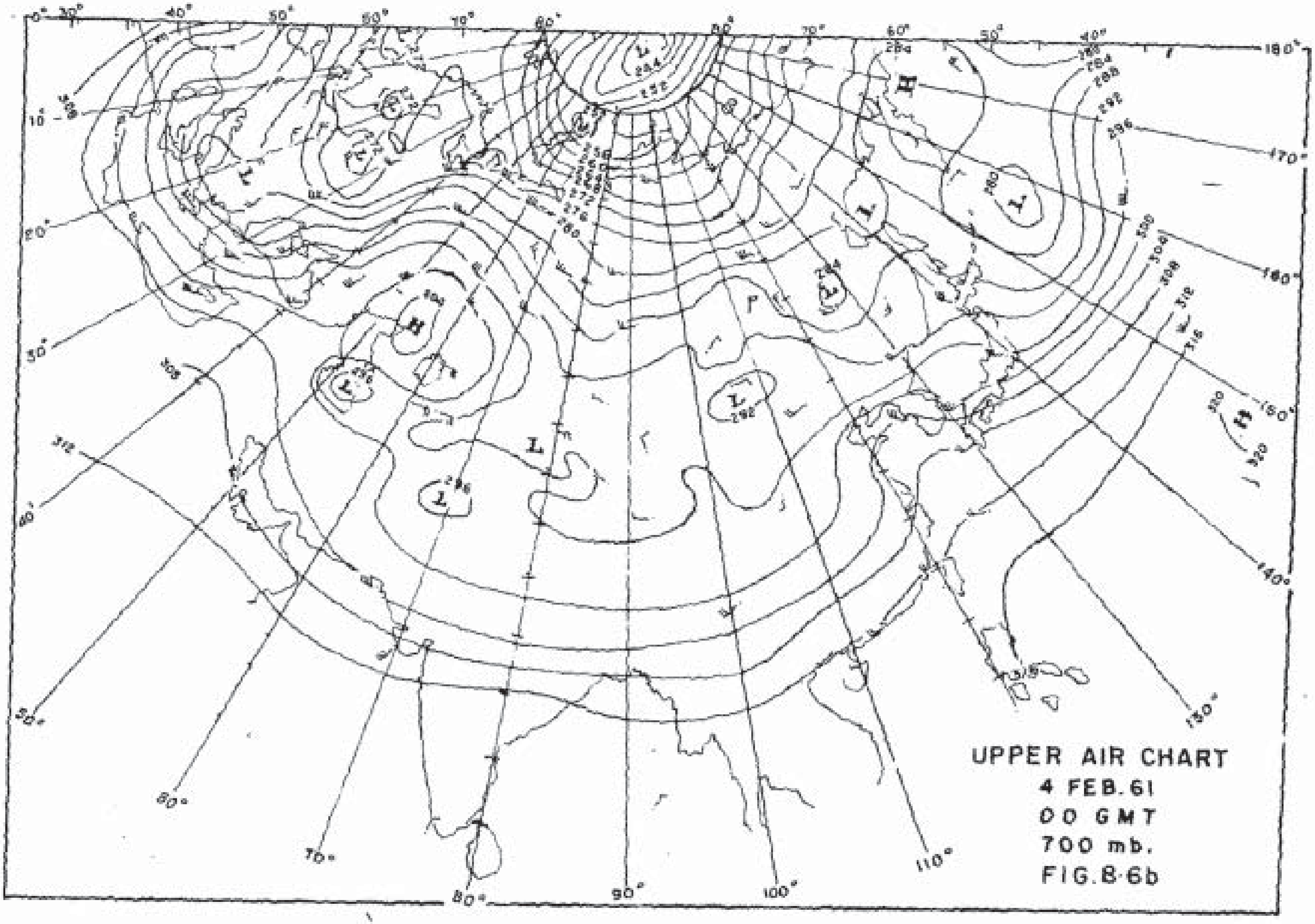
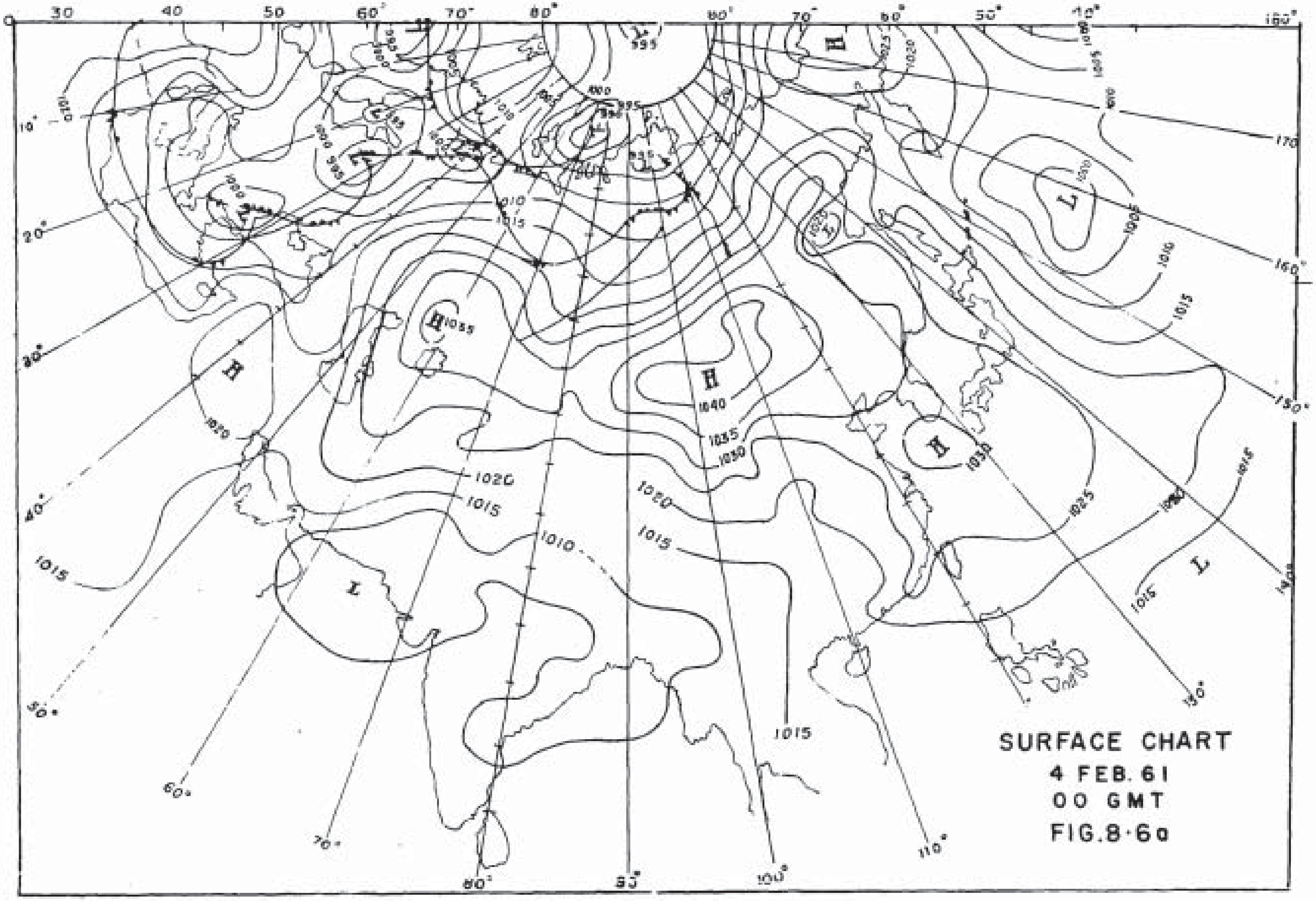


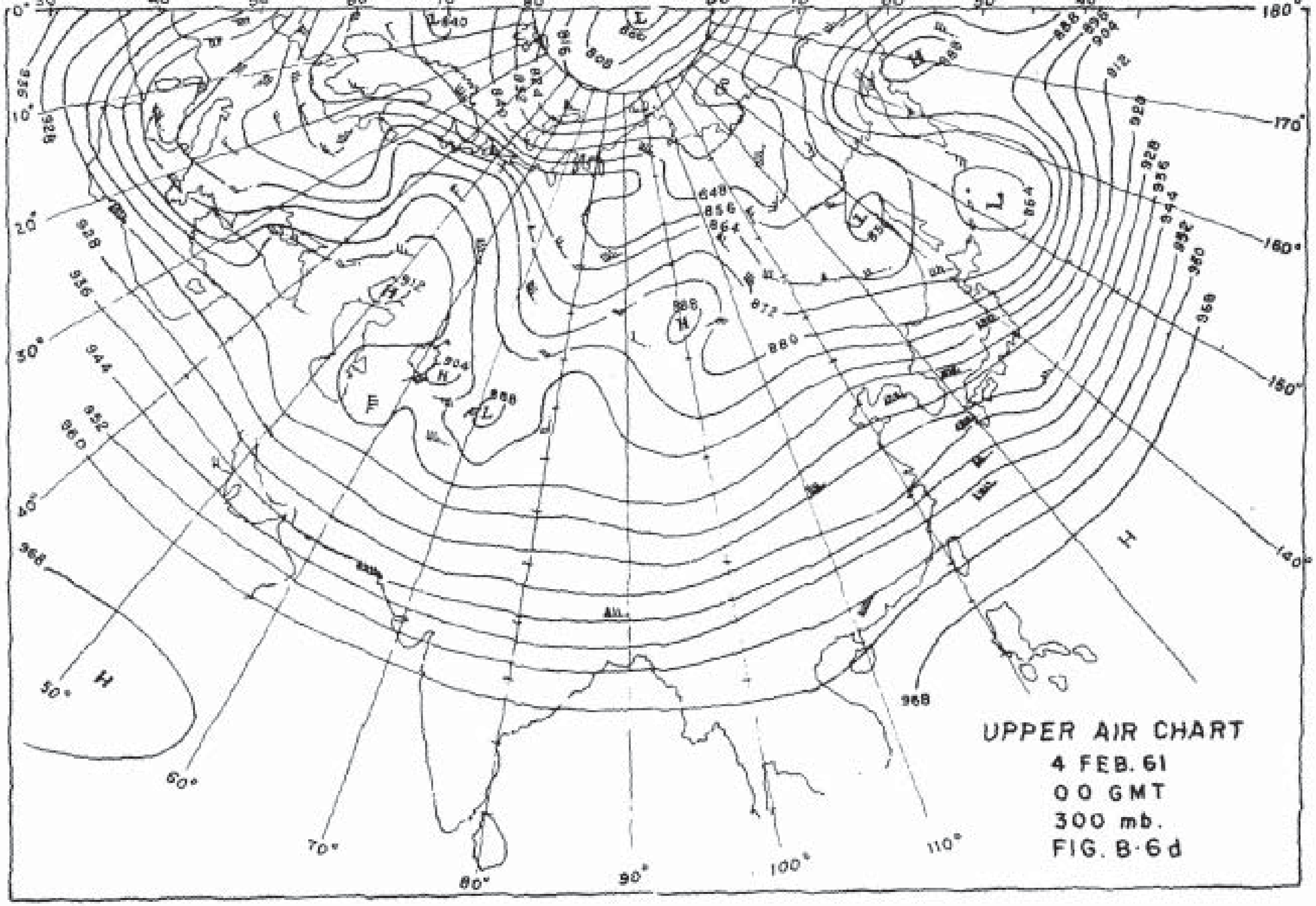
FIG. 8·4
24 HRS. PRESSURE CHANGE (mb.)
DATE : 4 FEB. 61
TIME : 03 GMT
FIG 8·4
PRESSURE DEP. FROM NORMAL (mb)
DATE : 4 FEB. 61
TIME : 03 GMT



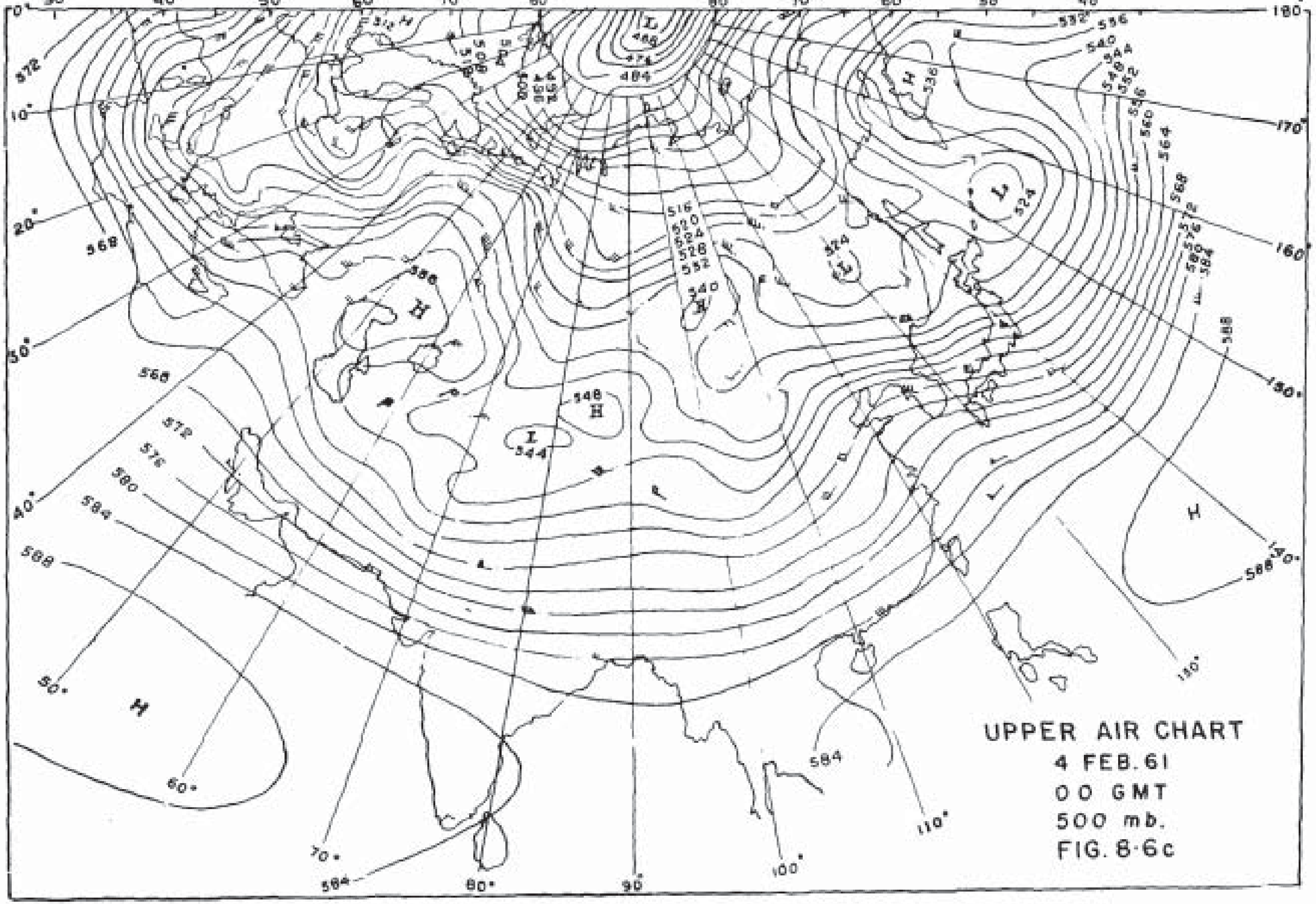
UPPER AIR CHART
4 FEB. 61
00 GMT
700 mb.
FIG. 8·6b



SURFACE CHART
4 FEB. 61
00 GMT
FIG. 8·6a



UPPER AIR CHART
4 FEB. 61
00 GMT
300 mb.
FIG. B-6d



UPPER AIR CHART
4 FEB. 61
00 GMT
500 mb.
FIG. 8·6c

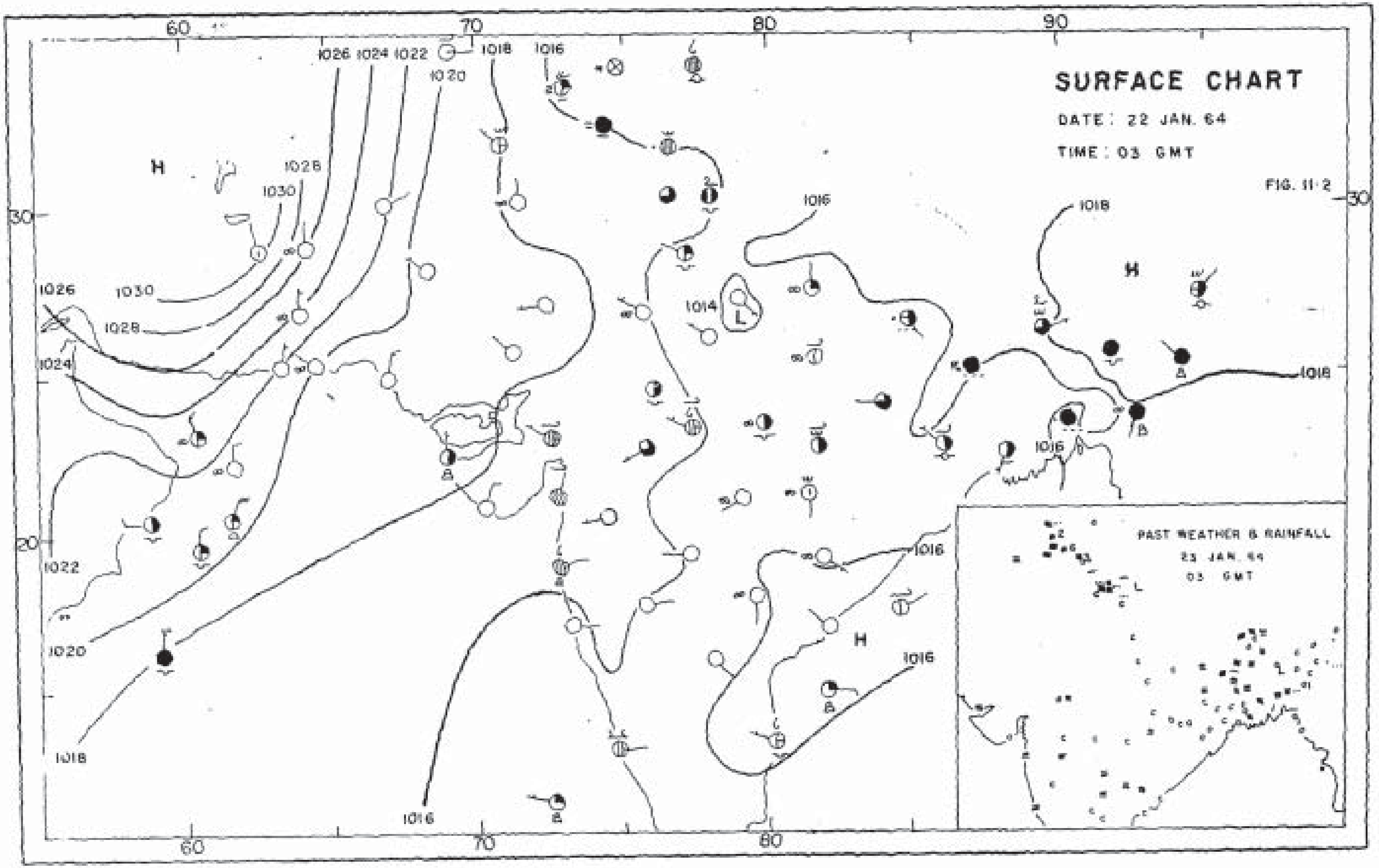
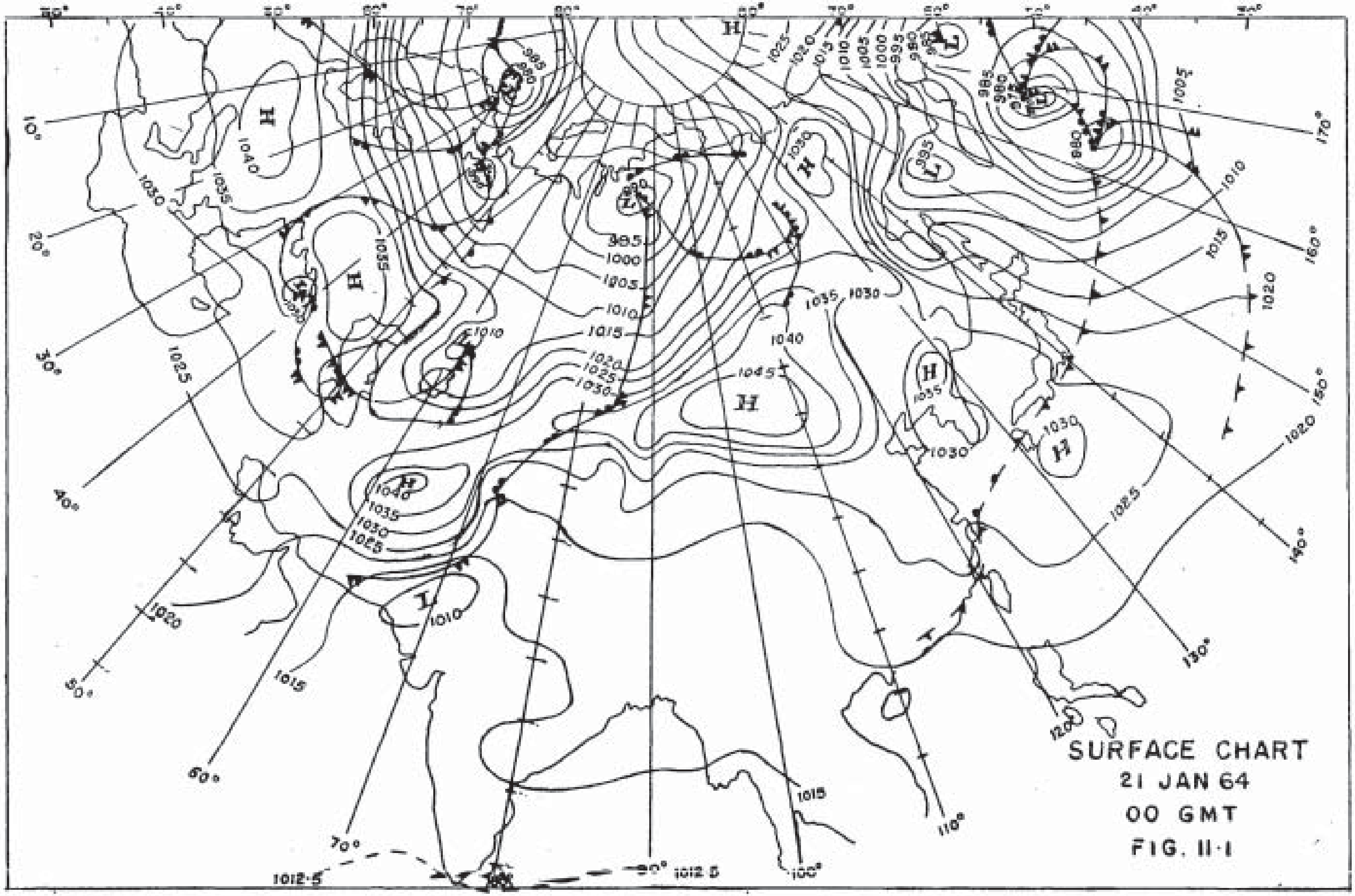

SURFACE CHART
DATE : 22 JAN. 64
TIME : 03 GMT
PAST WEATHER & RAINFALL
23 JAN. 64
03 GMT
H
L
1030
1028
1026
1024
1022
1020
1018
1016
1014
60
70
80
90
20
30

FIG. 11·2



SURFACE CHART
21 JAN 64
00 GMT
FIG. II·1

FIG. II·3 UPPER WINDS. DATE : 22 JAN. 64. TIME : 00 GMT

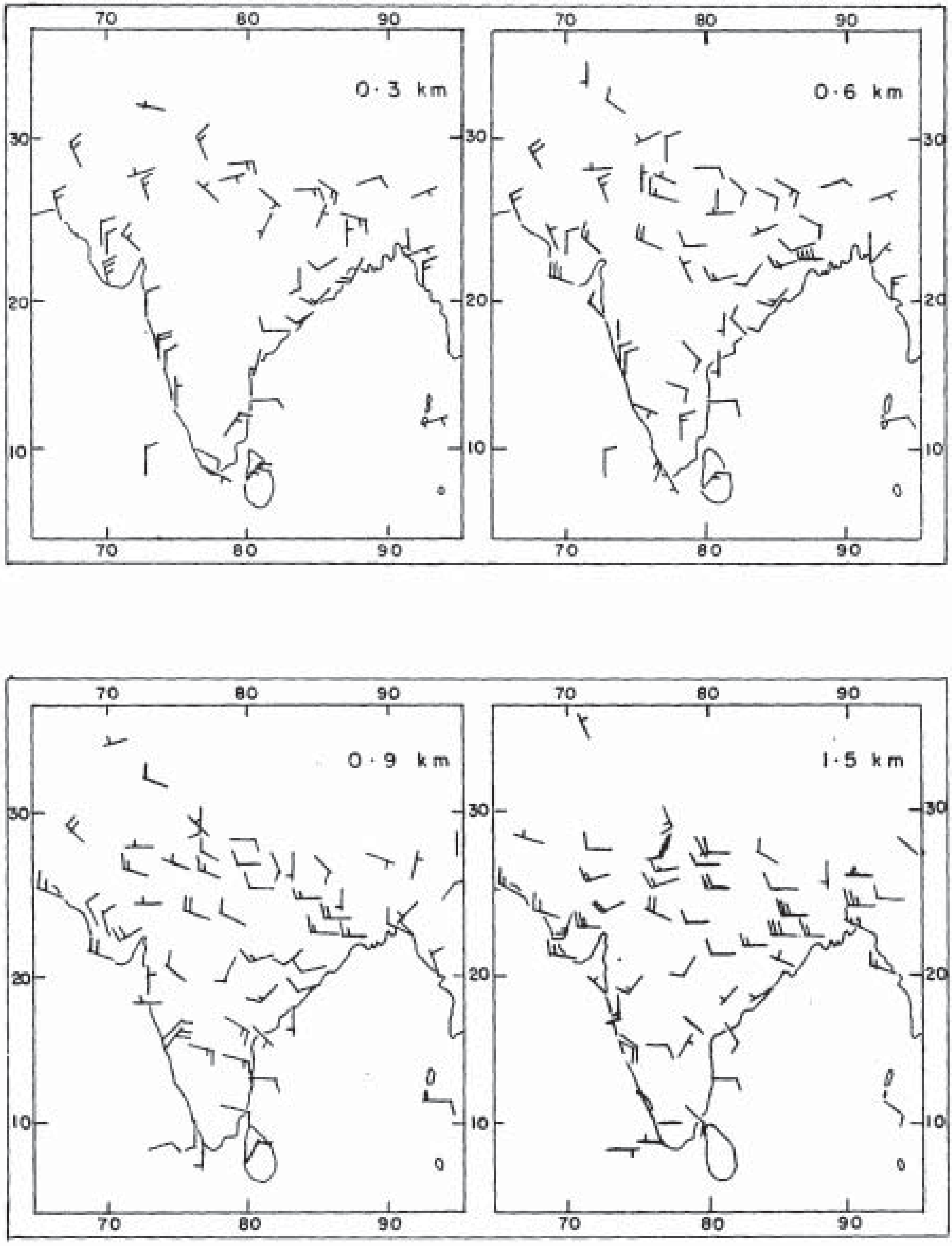


FIG. II-4 DATE: 22 JAN. 64 TIME: 03 GMT

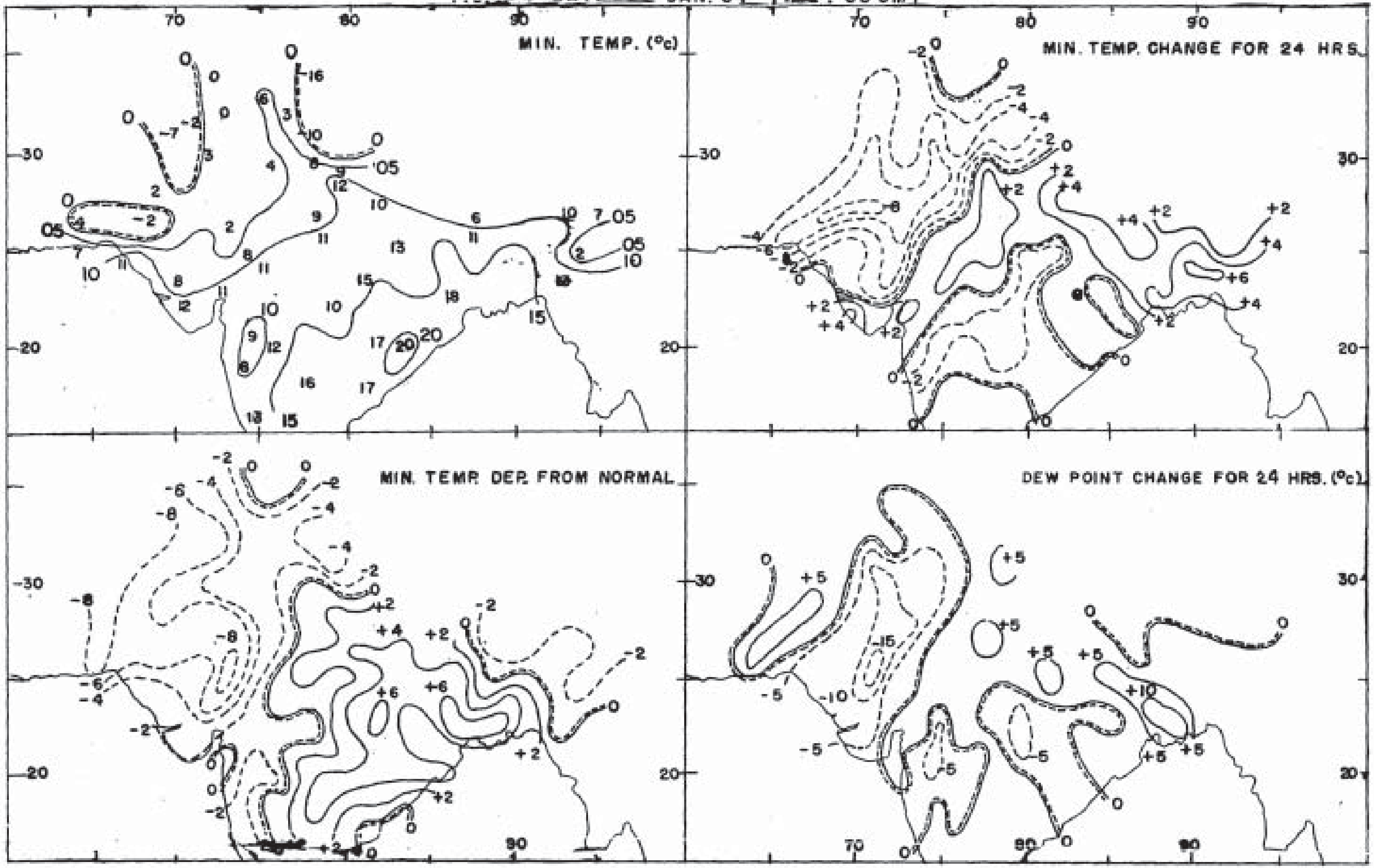


FIG. II·5 UPPER WINDS. DATE: 23 JAN. 64 TIME: 00 GMT

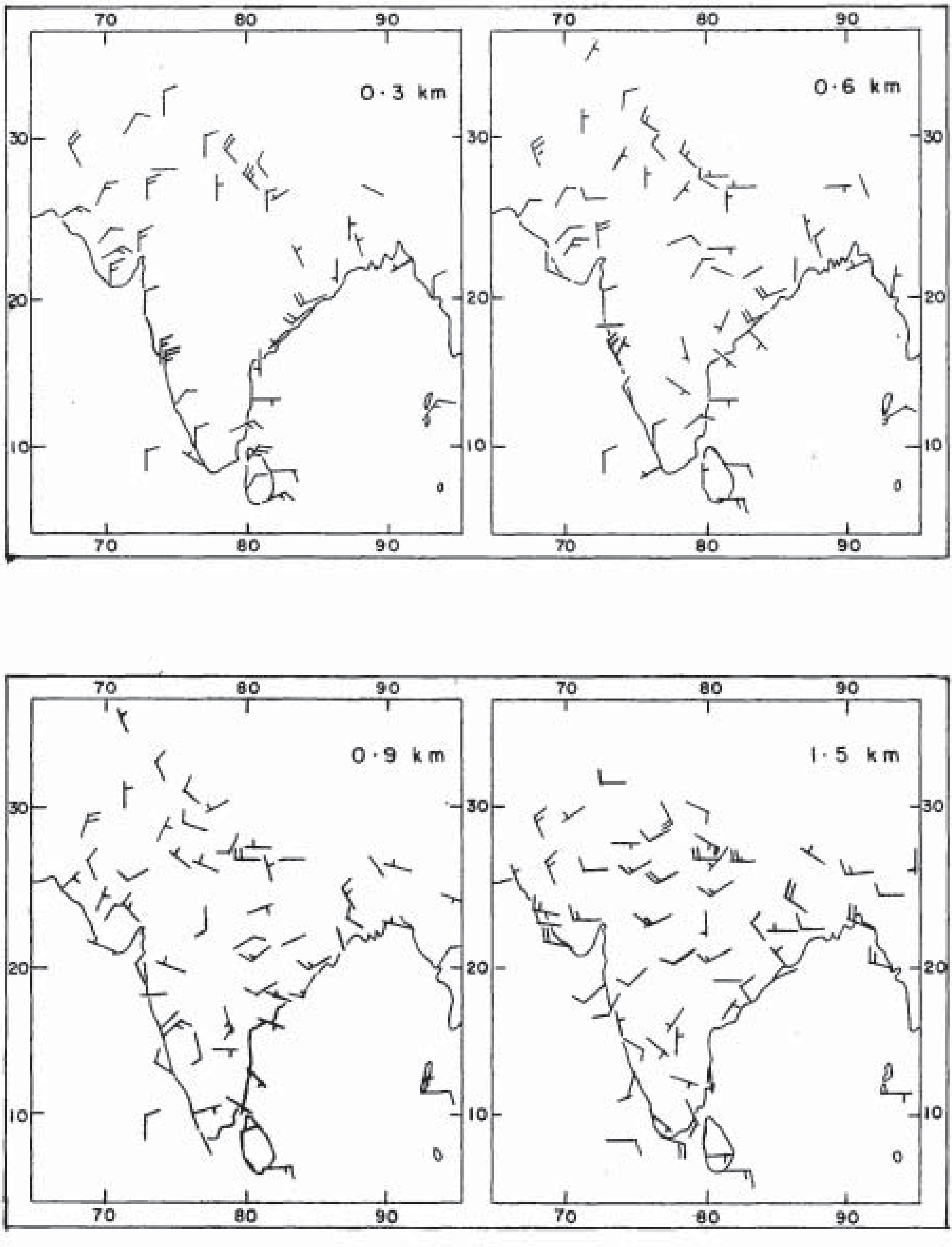
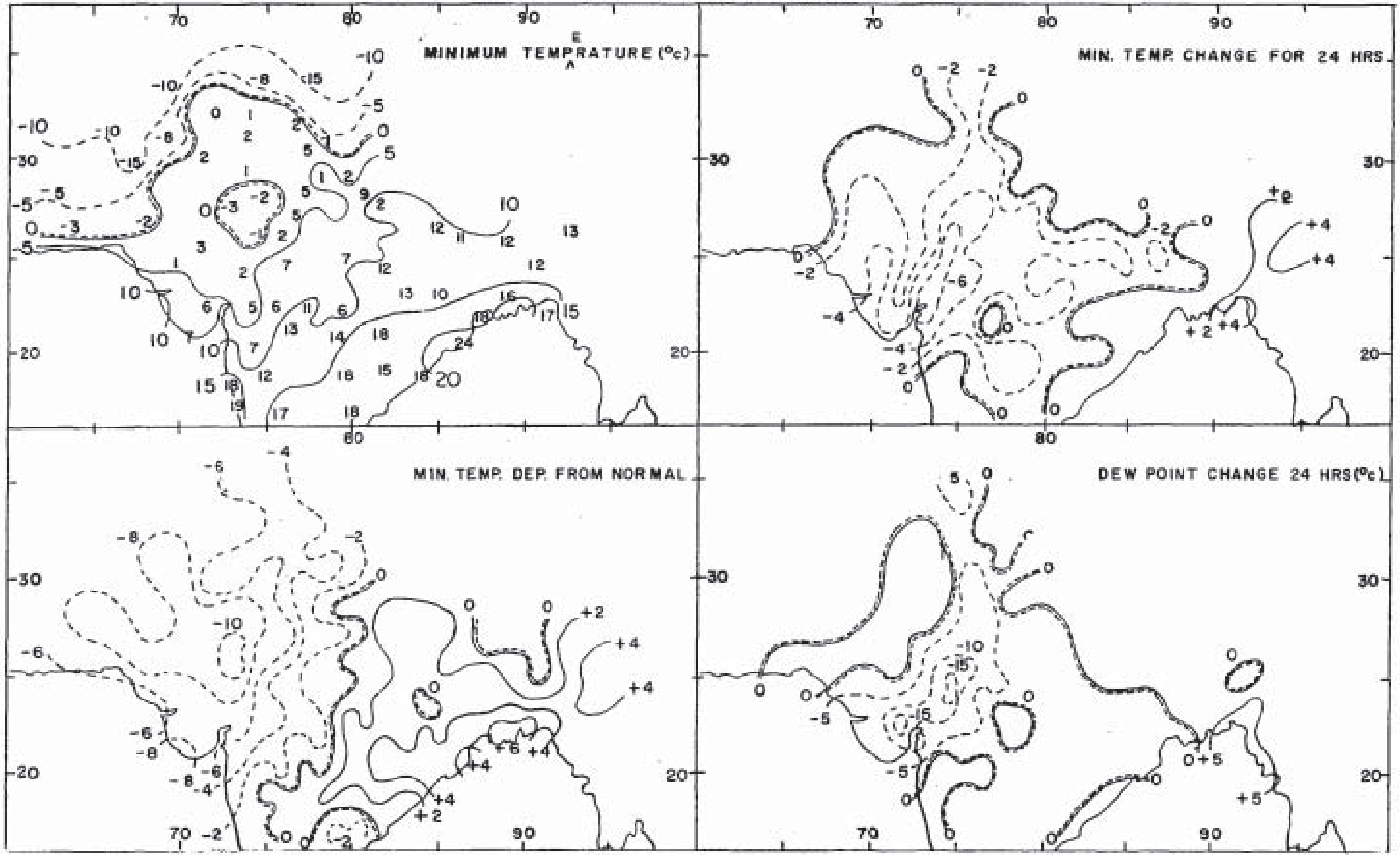


FIG. II-6 DATE : 23 JAN 64 TIME : 03 G M T



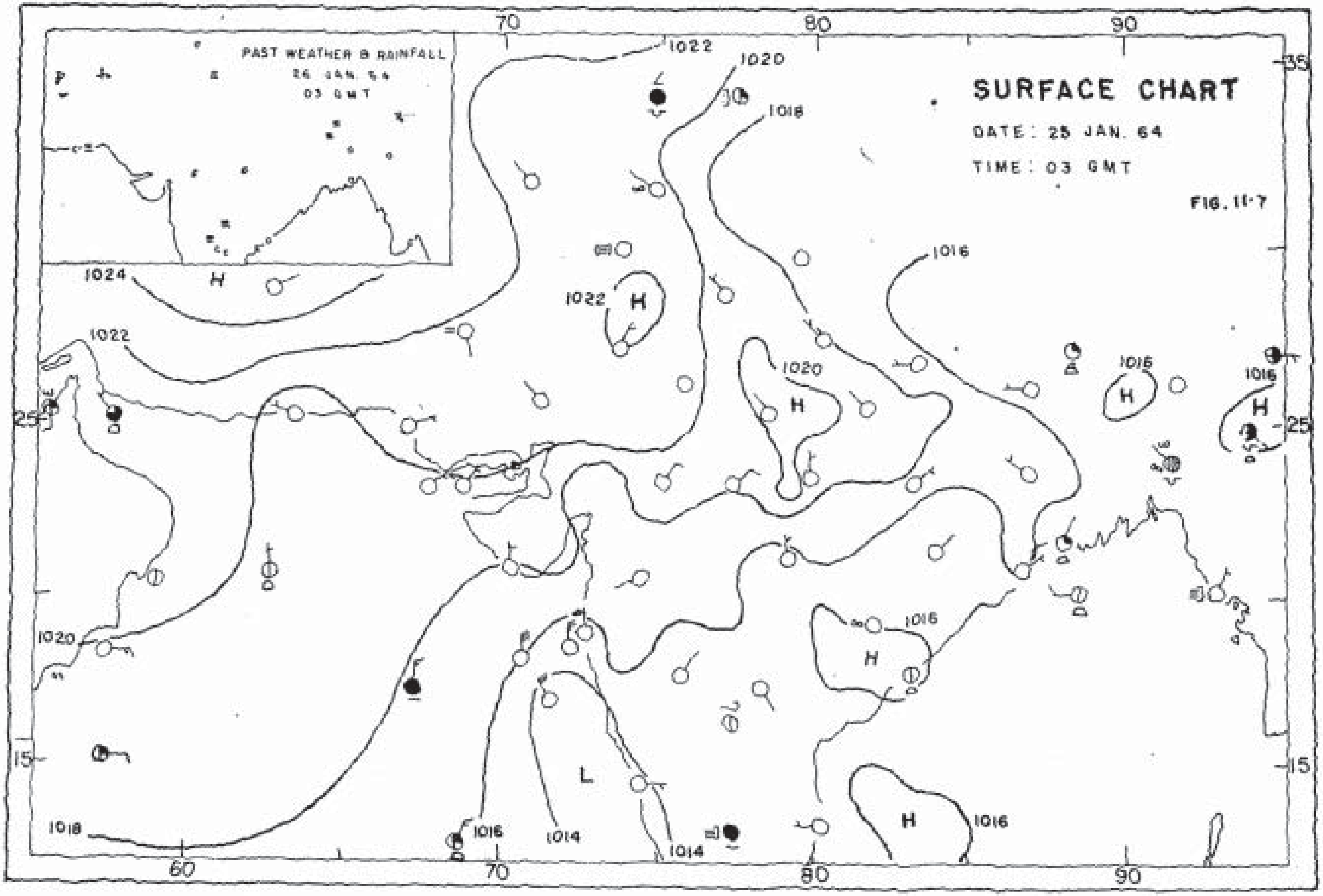

SURFACE CHART
DATE : 25 JAN. 64
TIME : 03 GMT
PAST WEATHER & RAINFALL
25 JAN. 64
03 GMT
1024
1022
1020
1018
1016
1014
H
L
60
70
80
90
35
25
15
FIG. 11·7

FIG. II·8 UPPER WINDS. DATE : 26 JAN. 64. TIME : 00 GMT

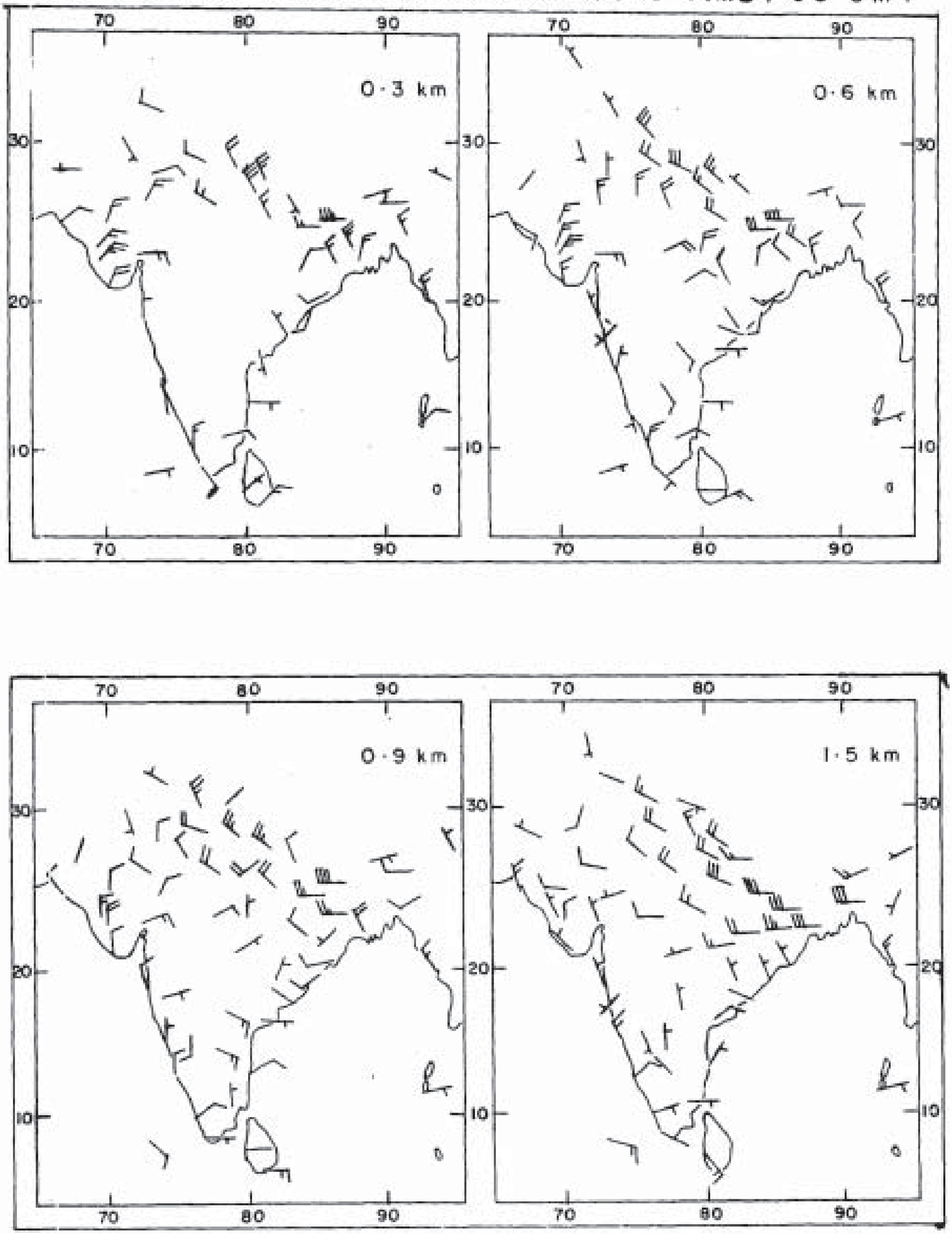


FIG. II-9 DATE: 26 JAN 64 TIME: 03 GMT

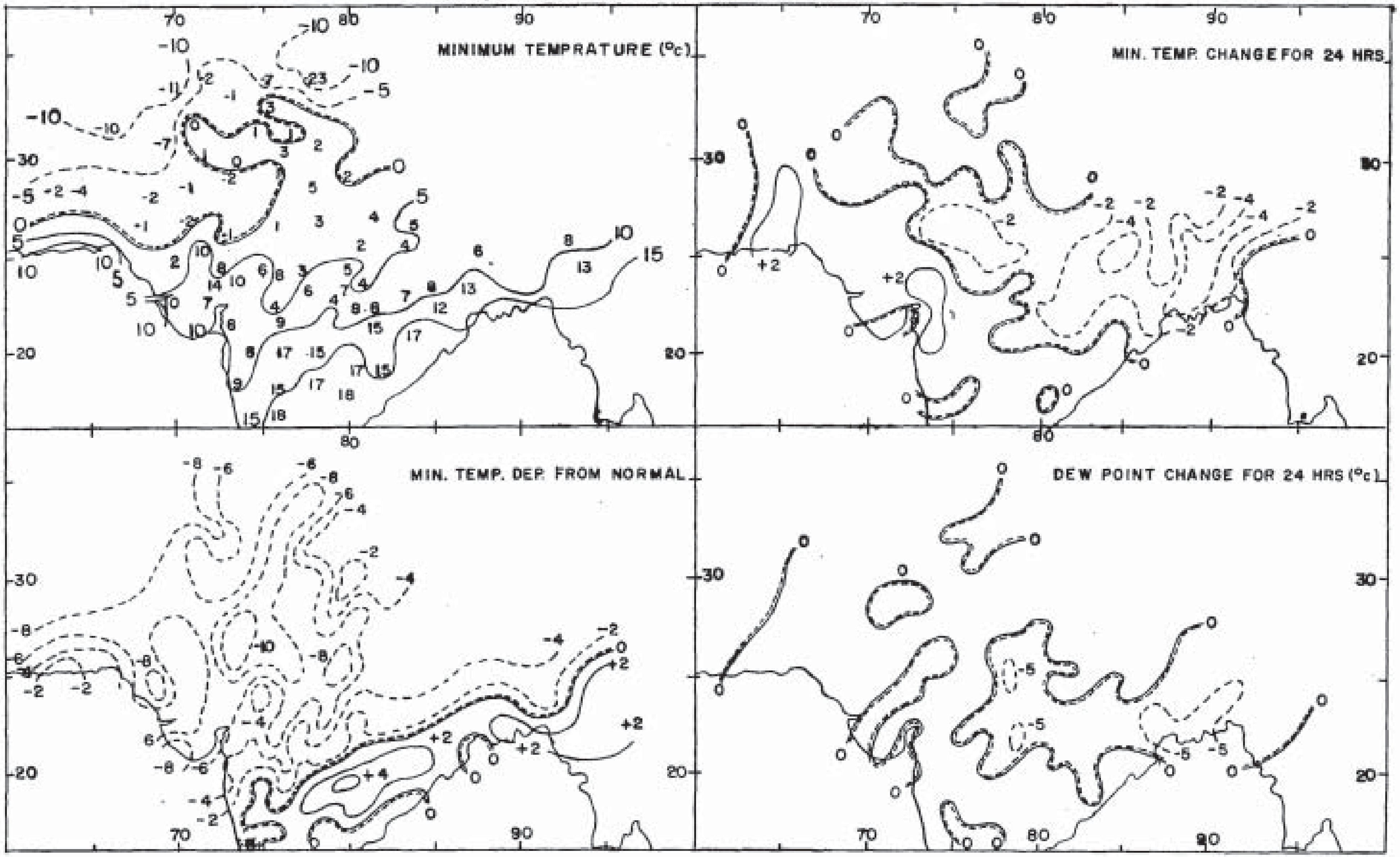


FIG. 11-19 DATE: 27 JAN 64 TIME: 03 GMT

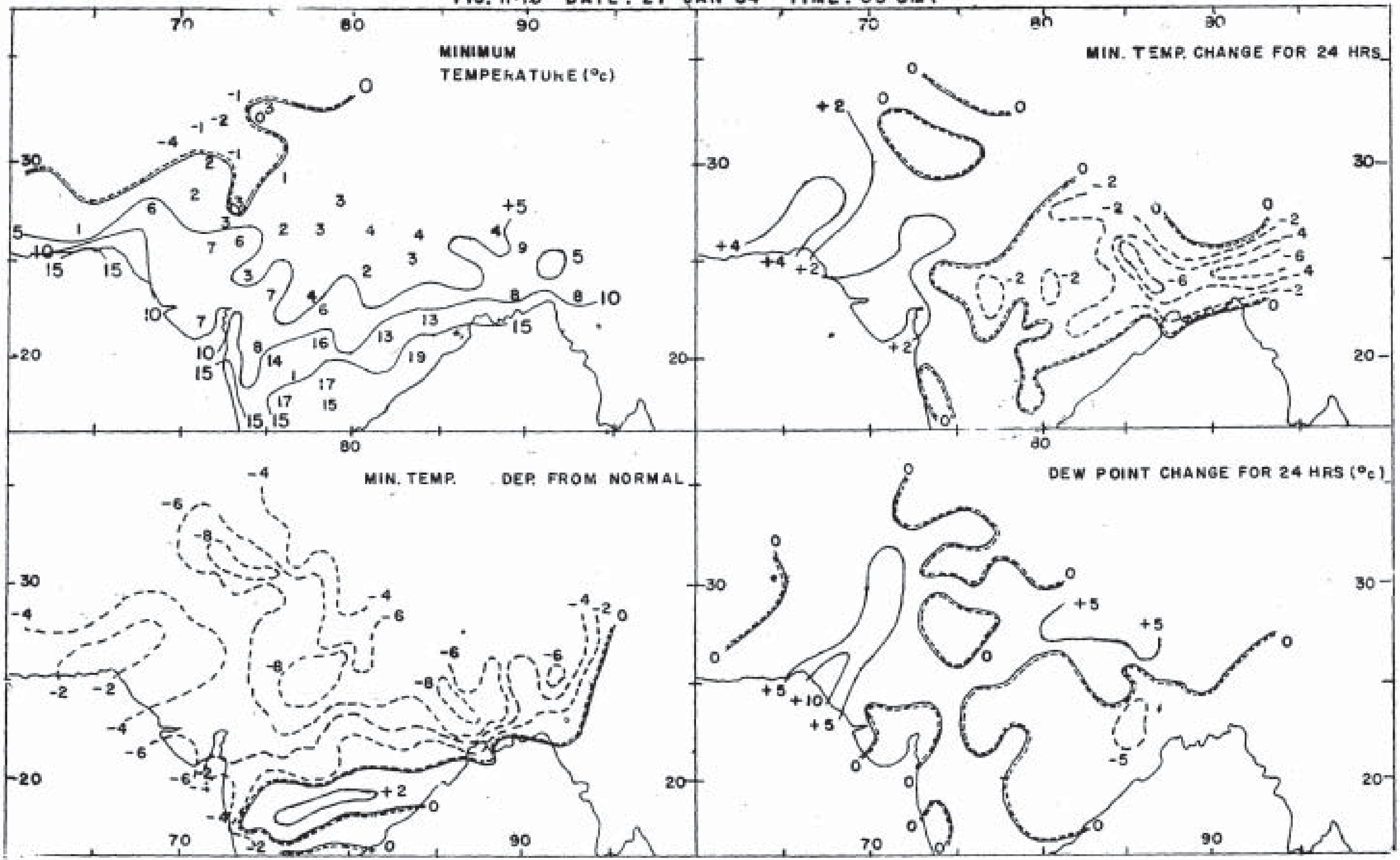


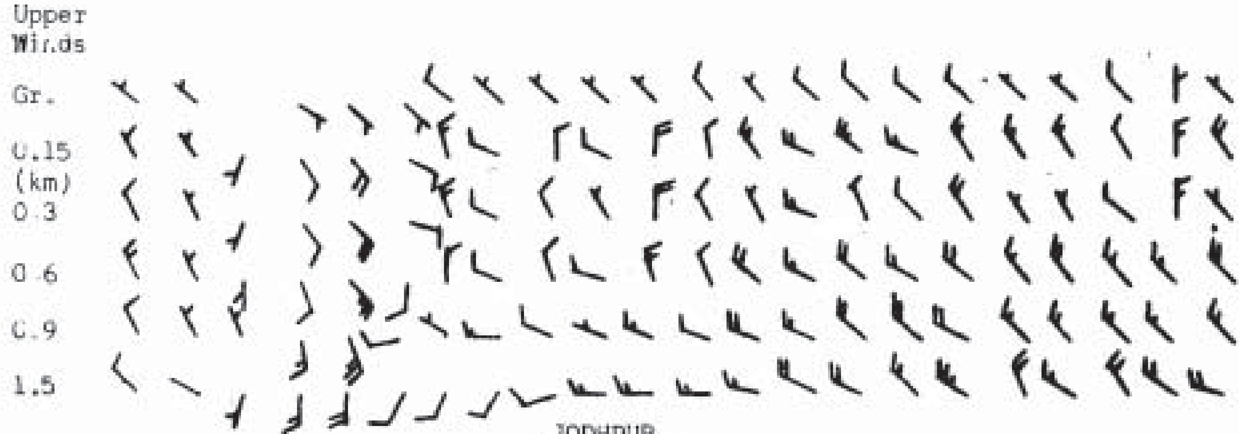
Fig. 11.11

Time-Section of Low Level Winds and Maximum and Minimum Temperatures (°C)

Date	19	20	21	22	23	24	25	26	28	28	29

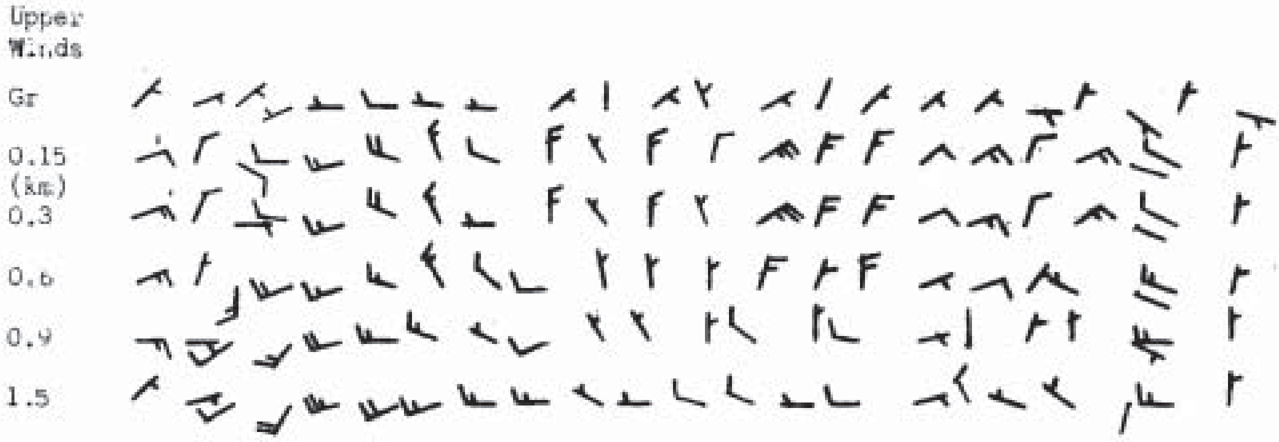
NEW DELHI (Safdarjung)

Min.	3	4	6	9	5	5	1	1	1	4	3
Dep.	- 5	- 4	- 2	1	- 3	- 3	- 7	- 7	- 7	- 4	- 5
Max.	18	19	19	20	19	16	15	15	15	17	18
Dep.	- 3	- 2	- 3	- 2	- 3	- 6	- 7	- 7	- 7	- 5	- 4
Weather	z	f	z	r	z	z	-	-	-	-	-

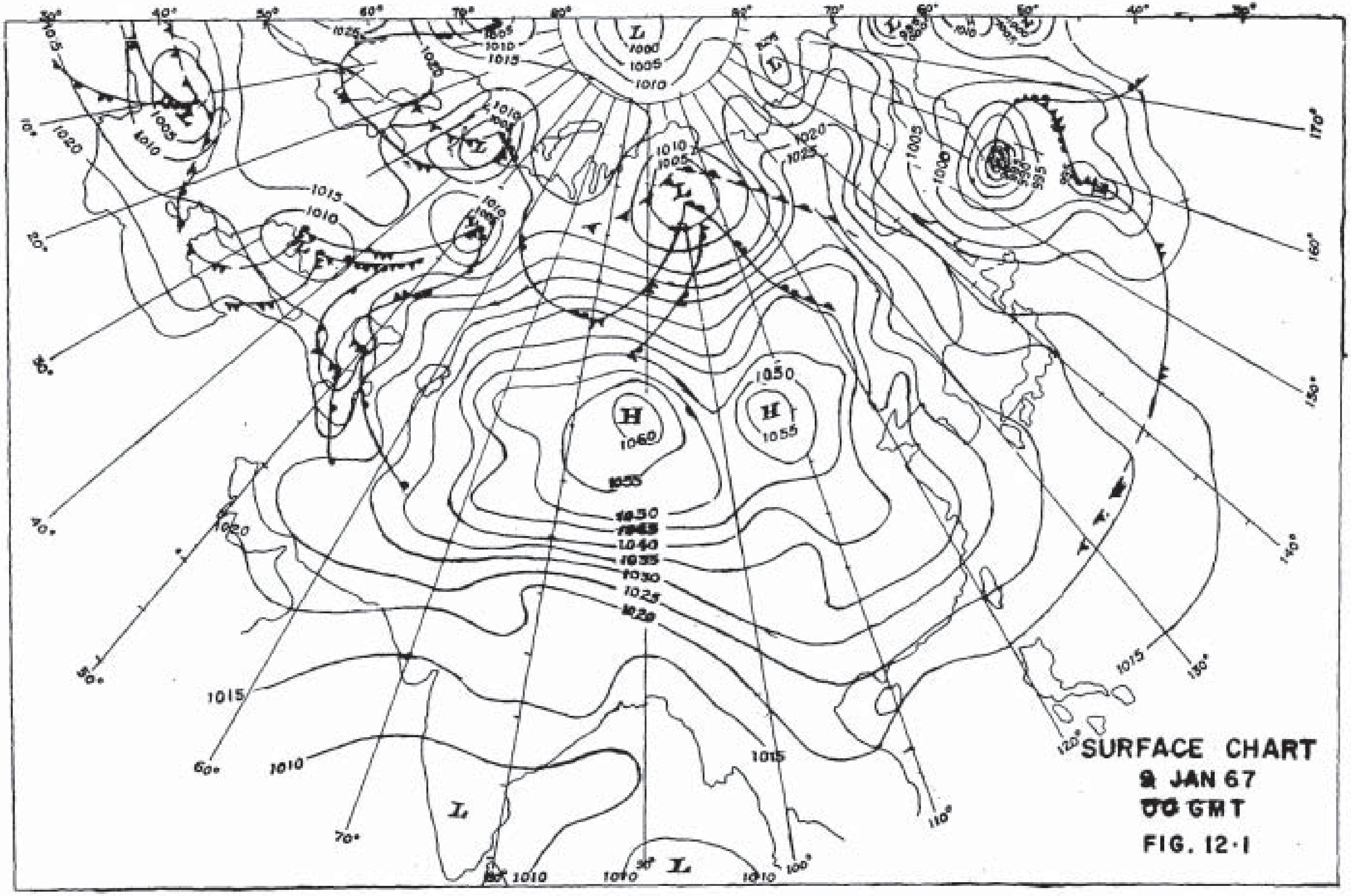


JODHPUR

Min.	4	9	11	2	0	4	5	- 1	6	6	9
Dep.	- 4	1	1	- 8	-10	- 6	- 5	-11	- 4	- 4	- 1
Max.	21	22	25	21	18	18	19	19	20	23	25
Dep.	- 3	- 2	0	- 4	- 7	- 7	- 6	- 7	- 6	- 3	- 1
Weather	-	-	-	z	z	-	-	-	-		-



z - Haze f - Fog r - Rain



SURFACE CHART
9 JAN 67
00 GMT
FIG. 12·1

FIG. 12·2 UPPER WINDS DATE: 9 JAN 67 TIME: 00 GMT

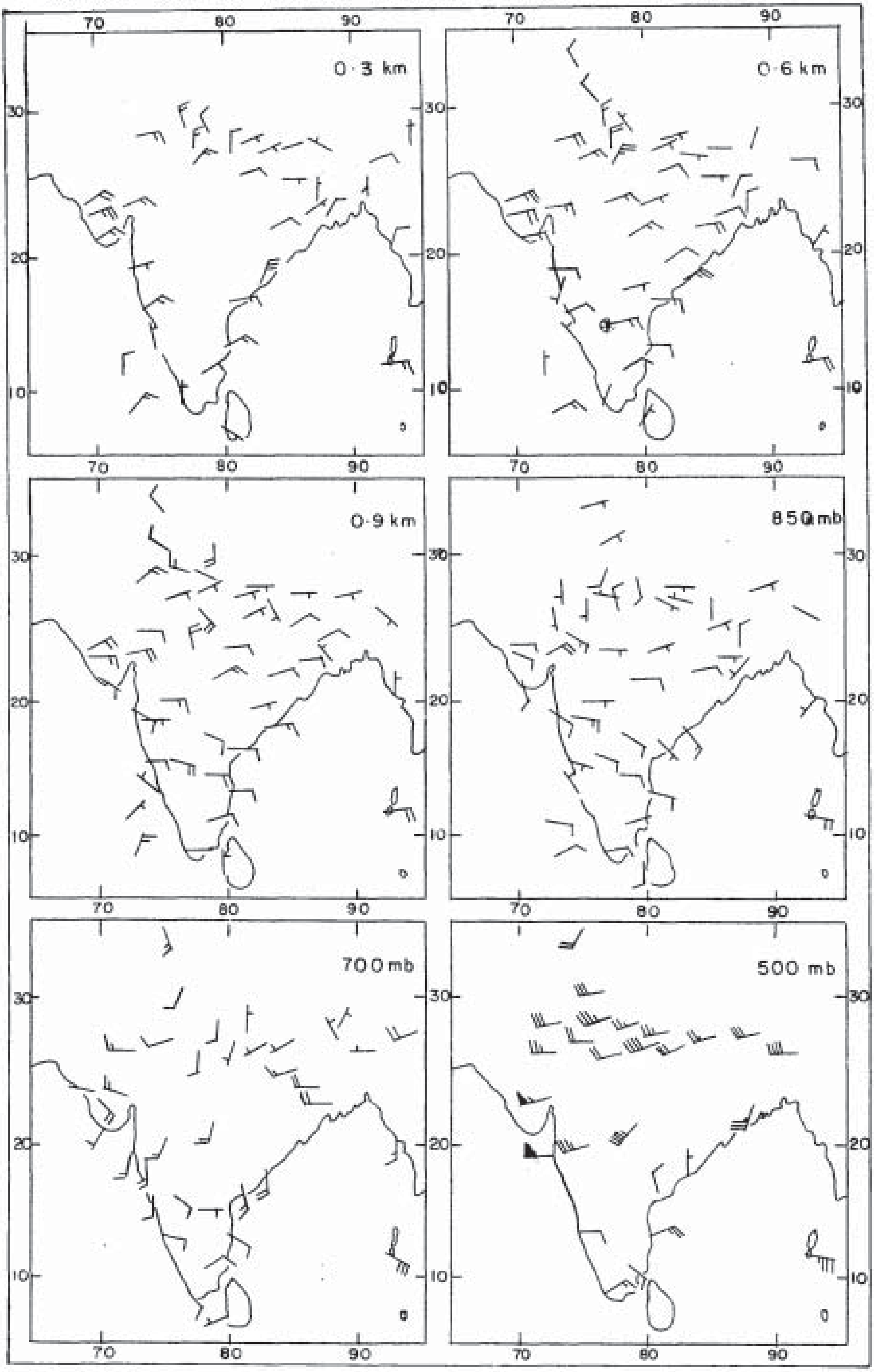


FIG. 12·3. UPPER WINDS DATE: 10 JAN. 67. TIME: 00 GMT

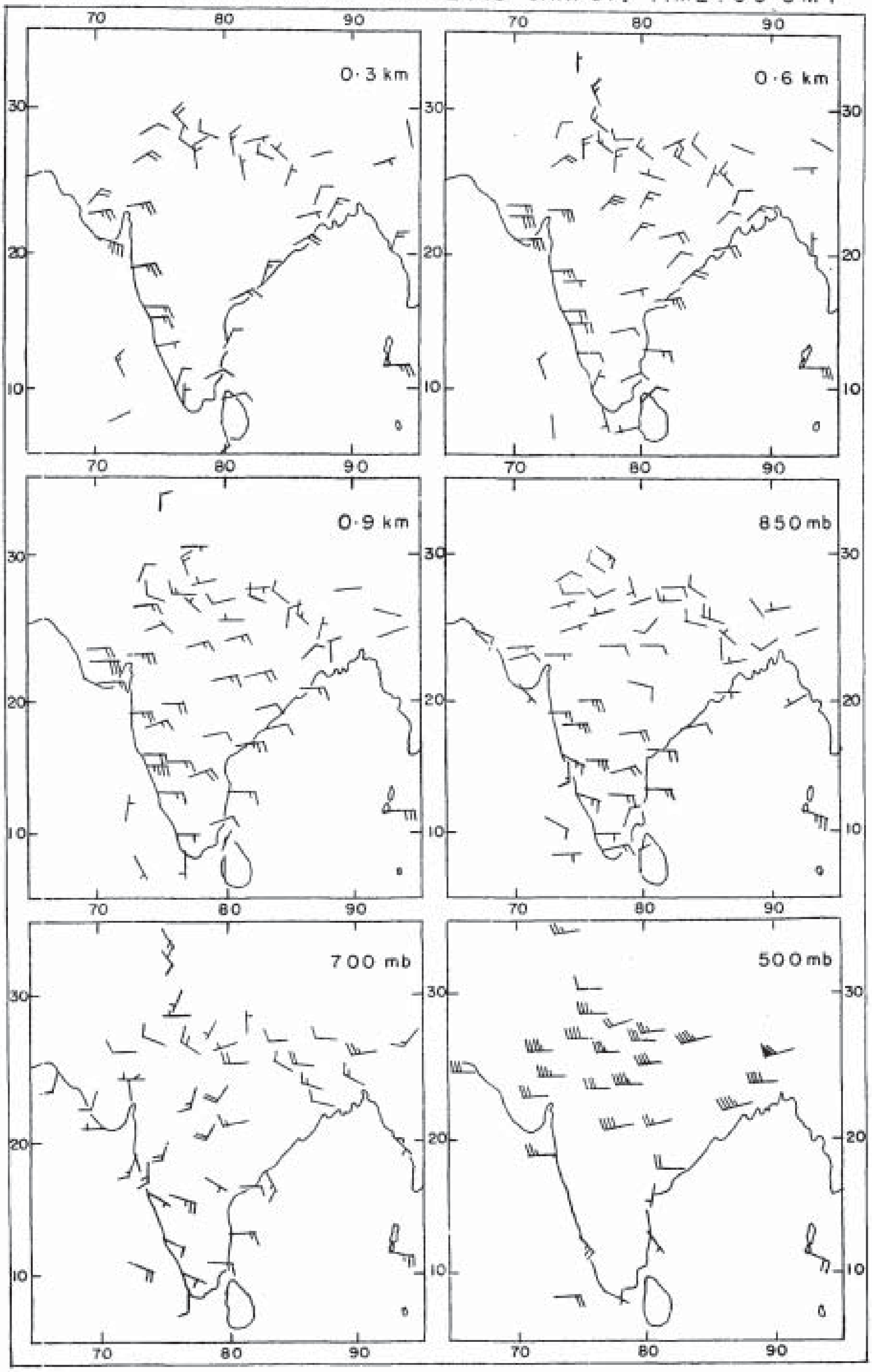


FIG. 12-4 DATE: 10 JAN. 67 TIME: 03 GMT

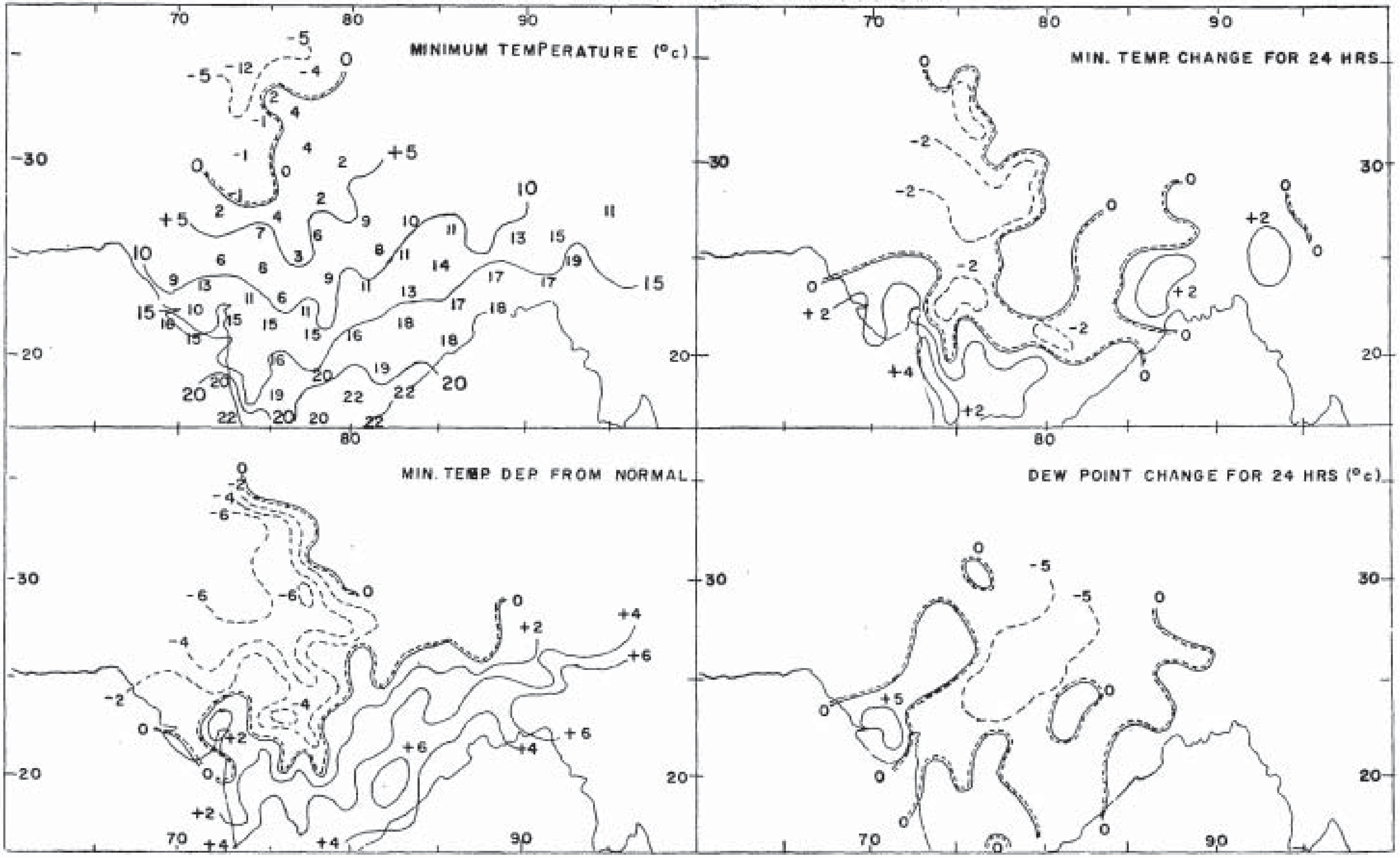


FIG. 12-5 DATE : 11 JAN. 67 TIME : 03 G M T

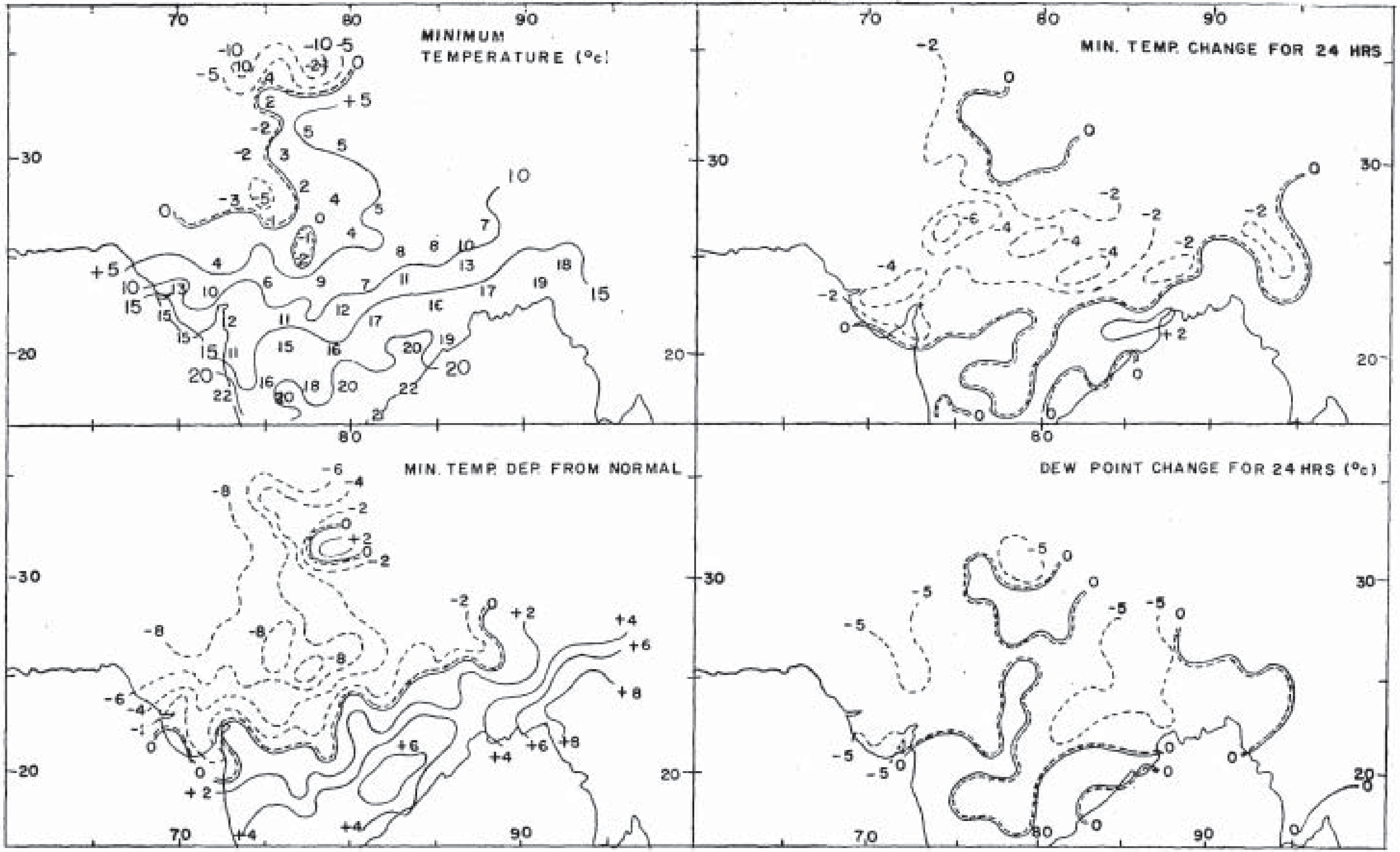


FIG. 12·6. UPPER WINDS. DATE: 13 JAN. 67. TIME 00 GMT

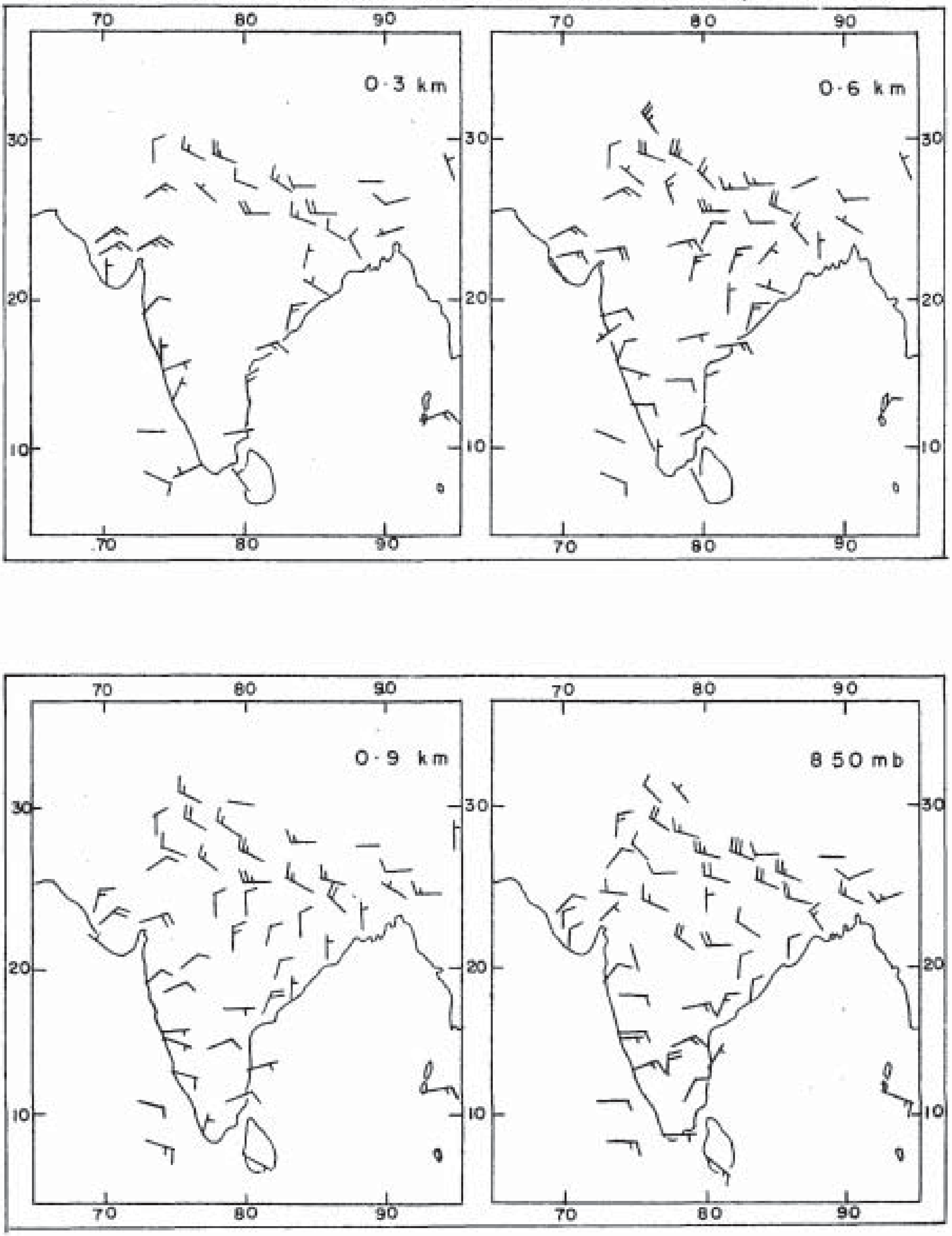
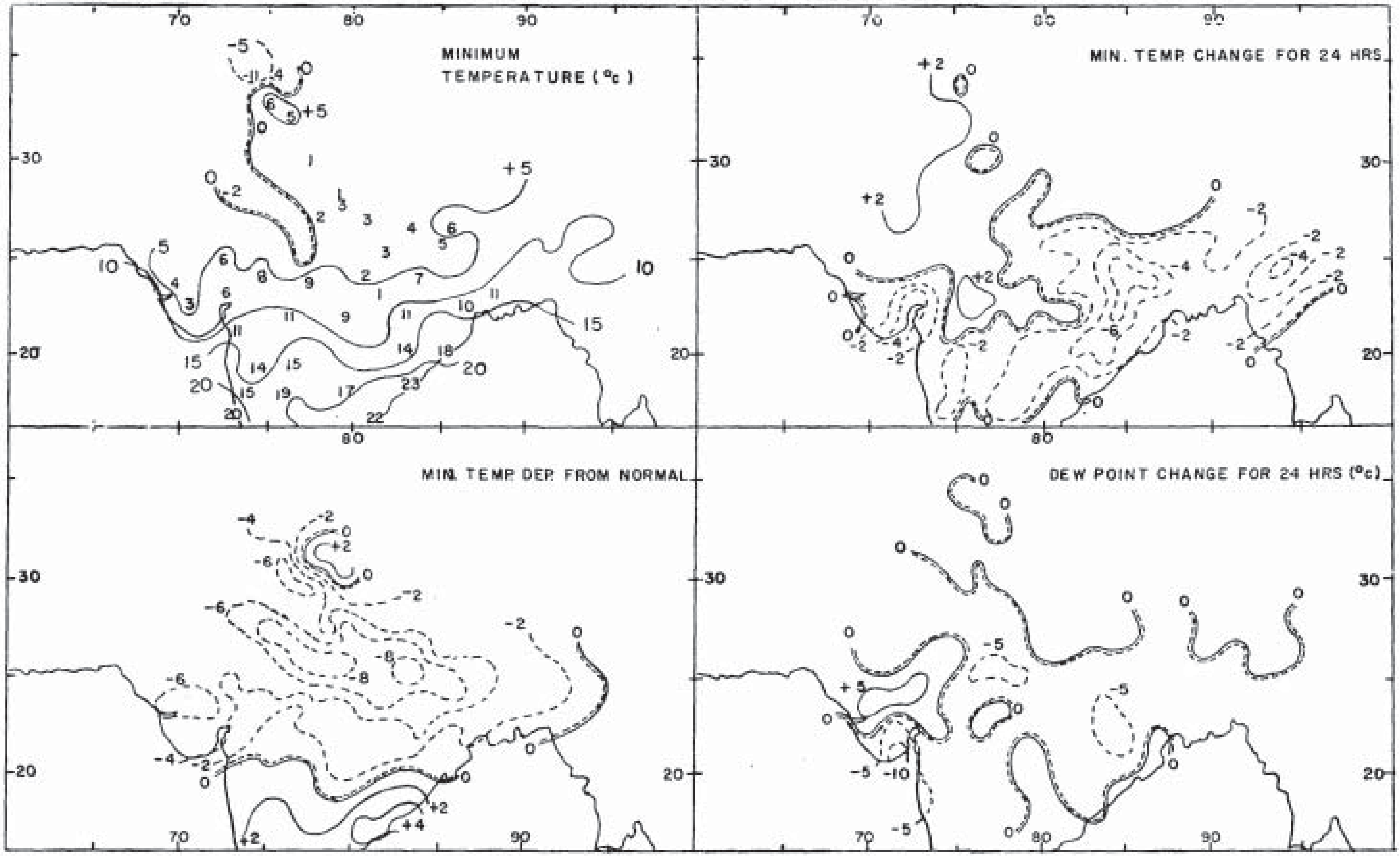
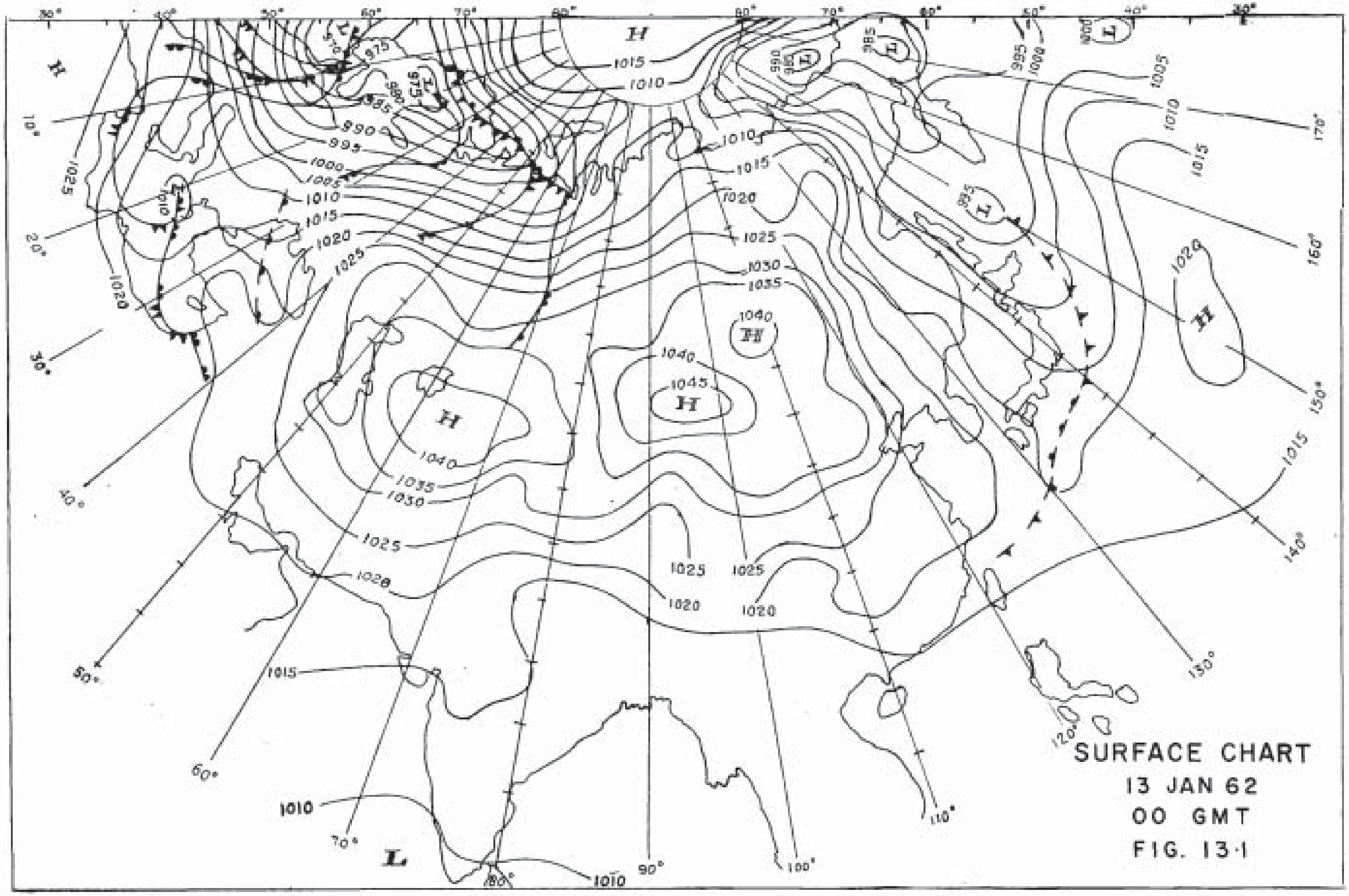


FIG. 12·7 DATE : 14 JAN 67 TIME : 03 GMT





SURFACE CHART
13 JAN 62
00 GMT
FIG. 13·1

FIG. 13·2 UPPER WINDS

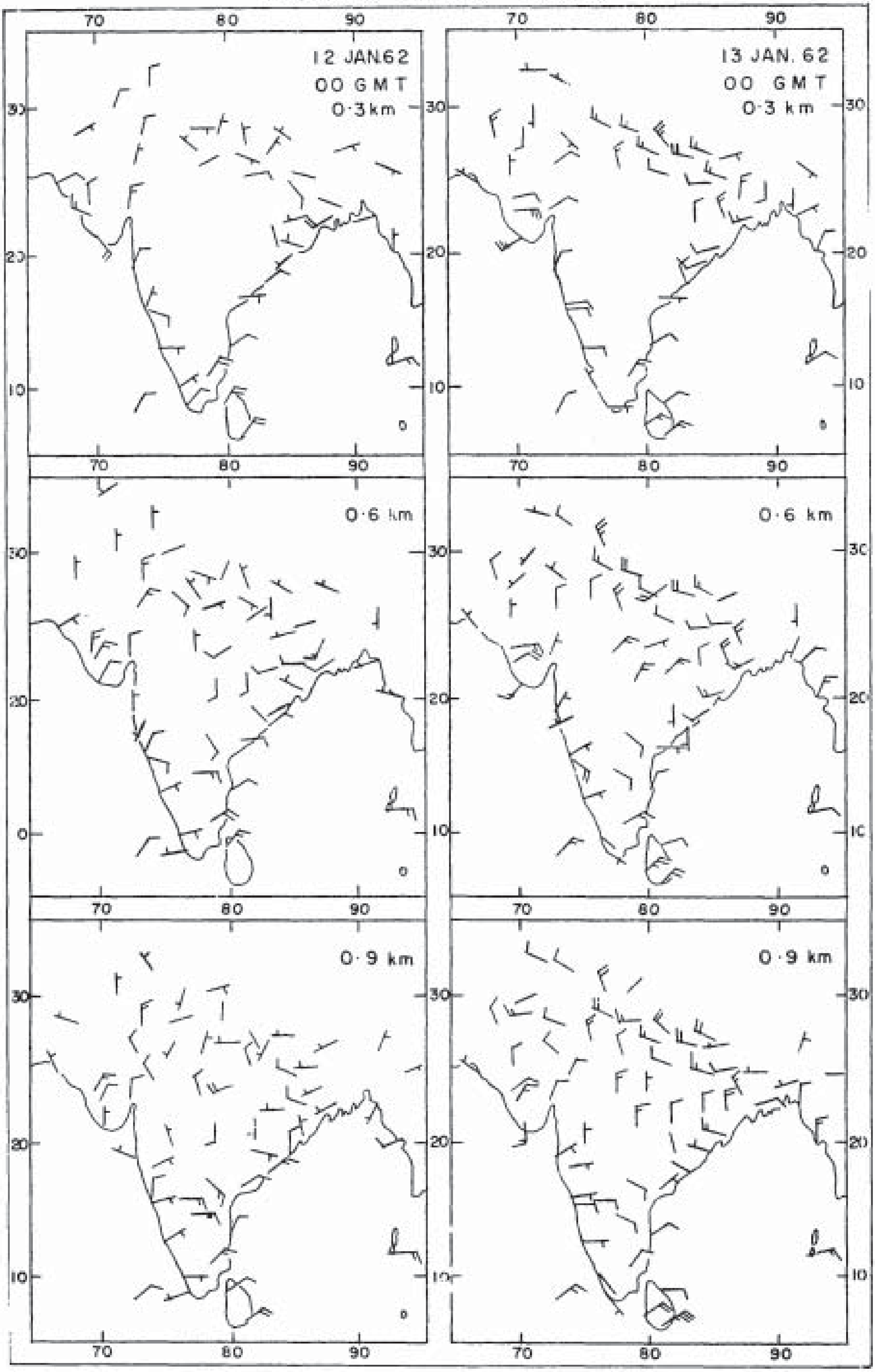


FIG. 13-3 DATE: 13 JAN 62 TIME: 03 GMT

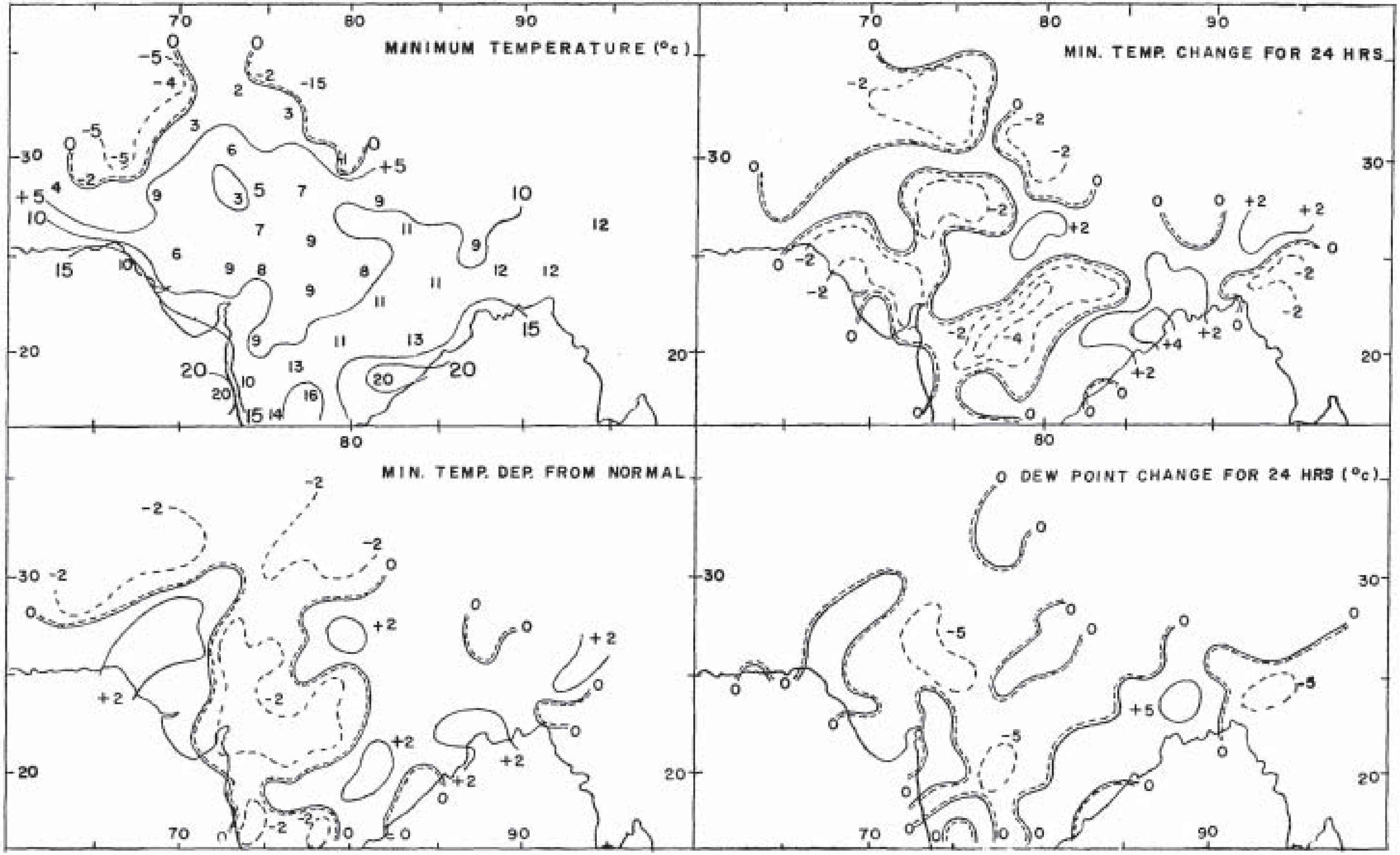


FIG. 13·4 DATE : 16 JAN 62 TIME : 03 GMT

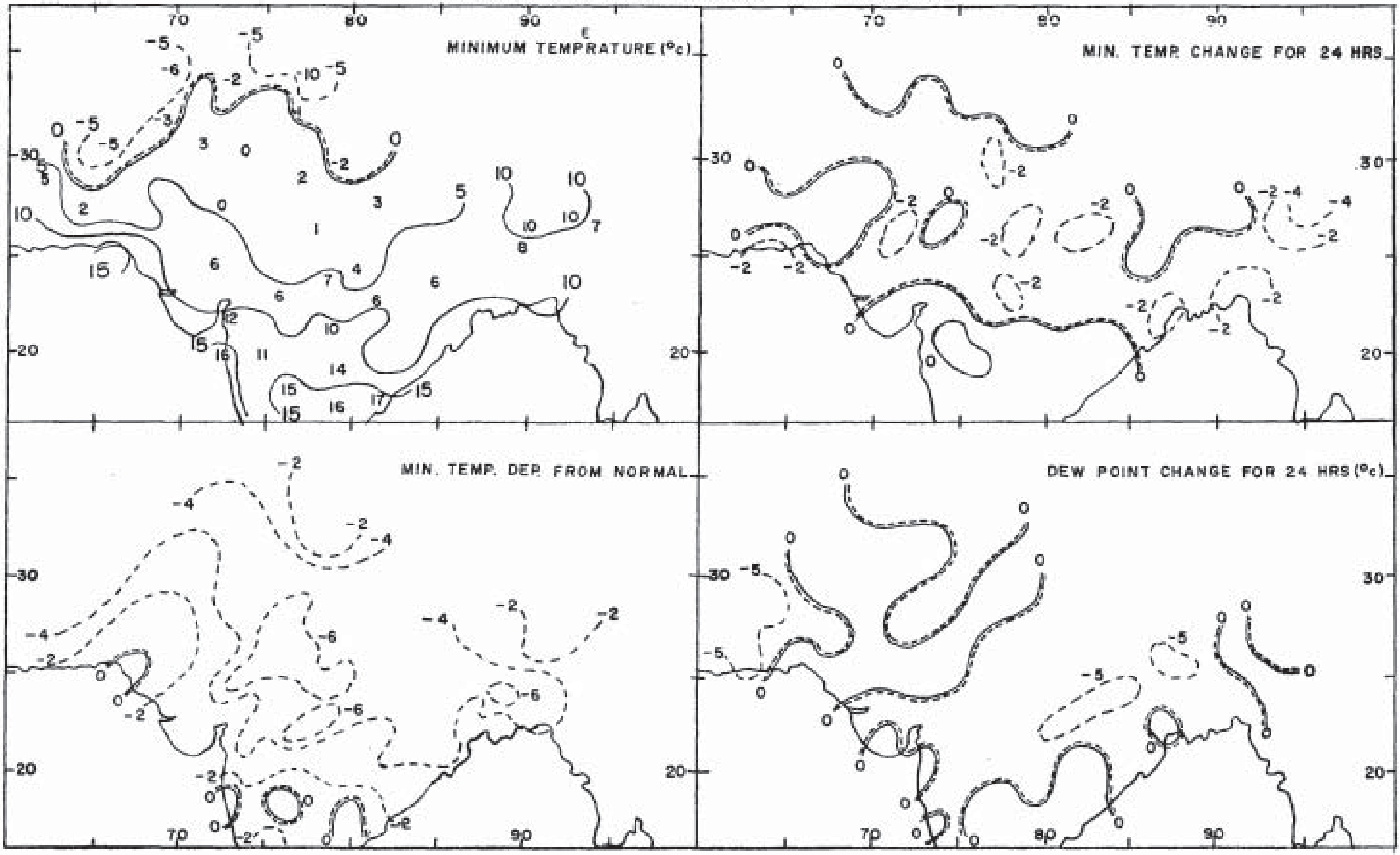


FIG. 13-5 DATE : 17 JAN 62 TIME : 03 GMT

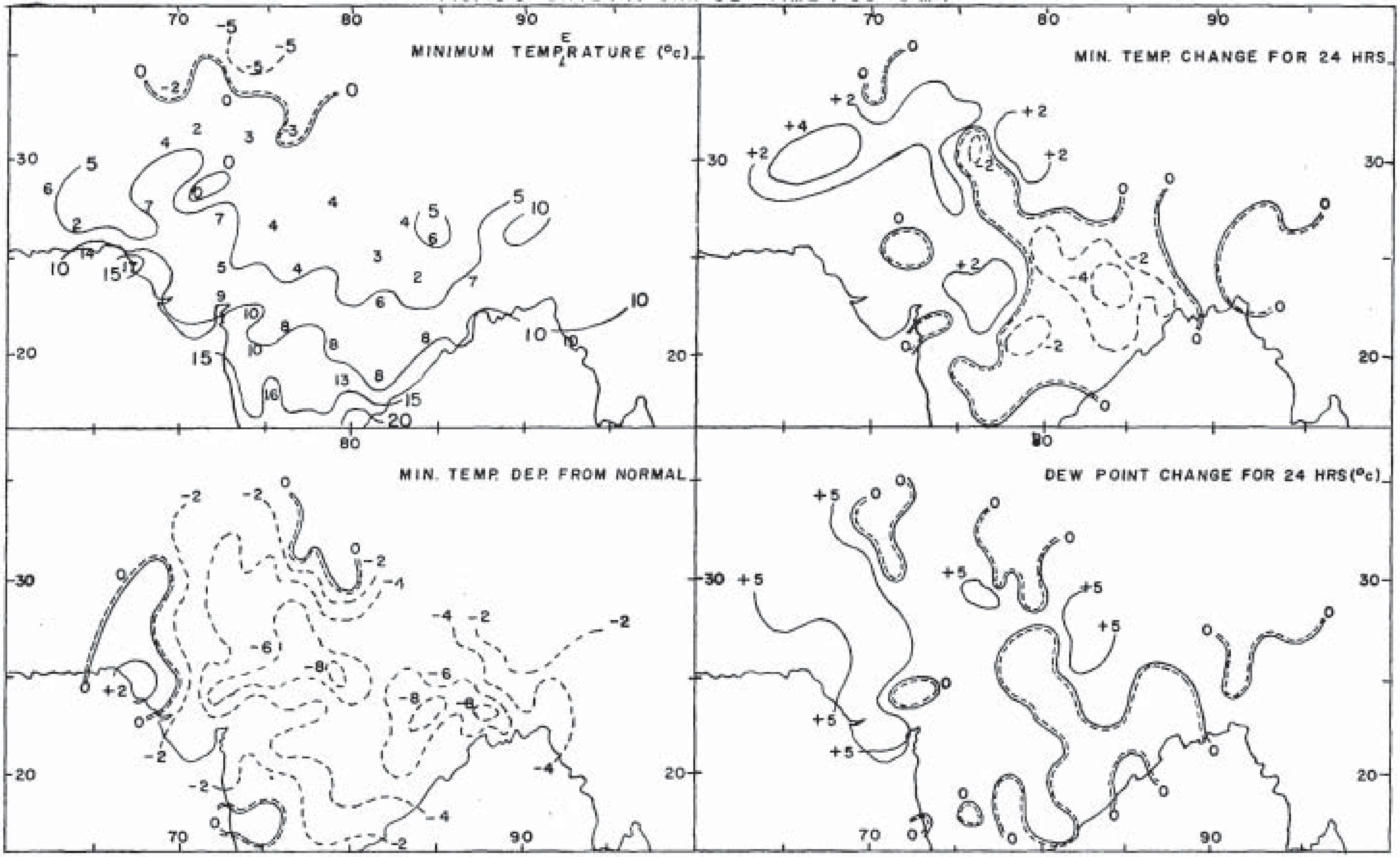
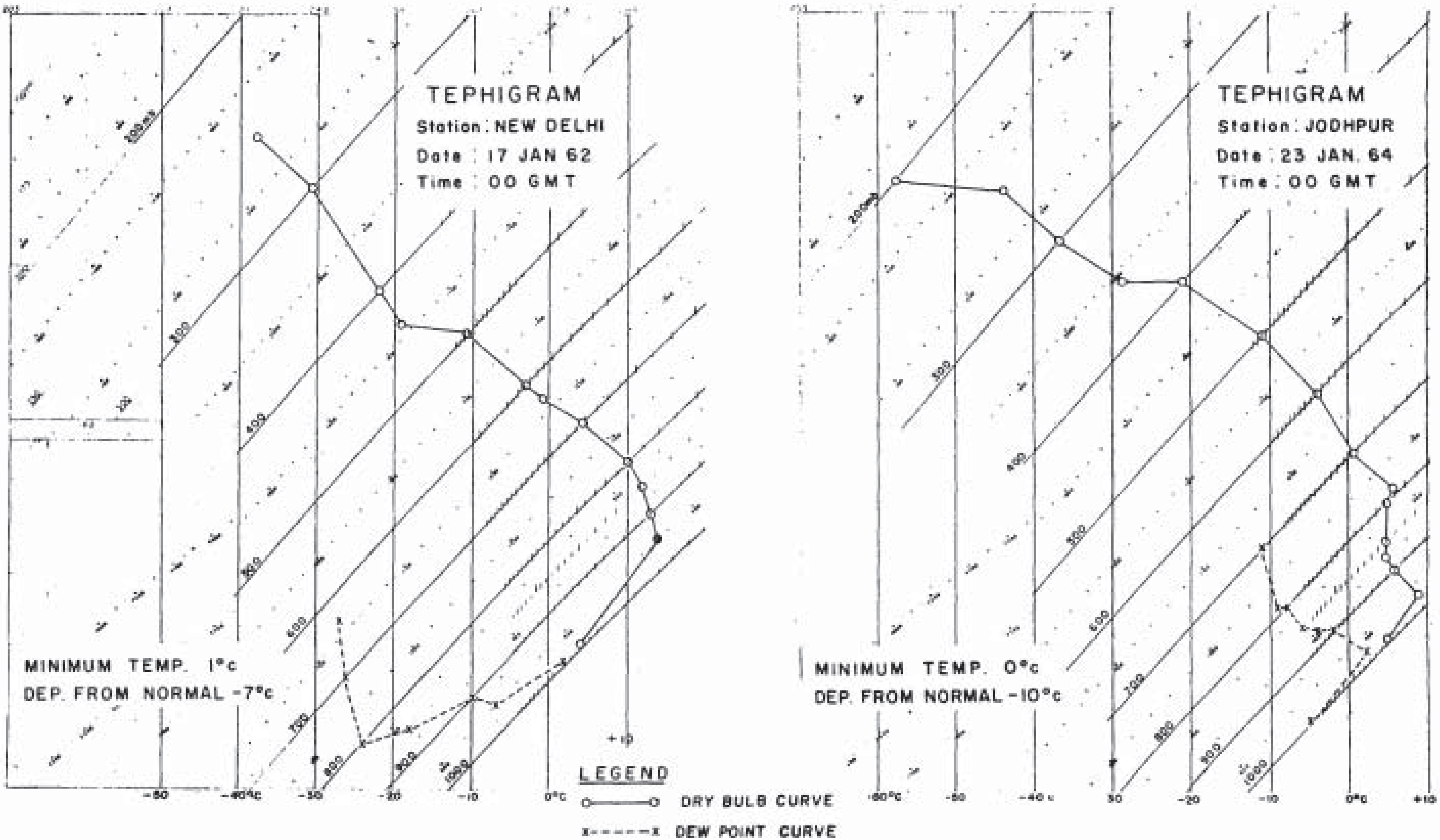


FIG. 14·1 RADIOSONDE ASCENTS AT NEW DELHI & JODHPUR



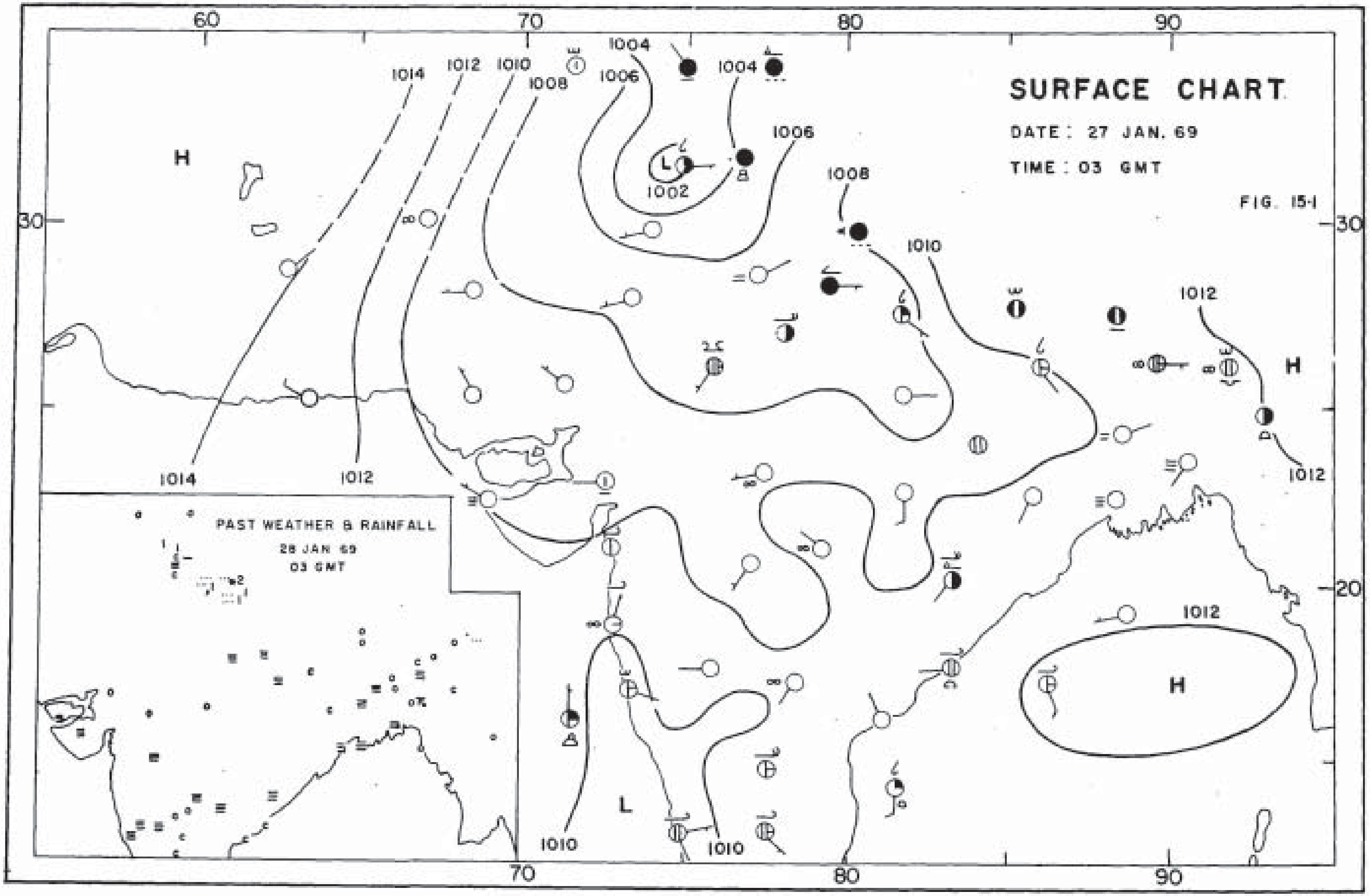

SURFACE CHART
DATE : 27 JAN. 69
TIME : 03 GMT
FIG. 15-1
60
70
80
90
30
20
H
L
1002
1004
1006
1008
1010
1012
1014
PAST WEATHER & RAINFALL
28 JAN 69
03 GMT

FIG. 15·2 UPPER WINDS

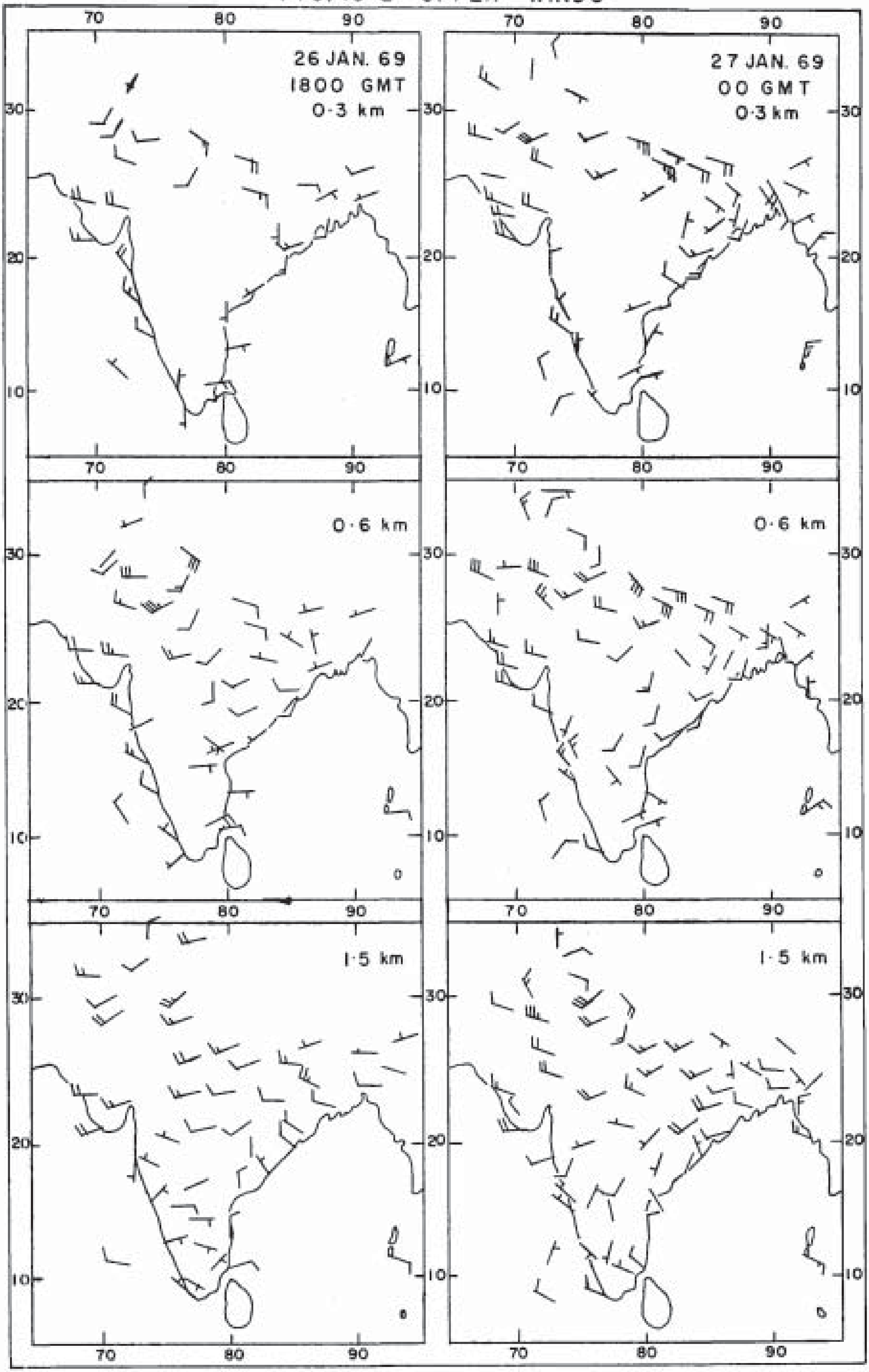


FIG. 15·3. DATE : 27 JAN. 69, TIME : 03 GMT

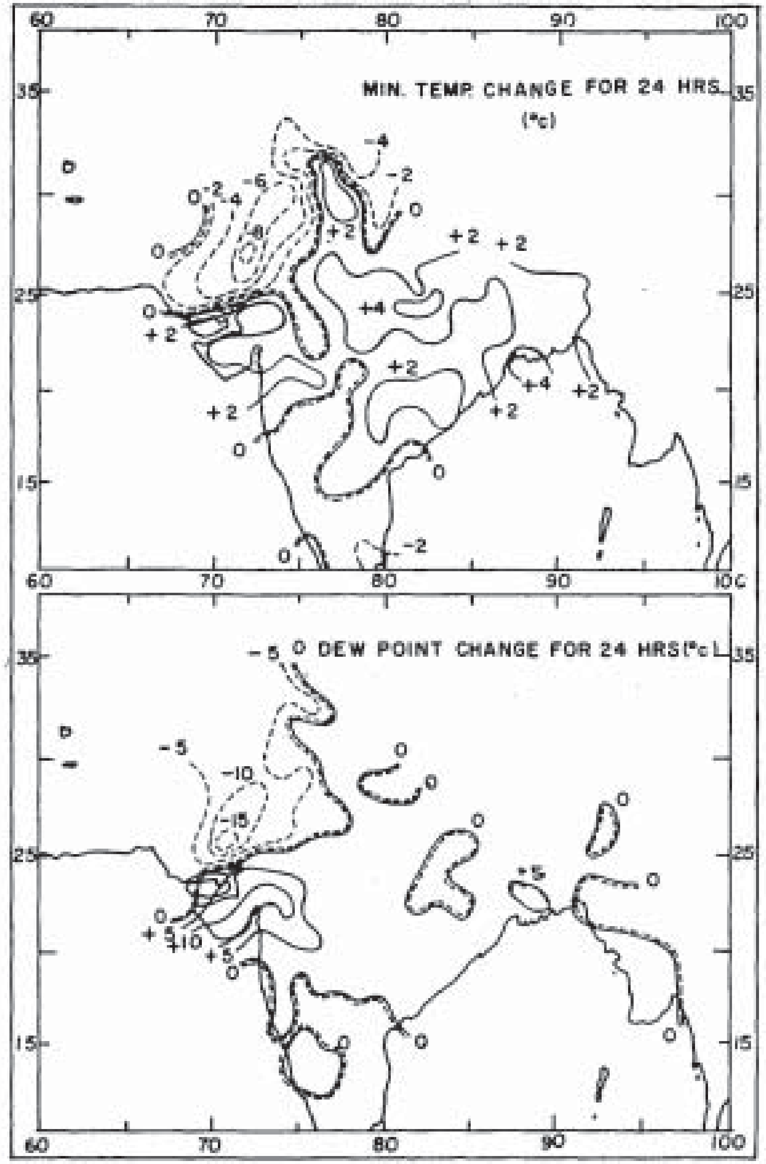


FIG. 15·4 RADIOSONDE ASCENT AT CALCUTTA

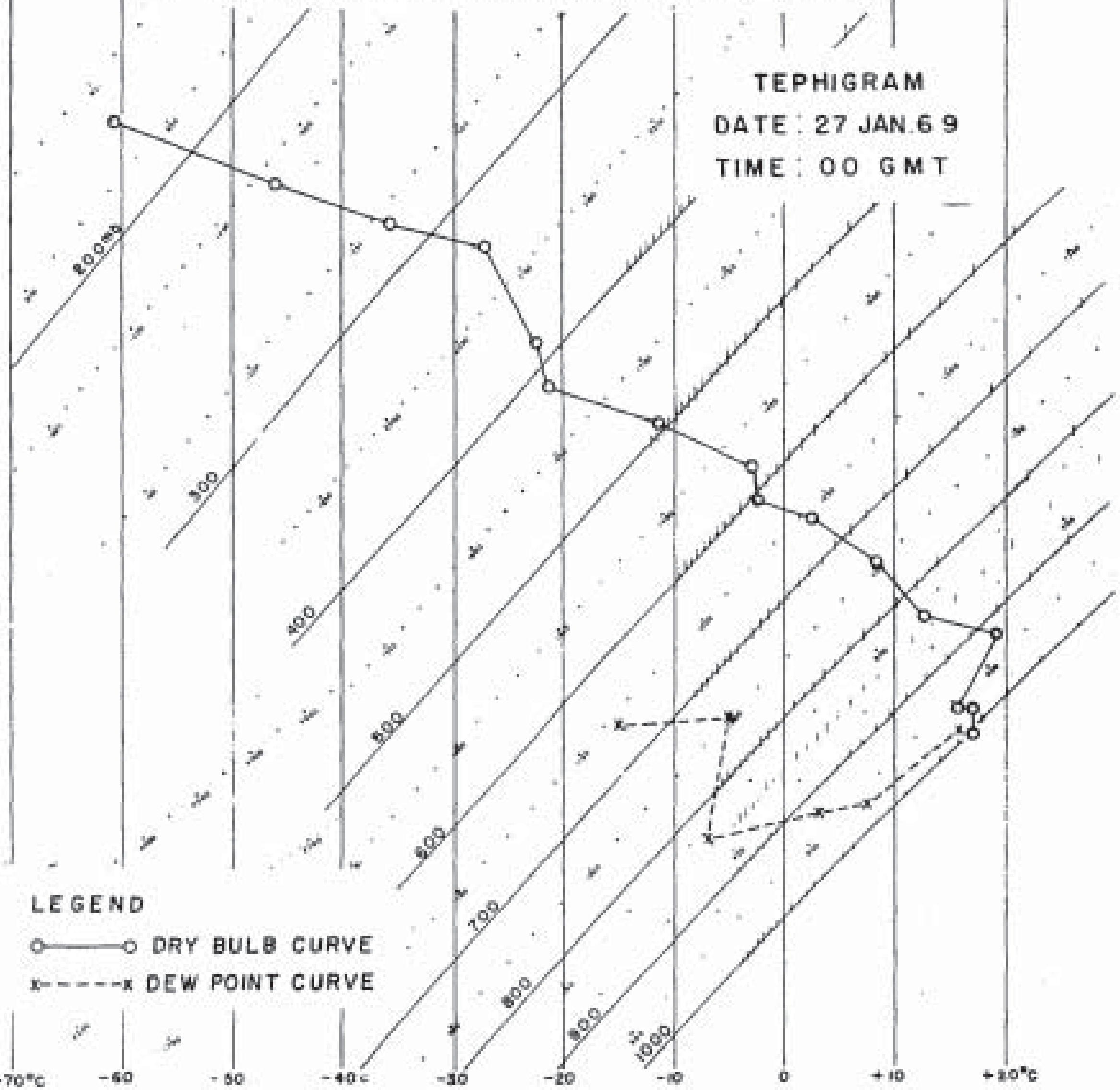
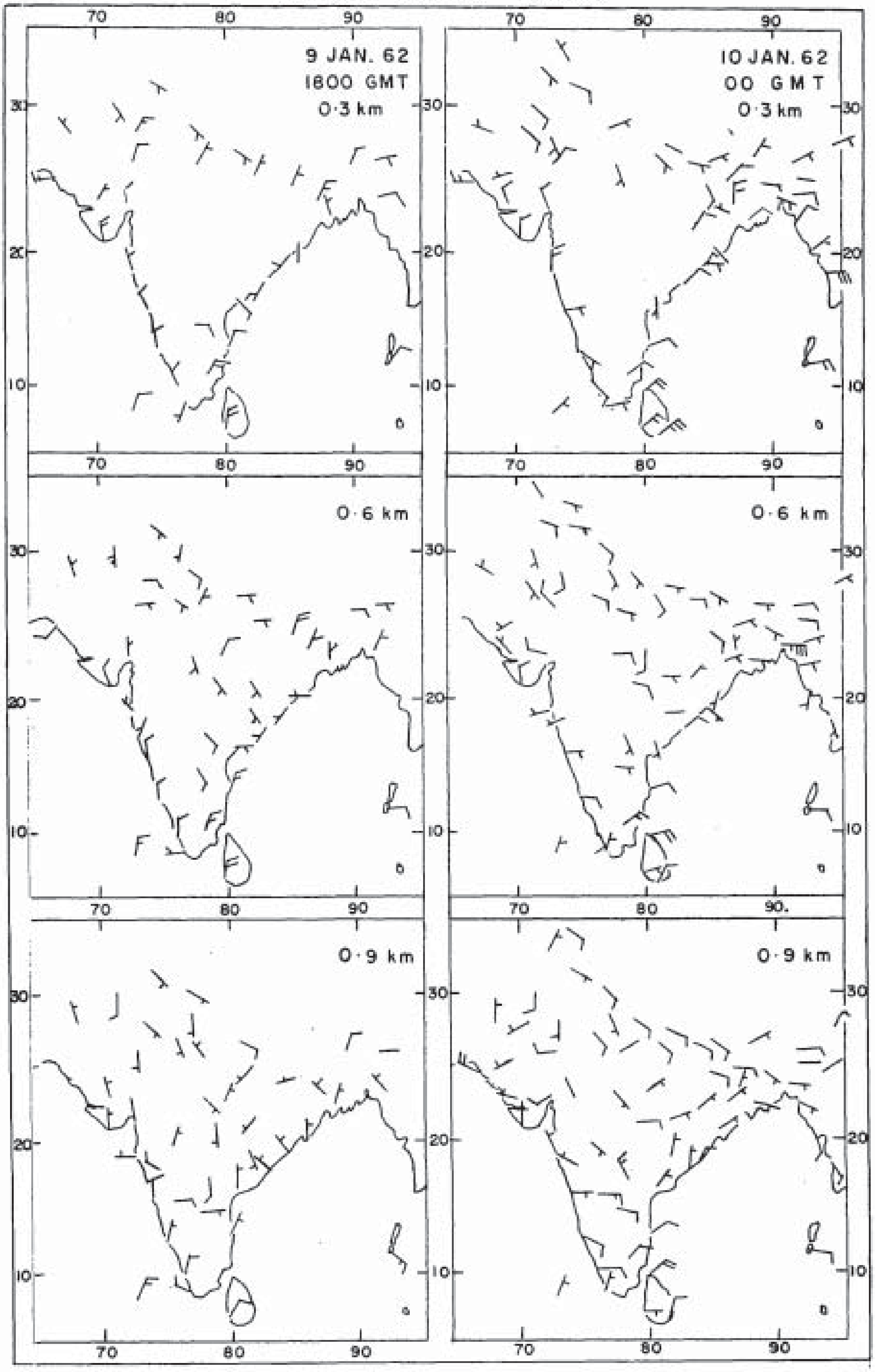


FIG. 15·5 UPPER WINDS



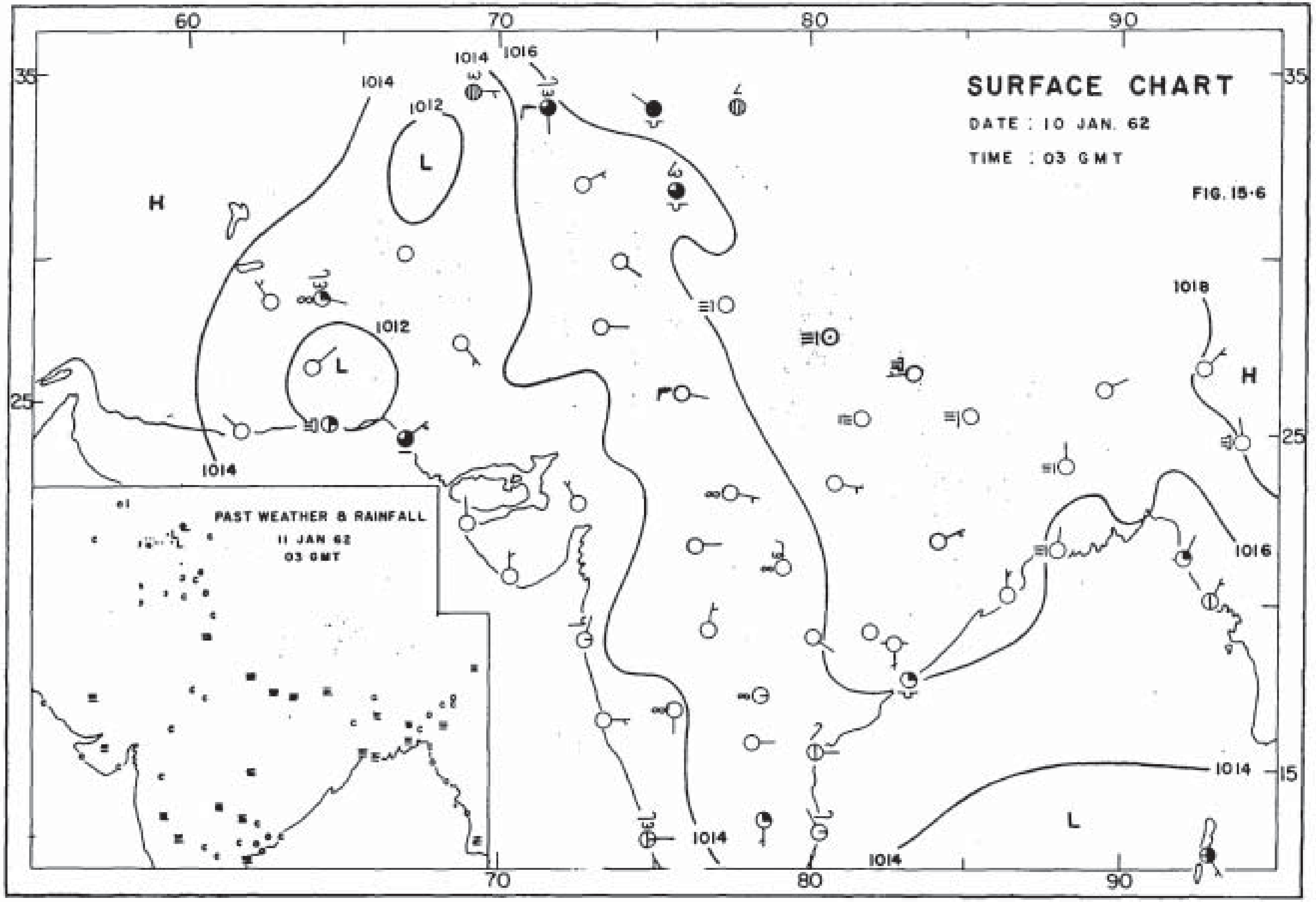
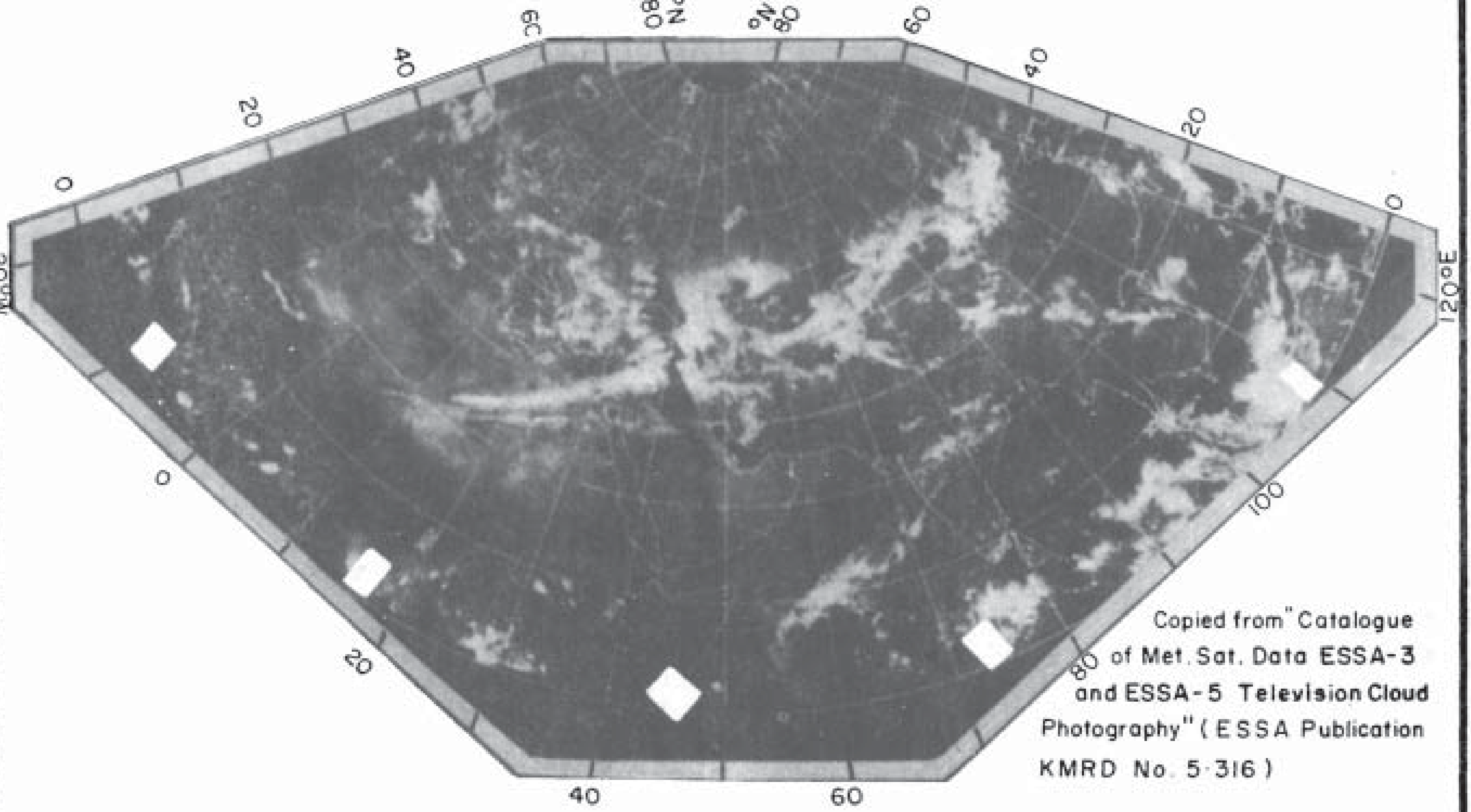
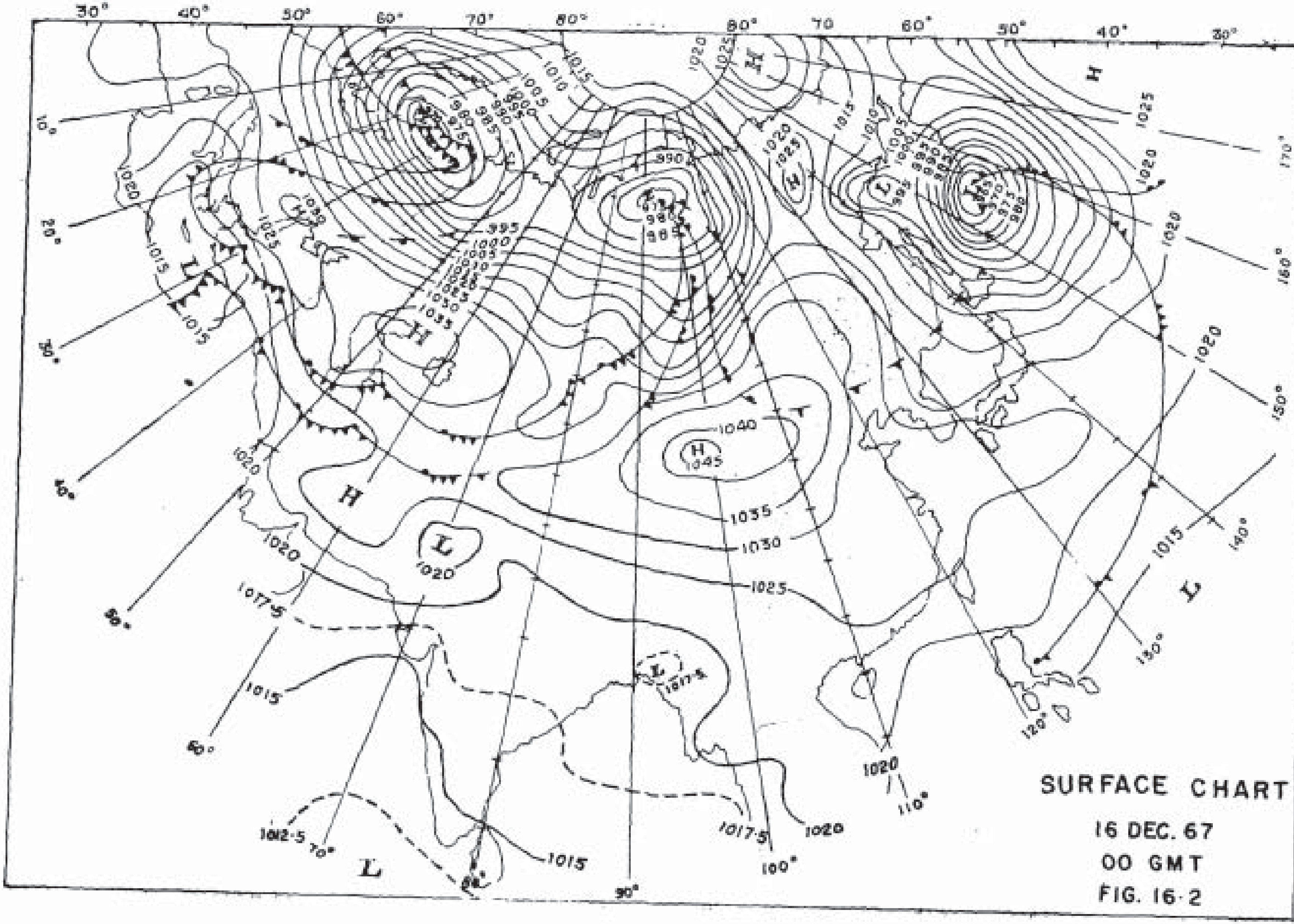

SURFACE CHART
DATE : 10 JAN. 62
TIME : 03 GMT
FIG. 15·6
PAST WEATHER & RAINFALL
11 JAN 62
03 GMT
60
70
80
90
35
25
15
1012
1014
1016
1018
H
L

FIG. 16·1 ESSA - 3 16 DEC 1967



Copied from "Catalogue of Met. Sat. Data ESSA-3 and ESSA-5 Television Cloud Photography" (ESSA Publication KMRD No. 5·316)



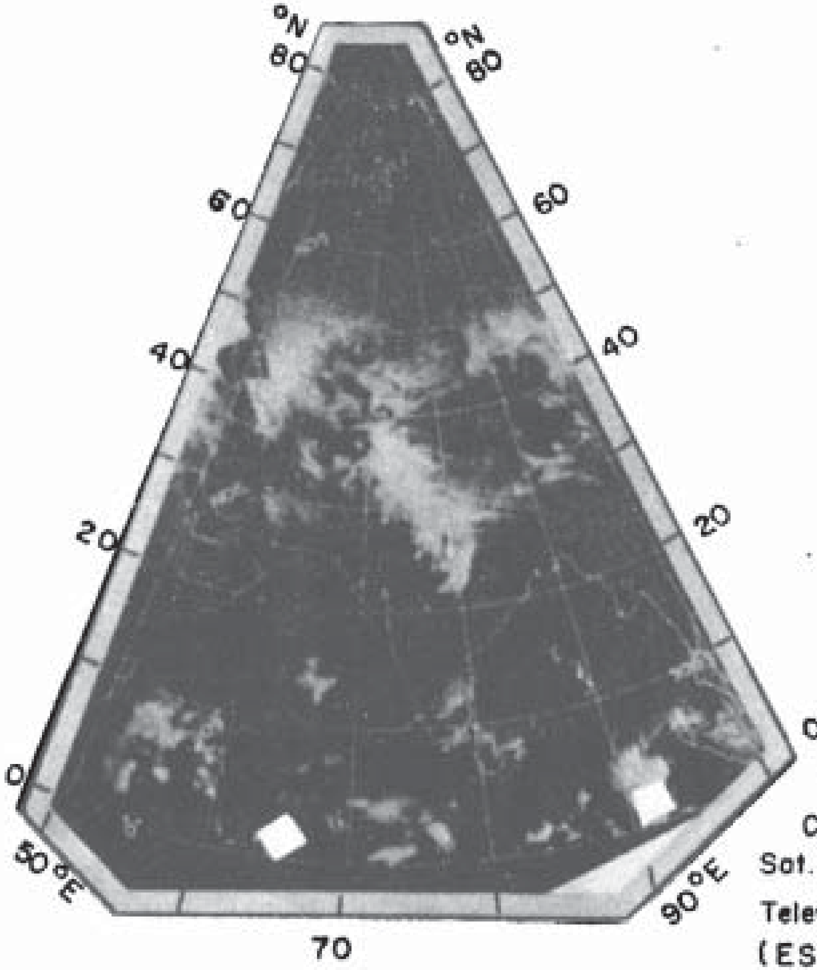
SURFACE CHART

16 DEC. 67

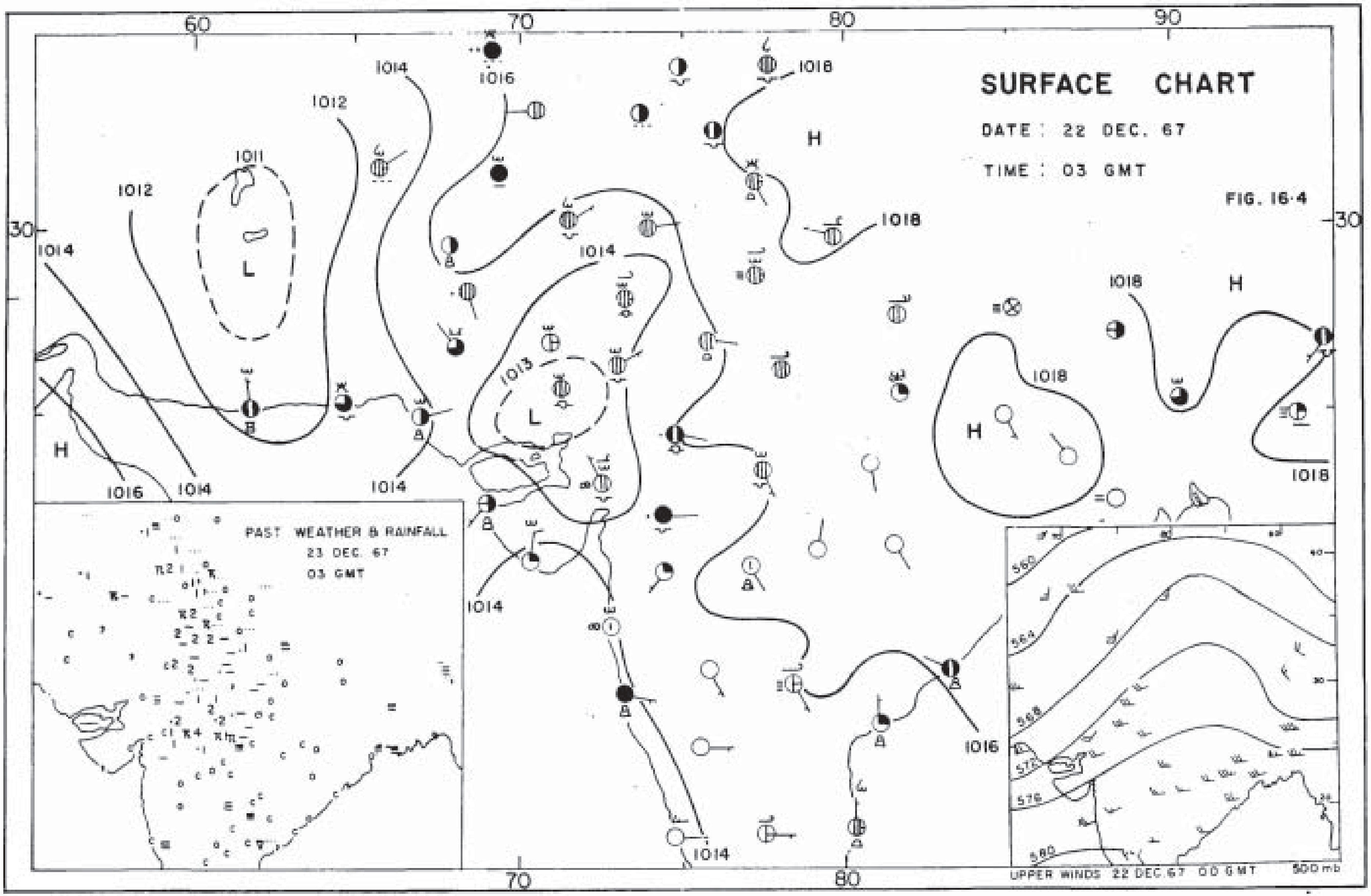
00 GMT

FIG. 16·2

FIG. 16·3 ESSA-3 22 DEC 1967



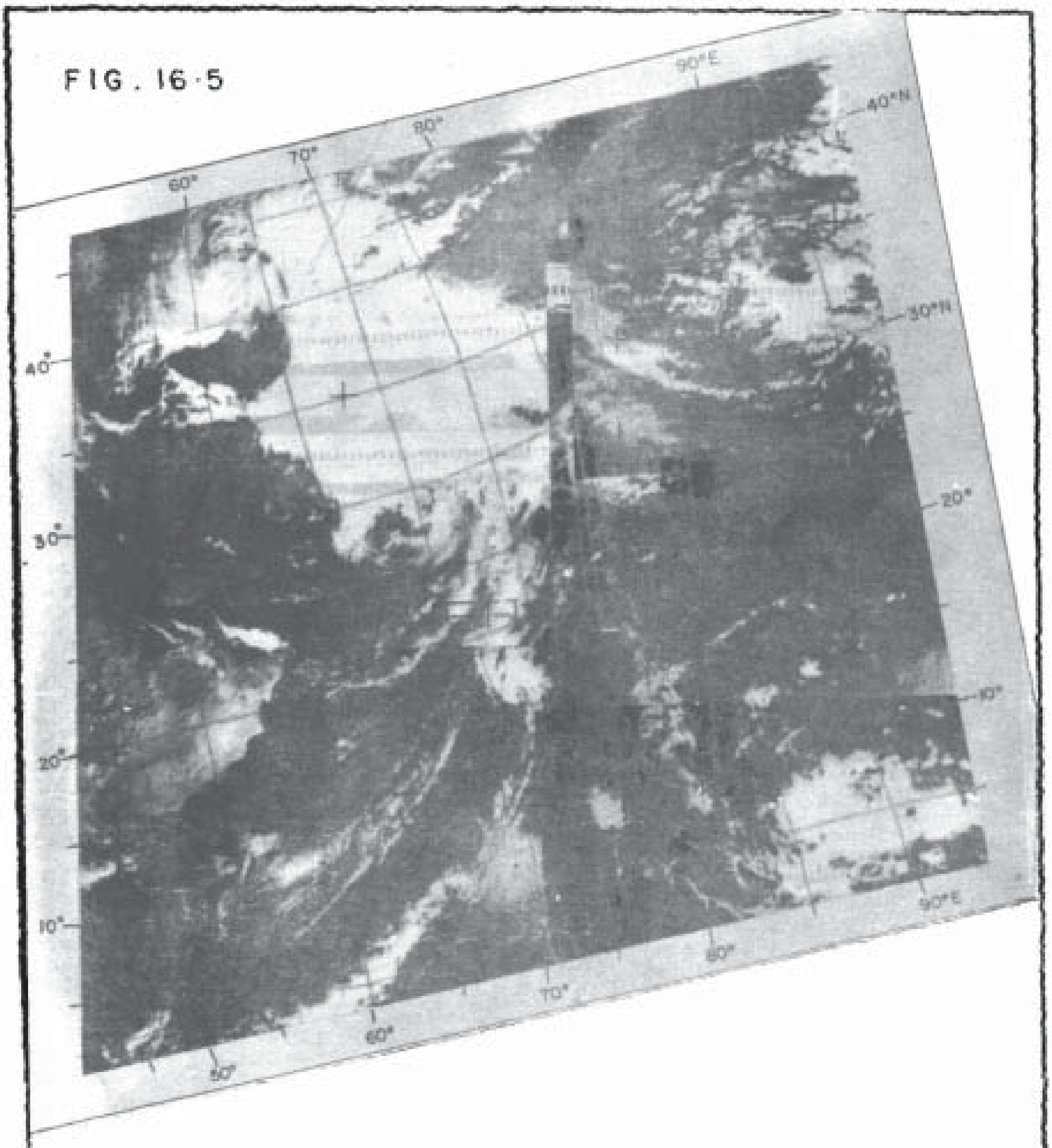
Copied from "Catalogue of Met. Sat. Data ESSA-3 and ESSA-5 Television Cloud Photography."
(ESSA Publication KMRD No. 5·316)



SURFACE CHART
DATE : 22 DEC. 67
TIME : 03 GMT
60
70
80
90
30
1011
1012
1013
1014
1016
1018
H
L
PAST WEATHER & RAINFALL
23 DEC. 67
03 GMT
UPPER WINDS 22 DEC. 67 00 GMT
500 mb
560
564
568
572
576
580

FIG. 16·4

FIG. 16·5



ESSA - 6

ORBIT : 569 ; 570

DATE : 26 DEC 67