FMU Rep. No. I-2
(JULY 1968)
(Reprinted JANUARY 1972)

INDIA METEOROLOGICAL DEPARTMENT

FORECASTING MANUAL

PART I

CLIMATOLOGY OF INDIA AND NEIGHBOURHOOD

2: CLIMATE OF INDIA

BY

Y.P. RAO AND K.S. RAMAMURTI

ISSUED BY

THE DEPUTY DIRECTOR GENERAL OF OBSERVATORIES
(FORECASTING)
POONA-5

FMU. Rep. No. I - 2
(July 1968)

(Reprinted August 1971)

FORECASTING MANUAL

Part I. Climatology of India and Neighbourhood

2. Climate of India*

by

Y.P. Rao and K.S. Ramamurti

* Apart from the broad climatic features covering the wide area mentioned in FMU Report No. I-1, the forecaster in India needs a detailed knowledge of the Climate of India. The present report aims to meet this requirement.

Contents

1. Introduction

1.1 There is need for a brief description of the climate of India. While there have been many important papers discussing at great length some particular climatic feature or other and tables giving mean values of many elements, a broad description of the mean distribution of various elements has been lacking. This report describes the mean distribution of some elements at the surface level and in the upper air.

1.2 Pressure systems over and around India have been described with special reference to the reversal of circulation with the monsoons. Distribution of mean, maximum and minimum temperatures and their range has been discussed in relation to some of the salient factors influencing them. Differences of the temperature variations over India from the usual seasonal variations elsewhere have been stressed. Annual and seasonal variation of rainfall, as well as the influence of orography on it, is presented without much reference to synoptic causes. From recent data, upper air temperatures, their variability, lapse rates, upper winds and jet streams have been described.

2. Sea-level Pressure

2.1 The distribution of sea-level pressure over the Indian sub-continent undergoes a complete reversal from January to July, so that a description of mean annual pressure pattern has no significance. January, the month of north-east trades (monsoon), has a pressure gradient towards south. The pressure gradient is strong and directed to north in July, the southwest monsoon month. In the transition months of April and October pressure distribution over India is practically even. Figs. 2.1 to 2.4 show the isobars and winds in January, April, July and October over India and neighbourhood. The features over Asia, Africa and Australia are shown in the Monthly Mean Sea Level Isobaric charts of FMU Report No. I - 1.

2.2.1 <u>January</u>: In this month, India is at the periphery of the Siberian High Centred at 45°N and 105°E. The Siberian High is the result of accumulation of cold continental air over the east central parts of Asia and the effect of sub-tropical high pressure belt which becomes prominent over land. The Himalayas obstruct the spreading of cold air from central Asia into northern India. A ridge runs from the Siberian High along the seaboard off China. The Siberian High persists at its maximum intensity through December, January and February. Pressure gradient round the Siberian High is strong to the north of the Himalayas and weak over India. The sub-tropical high pressure belt in the Southern Hemisphere has a cell at 35°S covering the Indian longitudes. The position of the equatorial low pressure area in the Indian Ocean in this month is between the Equator and 10°S extending to northern Australia. In the eastern part of Africa also, a summer continental low is seen south of the Equator.

2.2.2 In the Indian area (Fig. 2.1) a weak ridge runs from west Rajasthan to the central parts of Bihar with a weak trough to its north in Uttar Pradesh and Bihar, along the foot of the Himalayas. A marked trough extends from Kerala to Gujarat and a similar one from off Tenasserim Coast to upper Burma and Assam. The ridge between these is prominent along the east coast of the Peninsula. The pressure pattern in December and February is generally similar to that in January.

2.3.1 <u>April</u>: Development of low due to increased heating over land starts over India in March itself, when the whole country has a flat pressure distribution with slightly higher pressures over the Arabian Sea and the Bay of Bengal. By April the global land lows have begun establishing themselves along about 10°N in North Africa and about the Tropic of Cancer in the Indian region and Burma. The peninsular India south of 20°N has a tapering shape and is narrow south of 15°N. The latter comes under considerable maritime influence. This makes the heating over land more prominent to the north of 20°N and the axis of the low is at a more northerly latitude over India (Fig. 2.2). There is a weak cell over upper Sind and another in Bihar and

East Uttar Pradesh. Over the Peninsula a trough forms with axis along longitude 78°E.

2.3.2 A ridge runs from Arabia into the west Arabian Sea where a clockwise wind circulation is found around 14°N and 60°E. A similar circulation is also present over the Bay of Bengal around 14°N and 90°E.

2.3.3 The Siberian High has weakened considerably and shifted to west. The ridge along the eastern sea board of tropical Asia has weakened. The heat low over the North American continent is over the south-west United States centred near 30°N, farther to the north than over India. The central American area is too narrow to show any continental effect. The sub-tropical high in the south Indian Ocean is along 30°S. The cell over the Indian longitudes tends to shift westwards and another cell forms over southeast Australia.

2.3.4 By May, the summer continental low pressure area completely dominates North Africa and Asia. Its main centre is near 30°N and 75°E. There is an extension of it as a trough upto Orissa. It is still more marked in June with the main centre over ~~West~~ Pakistan. In these months, there are subsidiary centres of low in Africa and other parts of Asia. By May the trough over the Deccan has shifted to 79°E, along the Madras Coast.

2.4.1 <u>July</u>: The low pressure area extending from North Africa to Northeast Siberia is most intense. Its main centre is over north Baluchistan and neighbourhood (Fig. 2.3). The axis of this low pressure belt runs from SW to NE. A trough lies over north India with axis from Sriganganagar to the Head Bay, which is referred to as the monsoon trough. The Indian Ocean High has strengthened and is centred at 30°S and about 60°E. The high over Australia covers more than half of the continent. Pressure continuously decreases over the Indian Ocean northwards of this high pressure belt. Weak ridges are present in the Arabian Sea off the west coast of India and in the Bay off Tenasserim coast and over Burma. The weak trough off the east coast of the south Peninsula persists through the monsoon months and is more pronounced in September.

2.4.2 In August, intensity of the Afro-Asian low is decreasing. By September, pressure is rising north of 40°N over Asia and the Afro-Asian low is oriented east-west.

2.5 October: The trough over northern India shifts to the Bay of Bengal with the trough line along 13°N and the pressure field is flat over the country (Fig. 2.4). The low pressure belt runs from Africa to the West Pacific between the equator and 20°N with centres over Africa, the Bay of Bengal and the West Pacific. The Asian High is establishing along 50°N and is centred at about 90°E. The centre of the Indian Ocean High at 30°S is shifting to east and by November is at 80°E. In October, the ridge along the sea board off China is also established. The trough in the South Bay persists in November but disappears in December with the development of a trough to the south of the equator.

3. Surface Winds.

3.1.1 January: Surface winds (Fig. 2.1) are mainly from NE to the south of about 25°N both over land and over sea. At some places in this area wind may be from some other direction between north and east. North of 25°N and west of 88°E(except Rajasthan where it is NE), the wind direction is mainly NW. Easterlies prevail over Assam. Mean speed is generally light over the land and about 10 kt over the sea, strengthening a little over Southwest Arabian Sea off the African coast. Light Westerlies prevail very near the equator to the east of 90°E. December and February have similar winter-type wind distribution.

3.1.2 In March over land, north of 17°N winds are from west and south of it from east. Anti-cyclonic wind circulations have developed with centres at 18°N and 60°E in the Arabian Sea and 16°N and 90°E in the Bay of Bengal.

Westerlies occur close to the Equator to the east of 80°E.

3.2.1 April: With the development of a low over Uttar Pradesh, east Madhya Pradesh and Bihar and a trough running from it southwards, winds are W to NW to the west of the trough line and S to SW to the east (Fig. 2.2). Over West Rajasthan winds are W to SW, on account of a trough extending into the region. Easterlies continue over Assam and extend into East Uttar Pradesh in the morning hours. Winds blow anticyclonically in the area between latitudes 10°N and 20°N and longitudes 55°E and 65°E in the Arabian Sea around a centre at 14°N and 60°E. In the Bay there is a similar circulation around centre at 14°N and 90°E. Between the equator and 5°N to the east of 55°E, westerly winds prevail. Mean speeds are nowhere greater than 10 kt.

3.2.2 In May winds are southwesterly over West Rajasthan and the adjoining parts with the main low pressure area extending from Upper Sind to the Punjab (P). In association with a trough extending from this main low upto Orissa, Assam easterlies extend upto north Uttar Pradesh. Over Oriasa, Gangetic West Bengal and Bihar Plateau, winds are mainly southerly. Over the rest of the country, winds are mainly west to northwesterly to the west and southwesterly to the east of 79°E.along which the seasonal trough lies. In the Bay to the north of 10°N winds are from SW while over the rest of the Bay and the Arabian Sea they are from W to WSW.

3.2.3 In June winds are from east to the north of the line running through Lahore, Allahabad and Silchar. Over Gangetic West Bengal winds are mainly from south. Over the rest of India, winds blow from W to SW, more westerly off the west coast of the Peninsula and practically southwesterly in the Bay. Between 5°N and 15°N and west of 65°E the speed is 20 kt in the Arabian Sea. Elsewhere the range is 10 to 15 kt.

3.3 July: Easterlies of Assam extend to north of the line through Hissar, Gaya and Silchar (Fig. 2.3). To the south of this line, southerlies occur over

West Bengal and Southwest to westerlies elsewhere. Strongest winds are in the Southwest Arabian Sea. Nearer the west coast of the Peninsula the direction is westsouthwest to west except over the Malabar coast where northwesterlies are observed. Mean speeds over land are not more than 10 kt. They are between 10 kt and 20 kt along the west coast. In the Arabian Sea west of 68°E and between 10°N and 20°N, it is over 25 kt. Over most of the Bay and the rest of the Arabian Sea the speed is about 15 kt. Winds are somewhat weaker between the equator and 5°N. August is like July. By September there is weakening of pressure gradient and winds weaken particularly over the sea areas.

3.4.1 October: Winds are light and very much variable over the country as a whole, in association with flat pressure distribution (Fig. 2.4). In the Arabian Sea, winds are mainly westerly south of 8°N, and northerly between 8°N and 18°N changing to westerlies in the north Arabian Sea. There is an anti-clockwise circulation of wind with centre at about 17°N 60°E. In the Bay, winds are mainly westsouthwest to the south of the trough line along 13°N and about southeasterly to the north of it. Speeds are about 10 kt south of 5°N between 65°E and 85°E and less than 10 kt elsewhere.

3.4.2 In November, the elongated trough in the Bay is near 7°N with north to northeasterlies to the north. Weak westerlies still prevail south of 5°N both in the Arabian Sea and the Bay of Bengal. Winds are from northnortheast to northeast in the Arabian Sea north of 5°N, becoming northnorthwest in Laccadives area.

3.5 The winds over land described above refer to the morning hours. The effect of sea breeze is noticed along the coast in the afternoons. Where the prevailing wind is on-shore, sea breeze penetrates nearly 100 miles inland.

4. Surface Temperatures

4.1 Correction for altitude

4.1.1 The mean temperature of the air at any place depends on many factors, of which altitude, latitude, proximity to the sea, temperature of the sea and the exposure are the chief. The mean temperature falls about 5.5°C per kilometer of ascent but only 0.75°C for every increase of a degree of latitude even in the middle latitudes. These values differ in different parts of the world and in different seasons. The altitude effect is thus dominant. A description of the actual temperatures over the country would therefore describe only the contour configurations. For students of meteorology, an understanding of the physical causes of climate and of the variations of the climatic elements in space and time and due to general synoptic conditions is important. Temperatures reduced to a constant level would bring out these influences more clearly. After a statistical analysis of the variation of the mean daily temperature, the mean daily maximum temperature and the mean daily minimum temperature with altitude, a uniform reduction factor of 6°C per kilometer was considered to be the most suitable for reducing these temperatures to sea-level. This factor was chosen as the best approximation, which facilitates easy computations. The error in the reduced values is not likely to exceed 1°C for the stations with altitudes of less than a kilometre, and the few stations with greater altitudes were not considered.

4.1.2 The temperature charts discussed hereafter are based on the data for the period 1931 to 1960 for the Indian stations. For neighbouring areas, data do not refer to the same period, but significant differences may not arise on this account. Air temperatures over sea have been taken from the Monthly Meteorological charts of the Indian Ocean published by the London Meteorological Office, (1949).

4.2 Mean daily temperature

4.2.1 Fig. 4.1 shows the distribution of mean daily temperature (reduced to sea level) in the four representative months of January, April, July and October. Mean daily temperature is the average of the mean daily maximum and the mean daily minimum temperatures.

4.2.2 January: The mean isotherms run more or less parallel to the latitudes except near the coasts and the gradient of temperature is towards north and is about 0.9°C per degree of latitude between 20°N and 30°N along the longitude of Delhi. Temperature is about 22°C along lat. 22°N and falls towards north to about 15°C at Dehra Dun. The increase of temperature towards the south continues down to about 17°N. Temperatures are more even in the rest of the Peninsula with comparatively higher values between Gadag and Coimbatore. Lower values on the east coast below 17°N are due to the effect of the colder northeasterlies with a trajectory over the Bay with similar temperature; and the higher temperatures on the west coast are the result of the warming of the northeasterlies over land. The range through India is about 13°C, from 14°C to 27°C.

4.2.3 April: Land is getting progressively heated after December-January and by April, temperatures of the order of 33°C to 35°C cover the Deccan and adjoining inland areas upto about 24°N. Temperatures along the coasts are between 28° and 30°C. The gradient of temperature is steep, normal to the west coast, and reaches about 5°C per degree of longitude at some places while it does not exceed 2.5°C per degree longitude towards the east coast. The gradient to the north is also gradual. The spatial range of temperature is reduced to about 8°C. The highest temperatures over India and Burma occur at about 20°N.

4.2.4 July: The Southwest Monsoon is established over India by July with its associated clouding pattern. The cloudiness is heavy between 17°N and 24°N in the central regions, west of 77°E and south of 17°N in the Peninsula, and to the east of approximately 85°E in northeast India. Temperatures are even in these regions being generally between 28°C and 29°C; but on the west coast temperatures of the order of 26° to 27°C are experienced which are lower than mean air temperatures over the open sea. Similar feature is noticed along the Burma coast. To the east of 77°E and south of 17°N temperatures are

30° to 31°C. This large difference of 4°C is due to föhn effect and to lesser cloudiness. The hottest areas in India lie over West Rajasthan with higher temperatures further west. The spatial range over India is about 9°C.

4.2.5 October: Temperatures are generally within a degree of 28°C practically throughout India. Spatial range is about 3°C. This is the month of most equable distribution of temperature in India. North India, cooled down by the monsoon is nearing winter and south India is experiencing the northeast monsoon rains. The temperatures along the west coast of the Peninsula and Burma are still lower than out at sea. It may be noted that along north Orissa Coast and Sind-Mekran Coasts, air temperature is lower than over the neighbouring sea.

4.2.6 Annual: The annual mean temperatures are the highest over Rayalaseema, north interior Mysore and adjoining areas being about 30°C, partly the effect of the black cotton soil in this area. The lowest temperatures of about 25° or less are experienced in the northern parts of the Gangetic Plains and northwest India.

4.3 Mean daily maximum temperature

4.3.1 Fig. 4.2 gives the mean maximum temperature distribution reduced to sea level. The isotherms are more or less similar to the mean daily temperature charts.

4.3.2 January: The temperature is high (about 33°C) in the strip between the Western Ghats, Long.78°E and Lats. 11°N and 20°N. The air coming over this region from some easterly direction would have experienced maximum heating over land. From there temperature decreases in all directions. To the north of 20°N the isotherms run along latitudes. 22.5°C isotherm runs slightly south of 30°N. On the West coast temperatures are more than 30°C south of 17°N but are less to the north of it. The east coast records a more uniform temperature of about 28°C though it is slightly warmer between Madras and Ongole. In this season, the influence of sea breeze is greater on the east coast due to favourable pressure gradient. The spatial range of temperature is about 13°C.

4.3.3 April: A large part of the country between 72°E and 85°E and 14°N and 25°N has a uniform temperature between 40° and 42°C. The large contrast in the maximum temperature between air over land and sea in this month is seen as packing of isotherms along the coasts which extends also inland on account of sea breeze effect. Lack of information handicaps the spacing of isotherms off the coasts. Temperatures are lower on a good part of the west coast than on the east coast, as prevailing wind is more favourable to the sea breeze on the west coast. However the Western Ghats seem to obstruct the spreading and mixing of the sea breeze very much beyond and the 40°C isotherm is much closer to the west coast than to the east coast. The black soil immediately to the east of the Western Ghats may also contribute to the higher temperature experienced there. The rather low temperatures along the coast between Visakhapatnam and Puri may be due to upwelling. The spatial range of temperature is about 13°C, mainly between the areas of continental and maritime influences.

4.3.4 July: With the spreading of the maritime airmass of the southwest monsoon over most of the country, temperature is nearly uniform except over Northwest India and along the west coast. The highest temperatures are over West Rajasthan where continental airmass prevails often and cloudiness is least, with still higher temperatures further west. Temperature decreases from West Rajasthan to West Bengal, the shape of the isotherms resembling closely the isobars. Assam is a little warmer than West Bengal. Compared to the west coast, temperatures are warmer by about 4°C within 100 miles to the east of the Western Ghats, both due to föhn effect and to the decrease in the thickness and amount of cloud. The warmest zone in the Peninsula is between 10° and 15°N and 78°E and the east coast where low cloud amount is small.

The spatial range of temperature is 9°C between Rajasthan and West Bengal and 12°C between Rajasthan and the west coast of the Peninsula.

4.3.5 October: Temperatures in north India decrease from Rajasthan to Bengal and Assam. It is about 37°C over Rajasthan and 30°C over northeast Assam. Over the Peninsula, temperature is more or less uniform, about 33°C, but for the maritime influence along the coasts, which reaches more inland on the east coast than on the west coast. Temperatures over the south Peninsula are lower than over Northwest India in spite of the greater elevation of the sun in the south. This is due to the greater cloudiness over the south Peninsula

4.4 Mean daily minimum temperature

4.4.1 Mean minimum temperature is much more affected by micro-meteorological conditions. But such variations are less likely to occur in the values recorded at observatory sites, which have been carefully chosen for good exposure to represent the general free atmospheric conditions. An analysis of the January chart also shows that such vitiating influences are very limited. Fig. 4.3 gives the mean daily minimum temperature (reduced to sea-level) in January, April, July and October.

4.4.2 January: This is the month of the steepest north-south temperature gradient. The mean minimum temperature varies most and has a range of about 16°C across the country, with an average gradient of 0.8°C per degree latitude. The gradient is steeper between 20°N and 25°N. The temperature varies from 22°C in the extreme south to 10°C in the Gangetic plains and 6°C in the Punjab. The isotherms are practically parallel to the latitudes. The coasts of the Peninsula have a higher minimum temperature than in-land due to maritime influence. In this month the contrast between air over land and over sea is very marked in minimum temperature. Tha packing of isotherms off the coast is the effect of land breeze.

4.4.3 April: Night temperatures are the highest in the area around Bidar and Anantapur. The run of the isotherms to the north of this area is more or less east-west; but Saurashtra, Kutch, north Konkan and the adjoining parts of Gujarat and Madhya Maharashtra have a lower minimum than further to the east. Minimum temperatures appear to decrease slightly inland from the coast but increase again after about 150 km.

4.4.4 July: Mean minimum temperature is practically uniform throughout India. It is generally within 2° of 26°C. In the Punjab, Rajasthan and parts of West Uttar Pradesh it is a little higher than 28°C. The west coast south of Bombay and a strip adjoining it about 200 km in breadth on the average, enjoy a night temperature of about 24°C.

4.4.5 October: Night temperatures begin to come down everywhere in India. The 22.5°C isotherm runs roughly east-west along the central latitude of the country. Temperatures are slightly lower than 20°C in the Punjab and northern parts of Rajasthan and 25°C near Kanya Kumari.

4.5 Diurnal range of temperature

4.5.1 Diurnal range of temperature is the difference between the maximum and the minimum temperatures. The range is mainly a function of continentality, vapour pressure, cloudiness, latitude and altitude. The range at hill stations (above 1 km) is generally lower than that at the neighbouring plain stations. Coastal stations also record lower ranges.

4.5.2 January: Over most of the country the range is high, about 13°C to 15°C, due to the prevailing continental airmass. The highest range, about 19°C, is between Baroda, Malegaon and Poona, where clouding is the least. Along the coasts it is generally less than 10°C due to maritime influence. The lowest values of about 5°C occur over southeastern Madras State, where clouding is high and rains persist.

4.5.3 April: The highest values of the diurnal range occurring in this month are about the same as in January, inspite of higher mean temperatures. Over most of the country north of 20°N, the range has increased; but it has decreased over upper Assam. The maximum range of about 18°C occurs in three regions, one covering parts of Gujarat, Saurashtra and Madhya Maharashtra, a second over north Madhya Pradesh and a third over north Rajasthan and the adjoining Punjab. Along the west coast, with the prevailing wind becoming on-shore, the range has come down to about 6°C.

4.5.4 July: With the general increase of cloudiness, the mean range has come down all over the country. Over the extreme western parts of north India, and over the Peninsula upto about 200 km from the east coast it is 8°C to 9°C. It is uniformly about 6°C over the rest of the country, except the whole of the west coast and the Orissa-Bengal coast where it is about 5°C. It is worth mentioning that Cherrapunji with the heaviest rainfall has a range of 3.8°C. Perhaps 4°C is about the lowest limit to the range in these latitudes.

4.5.5 October: In October the mean range increases all over the country. From about 6° to 7°C along the coasts it increases towards northwest to 16° to 17°C in the western-most regions of north India.

4.5.6 The annual range of the mean monthly diurnal ranges is also least along the coast and in the sub-Himalayan stations varying between 3° and 5.5°C and increases to as much as 11°C in the central portions of India, parts of Gujarat and parts of Maharashtra on the eastern foothills of the Ghats.

4.6 Heat waves and cold waves

4.6.1 Spells of abnormal maximum temperatures occur in various parts of India which are referred to as 'Heat Waves' during April to June. When the maximum temperatures recorded become 6°C or more above the normal, it is called "Heat Wave". A similar definition holds for "Cold Wave".

4.6.2 Heat Waves: For a climatological consideration, if the average daily maximum temperature for a month in a broad area exceeds the normal value by about 2°C, prolonged high temperatures would have been experienced there. If it exceeds by 4°C, the spells would have been very severe. Though most sub-divisions have recorded above average temperatures in more than 50 per cent of the years, not all of them experience heat waves to the same extent. The Punjab, Uttar Pradesh, Bihar, Madhya Pradesh, Orissa and Vidharba experience heat wave conditions in 30 to 40 per cent of the years in June, and in 20 to 30 per cent of the years in May. Severe heat waves are also confined to this area and occur in about 5 to 10 per cent of the years. Maximum number of heat waves and the severe ones usually occur in June.

4.6.3 Cold Waves: January and February are most prone to cold waves. While the eastern parts of the country (except NE India) are more affected by heat waves, cold waves prevail on more number of occasions and are more severe in the western parts of India to the north of latitude 20°N. Jammu and Kashmir, West Uttar Pradesh, Rajasthan, West Madhya Pradesh and Gujarat are the most affected regions; the Punjab region experiences comparatively lesser number of severe cold waves.

4.7 Other significant features

4.7.1 The seasonal temperature variation is considerably modified by the southwest monsoon. The maritime airmass brought by the monsoon over most of the country and associated increased cloudiness counteract the higher elevation of the sun and day temperatures decrease instead of increasing. In the western parts of the Peninsula the lowest mean daily maximum temperature is in July and August, during mid-southwest monsoon. The effect of moisture content of air and cloudiness are different on day and night temperatures so that they should be discussed separately.

4.7.2 Day temperatures are the highest in May over most of India after which the effect of the maritime airmass of the south-west monsoon brings down the temperatures. In some parts the prevailing circulation brings maritime influence earlier and the rise in temperatures is arrested. In the western half of the Peninsula to the south of 15°N day temperature decreases after April. Thunderstorm frequency is very high in May in this area. North of 15°N along the west coast, May has the highest mean day temperatures but there is a narrow strip to the east of the Western Ghats where April is the hottest month. At Trivandrum, March is the hottest and between Cuddalore and Nagapattinam, June.

4.7.3 To the east of 87°E (except Assam) day temperatures decrease after April. Maritime airmass prevails in lower levels in May and thunderstorms are very frequent. In Assam July or August is the hottest month in spite of the rains. Monsoon depressions form at the Head Bay at frequent intervals during July and August, and during their formation rainfall and cloudiness decrease in Assam and hence the day temperatures increase. In the Brahmaputra valley föhn effect may also be present.

4.7.4 In Kashmir the highest temperatures are reached in July. Sun attains its highest altitude in late June in these areas and temperature has usually a lag of a month. Along Saurashtra and Sind coasts, June is the hottest, while in the interior it is May. In the Andaman Islands day temperatures are highest in April.

4.7.5 North of 15°N day temperatures rise again towards the end of the monsoon and there is a second maximum. Between 15° and 23°N and to the west of 82°E the second maximum is in October and in the rest of the country to the north and east (except Assam and northern half of West Bengal) it is in September. Decrease in the cloudiness mainly accounts for this second rise in day temperatures. From Bombay to Marmugao this is in November and at Mangalore even in December-January. Port Blair shows this feature in October-November. The second maximum is not apparent in the east coast belt, about 200 km wide, to the south of Masulipatnam and along the west coast south of Mangalore; nor is it seen in Assam and the Himalayan foot-hill regions.

4.7.6 South of about 22.5°N, except in the western parts of the Deccan, day temperatures are the lowest in December and to the north in January. However, in Gujarat, January has the lowest maximum temperatures. South of 19°N along the west coast and for about 250 km into the interior July or August has the lowest day temperatures. Places further east in this zone enjoy low day temperatures without the heavy rains of the coast. The lowest day temperatures in the year occur in this region while the sun is almost overhead but obscured by clouds. In Andaman Islands, September is the month with the lowest maximum temperature.

4.7.7 Night temperatures are the highest in April along Kerala coast and in May in Konkan and Kanara coasts. In the Peninsula and between 75° and 85°E to the south of 24°N it occurs in May. Over the rest of India minimum temperatures are the highest in June, except in Kashmir, north Bihar and most of West Bengal where July experiences the warmest mornings. Assam also has the warmest July nights, but there this effect continues through August. Lowest minimum temperatures are in January except in the central parts, between 15°N and 25°N and 75°E and 80°E and between 18°N and 25°N and 80° and 85°E where they are in December. Port Blair records the highest minimum in June and the lowest in February.

4.7.8 The peculiar variation of temperature over India makes it necessary to discard the usual classification of the seasons into winter, spring, summer and autumn. Highest temperatures are attained in spring and hence March to May has been designated the Hot Weather period. June to September has been called the Southwest Monsoon period. October and November are called the Post-monsoon period, though December is also sometimes included in it, particularly while discussing conditions over the south Peninsula. December, January and February are classified under Winter though in some parts day temperatures are not the lowest at this time as already explained.

5. Rainfall

5.1 Annual rainfall

5.1.1 Fig. 5.1 shows the annual rainfall over India and neighbourhood. The rainfall data for Indian stations are for the period 1901-50 while for neighbouring areas they relate to slightly different periods. ~~The density of observations used in drawing the isohyets in extra-Indian areas is less than over India.~~

5.1.2 Hills and mountain ranges cause striking variations in rainfall. On the southern slopes of the Khasi-Jaintia hills rainfall is over 1000 cm at Cherrapunji while to the north in the Brahmaputra valley it drops to less than 200 cm. Cherrapunji's rainfall of 1142 cm at elevation of 1313 m, is obviously due to orographic lifting but its magnitude requires to be quantitatively explained. From the west coast rainfall increases along the slopes of the Western Ghats and rapidly decreases on the eastern side (leeside in the southwest monsoon season). No definite information is available about the increase of rainfall with elevation and the height at which the rainfall attains the highest value. In the higher reaches of the Western Ghats there are many places with rainfall of 600 cm. Within 50 miles on the leeside rainfall is only 50 to 60 cm. Though hill ranges elsewhere in India also cause increase of rainfall in their vicinity, difference in rainfall between the higher reaches and the neighbouring plains is not so conspicuous as much of the rain is associated with depressions and 'lows' in these regions.

5.1.3 From the east coast rainfall decreases inland in the Peninsula south of 17°N. This decrease continues upto the eastern side of the Western Ghats, except for some increase over the Eastern Ghats. The low rainfall of about 75 cm at the extreme south Peninsula and Gulf of Mannar, between 8° and 10°N to east of Western Ghats, is interesting, as along the coast one degree to the north, rainfall is almost double.

5.1.4 Between 17°N and 20°N, Eastern Ghats are closer to the coast than further south and rainfall increases from coast to the hill ranges. When the isopleths are drawn at closer intervals (not shown in Fig. 5.1) it is seen that behind the first range there is a slight decrease and again increase over the next range, From 80°E rainfall decreases continuously upto the east of the Western Ghats.

5.1.5 The lowest rainfall region in the Peninsula with less than 50 cm of rain occurs at about 18°N in the upper basin of river Bhima and its tributaries, just to the east of the Ghats.

5.1.6 From the coast of West Bengal and the hills of Orissa rainfall decreases inland. Further westwards, the Chota-Nagpur hills, the Maikala Range and the Mahadeo hills cause increase of rainfall with lesser amounts in the valleys in between. Effect of Vindhyas and rest of Satpuras is not so marked. But the Gir hills in Kathiawar have more rainfall than the neighbourhood. Mt. Abu in Aravallis has a rainfall of 160 cm while surrounding plains have only 60 to 80 cm.

5.1.7 Across northern India a line of rainfall minimum runs from 28.5°N, 75°E to 25°N, 88°E which is paradoxically close to the monsoon trough. Area to south falls in the track of monsoon depressions which are responsible for much of the rainfall. In tracts further to north there is probably some influence of the Himalayas in increasing the rainfall. Apart from this, there is decrease of rainfall from east to west, from about 150 cm in West Bengal to 20 cm in the Great Indian Desert in West Rajasthan.

5.1.8 In the Himalayas observations are extremely scanty, particularly from higher elevations where there is additional difficulty of measuring snowfall. Rainfall measured in river valleys may not be representative of the hill slopes. Between the Great Himalayan Range and the plains there are the Pir Panjal, the Siwalik and the Mahabharat Ranges. Most of the available observations are from these ranges. Rainfall increases up the slopes of these foot hills, presumably decreases on their northern slopes and increases again on the Himalayan slopes. Rainfall at Chaundrikara (9,000 ft) is 228 cm and at Namche Bazaar (11,000 ft) only 94 cm. Both are in Nepal and the distance between the two is hardly 10 miles. Therefore we can tentatively conclude that above some elevation near 3 km, rainfall may decrease with height on the Himalayan Range. In the Eastern Himalayas rainfall is more than in the Western portions. In the east rainfall of 500 cm has been recorded but only 280 cm in the west.

5.1.9 Over Tripura, Manipur, Nagaland and Mizo hills, which have multiple hill ranges, rainfall observations are very few.

5.1.10 Rainfall in the Andaman and Nicobar Islands is about 300 cm while in Laccadives (Minicoy and Aminidivi Islands) and Maldives in the Arabian Sea it is only about 150 cm, though both the groups are in the same latitude belt. Calicut on the mainland in the west coast however gets 300 cm, comparable with that of the Bay Islands.

5.2 Number of rainy days

5.2.1 Fig. 5.2 depicts the distribution of the annual number of rainy days (days on which 2.5 mm of rain or more is recorded) over India. The pattern of rainy days is similar to that of annual rainfall. Areas of more than hundred rainy days are the Andamans, west coast south of about 16°N, Western Ghats upto 19°N, most of Assam except the lower Brahmaputra valley, portions of sub-Himalayan West Bengal and probably the higher elevations of the Himalayas upto the Punjab. Places with over 150 days are in the Western Ghats between 9° and 13°N and the hills of Assam. Cherrapunji has about 160 rainy days which number appears to be about the maximum in all the above areas. Less than 20 rainy days are confined to Kutch, West Rajasthan and adjoining parts of the Punjab (India), some places in the Great Indian Desert having even less than five rainy days. In northern India the number increases from west to east upto West Bengal and towards the Himalayas.

5.2.2 In the Peninsula areas of less number of rainy days (between 30 and 50) are over South Madras State and in a belt from Madhya Maharashtra to southern parts of Andhra Pradesh. In Rayalaseema and adjoining Mysore two small pockets have less than 30 rainy days.

5.2.3 There seems to be a tendency for a maximum to occur between 9°N and 13°N. The maximum along the West Coast is at Alleppey which has 137 days. Madras has a greater number of rainy days than to the south or north, and so have Port Blair, Mergui and Victoria Point.

5.3 Seasonal rainfall

5.3.1 The Winter (January and February) rainfall over India is an insignificant percentage of the annual rainfall except in Kashmir and neighbourhood. Yet this rainfall is very important for the winter crops of northern India. Fig. 5.3 shows the rainfall distribution in winter. The highest rainfall of over 20 cm is over Kashmir and some places in Nicobar islandds. Jammu, north Punjab, Haryana, Himachal Pradesh and northwest Uttar Pradesh get over 5 cm. Other regions of over 5 cm of rain are northeast India east of 90°E, Bihar Plateau, the adjoining parts of Madhya Pradesh and Orissa, the Peninsula south of 10°N, the east coast strip south of 15°N, and the two island groups. There is no sharp rainshadow area in the extreme south Peninsula.

5.3.2 In the Hot Weather Period (March to May) chief areas of rainfall are Assam, Jammu and Kashmir, Kerala and their neighbouring areas. Fig. 5.4

shows the rainfall during this season. Cherrapunji already records over 200 cm. The next in importance is the tract from West Bengal to north coastal Andhra Pradesh. Western parts of India except the extreme north and south are the driest areas.

5.3.3 The rainfall distribution in the principal rainy season of India, the Southwest Monsoon period, lasting from June to September, is shown in Fig. 5.5. Except in Kashmir and neighbourhood, the extreme south Peninsula and the east coast areas, the annual rainfall is mainly accounted for by the falls in this season and hence the two are similar in distribution. Orographic influence is dominant in the distribution of rainfall in this season, as the prevailing winds blow almost at right angles against the Western Ghats and the Khasi-Jaintia hills. There is rapid increase of rainfall to the north of a line running from Ahmednagar to Masulipatnam up to the southern slopes of the Vindhyas. In the north Indian plains, a minimum rainfall belt runs from northwest Rajasthan to the central parts of West Bengal, practically along the axis of the monsoon trough. Rainfall decreases generally to the east of the Eastern Ghats and to the west of the Western Ghats, towards the coasts. In the extreme south where the Eastern Ghats split up into small hills and diffuse with the Western Ghats rainfall is more or less uniform.

5.3.4 Rainfall decreases very rapidly southwards along west coast from 9.5°N to Kanyakumari. The rainfall at Kanyakumari in this season is about the same as in the Great Indian Desert. To the east of the Western Ghats between 8° and 10°N rainfall decreases considerably with a very steep gradient along the eastern slopes and in the coastal strip rainfall is only 2 cm. With all the significant amounts of rainfall occurring on the Ghats, a saving feature of economic interest is that all the important rivers of South India emerge out of the Western Ghats to flow east through the plains having a rainfall of the order of that in West Rajasthan.

5.3.5 In October, November and December, called the Post Monsoon period, the south Peninsula, the east coast, Assam and parts of Kashmir are the Chief areas of rainfall as will be seen from Fig. 5.6. All along the east coast rainfall decreases inland from the coast, markedly so along Madras and Andhra coasts. South of 15°N, rainfall again increases over and near the Western Ghats but decreases towards the west coast. Rain shadow effects are not as marked as in the Southwest Monsoon season near the Western Ghats. Near the Eastern Ghats increase in rainfall is not marked.

6. Upper Air Temperatures

6.1 Differences between various types of radiosonde instruments, shortness of the period of data and sparse network of stations in Southeast Asia make possible only a broad description of large scale features. Figs. 6.1 to 6.4 show the isotherms in January, April, July and October for the levels 850, 700, 500 and 300 mb.

6.2.1 In January the temperature decreases northwards from 15°N at all levels from 850 to 300 mb. Difference in temperature between 15°N and 30°N is about 8°C at 850 mb and 700 mb and 10°C at 500 mb and 300 mb levels. At 200 mb the temperatures over India are within 2°C of 222°A. Higher up, the gradient reverses. At 150 mb the temperature rises by 7°C from 15°N to 30°N. At 100 mb level the northward increase of temperature starts from 10°N and is more marked. From 10°N to 30°N the rise is about 14°C. South of 15°N a thermal high exists at all levels upto 300 mb and a cold pool at 150 and 100 mb. At all these levels the gradient is weak.

6.2.2 The general run of the isotherms in areas of marked gradient is practically zonal. Though in some charts weak thermal troughs and ridges are seen, on account of so many uncertainties, doubt arises how far they should be identified as semi-permanent systems. The more important systems in the northern hemisphere in the lower and mid-troposphere are the thermal troughs over

Siberia and Canada and the ridges off the West European coast and the East coast of Asia covering Alaska. The systems over Asia are confined to north of 40°N and do not appear to show any extension over the Indian area.

6.2.3 Standard deviation of temperature is a little over 3°C in extreme northern India and decreases to 2°C in the south Peninsula at 700 mb and 500 mb. It increases aloft becoming 6°C in northern India at 150 mb and 3°C at the tip of the Peninsula, but decreases to 4° to 3°C, at 100 mb.

6.2.4 North of 25°N both the tropical and the polar tropopauses occur on many occasions in January. The tropical tropopause is between 100 and 115 mb over the whole country and the polar tropopause occurs between 195 and 225 mb. north of 25°N with temperature of about 220°A. Temperature at the tropical tropopause is about 205°A near 30°N decreasing to 197°A to the south of 15°N. Polar tropopause seems more frequent in India near 30°N, than either over the western Pacific or the Middle East.

6.2.5 Ground inversions are very common to the north of 20°N from after sunset to sometime after sunrise. Between 850 mb and 700 mb, lapse rate is the least (4°C Km^{-1}) in West Central and Southwest Bay and adjoining eastern parts. It is the highest (6°C Km^{-1}) in northwestern parts of the Peninsula and central parts of the country. The low lapse rate in the western Bay may be due to the trade wind inversion in the Northeast trades. Lapse rate is uniform and is near about 6°C Km^{-1} between 700 and 300 mb. It decreases from south to north between 300 and 100 mb, with lowest values north of 25°N. In that area low lapse rate is apparently due to the incursion of polar tropopause on many occasions. In the south Peninsula the lapse rate increases with height from the lower level, to attain its highest value of over 7°C Km^{-1} between 300 and 200 mb. It then decreases to 4°C Km^{-1} between 150 and 100 mb in the vicinity of the tropical tropopause.

6.3.1 By April a thermal high develops over India at 850 mb with centre near about 22°N and 80°E. Temperature decreases in all directions from this centre. The fall in temperature is about 7°C down to 8°N while it is 4°C upto 30°N. Further north meridional temperature gradient is very marked. By 700 mb the thermal high shifts southwards to 15°N and the temperature gradient is towards north. A ridge appears to run from North Arabian Sea to the Caspian Sea. At 500 mb also the temperature decreases to the north of 12°N and is uniform to the south. Temperature range from 17°N to 30°N is 4°C. At 300 mb a weak thermal high is over the south Peninsula and the temperature fall from 20° to 30°N is 6°C. Temperature is very flat at 200 mb (within 2°C of 223°A) but a marked increase towards north develops at 150 mb and 100 mb from the central parts of the Peninsula. At 100 mb the temperature difference is 12°C between 10° and 30°N.

6.3.2 Standard deviations of temperature are 2° to 4°C at 700 mb and 500 mb. They are 3° to 5°C from 300 to 100 mb, higher values being in the northern parts of India.

6.3.3 The tropical tropopause occurs in April near 100 mb and to the north of 25°N the polar tropopause also occurs at 200 mb. The temperature at the tropical tropopause is about 205°A north of 25°N, decreasing to 195°A below 15°N. The frequency of polar tropopause decreases from January to April over northern India unlike some other areas in the same latitude.

6.3.4 Between 850 and 700 mb the highest lapse rates of over 9°C Km^{-1} occur from the central parts of the country to Rajasthan. The lapse rate decreases to the south and to the east, becoming 5.5°C Km^{-1} at Trivandrum and Port Blair. From 700 to 500 mb it is over 7°C Km^{-1} over northwest India, while remaining 5.5°C Km^{-1} at Port Blair and Trivandrum. It is between 6° to 7°C Km^{-1} over the whole of India between 500 and 300 mb. Aloft, lapse rates decrease north of 25°N becoming 2° to 4°C in the layer 150 to 100 mb. South of 20°N high lapse rates of more than 7°C Km^{-1} are between 300 mb and 200 mb, decreasing higher above to 2° to 4°C Km^{-1} between 150 and 100.mb.

6.3.5 In May the thermal high at 850 mb shifts a little to the northwest and is centred at 23°N, 78°E. Temperature decreases markedly towards east and south, Gauhati and Trivandrum being 8° to 10°C cooler than Nagpur. At 700 mb the warmest region is still in the central parts but temperature gradient decreases markedly. Due to the higher lapse rate in the continental air mass in the hottest parts, at 500 and 300 mb the lowest temperatures are over the northwestern parts of India, though temperature gradients are very slack at these levels. Between 200 and 100 mb temperatures are nearly uniform over the Peninsula but increase towards north, the gradient increasing with height.

6.3.6 In June the highest temperatures at 850 mb are over extreme northwestern portions of India and adjoining ~~West~~ Pakistan. Temperature decreases markedly over northeast India and the Peninsula. At 700 mb this decrease in temperature is less. By 500 mb a weak thermal ridge develops between 25° and 30°N and persists there about up to 100 mb. Temperature decreases south of this ridge at all levels, though gradient is less over the south Peninsula. The level of tropopause south of 15°N is about 110 mb but it is between 95 and 100 mb north of 25°N.

6.3.7 In May lapse rates are over 9°C Km^{-1} between 850-700 mb over the central parts of the countryy; it decrease to 5.5°C Km^{-1} at Trivandrum and Port Blair and 6.0°C Km^{-1} at Gauhati. In this layer the lapse rates decrease by the next month.

6.4.1 In July, at the height of the southwest monsoon, a thermal high lies over Iran, Iraq and central parts of Arabia and a thermal ridge runs from it along 35°N latitude to the north of India at 850 mb. Two thermal troughs run - one along the west coast of the Peninsula and the other along the Burma coast while a thermal ridge is present over the west Bay and neighbourhood. The thermal pattern at 700 mb is about the same except that the troughs and ridges are absent to the south of about 20°N and the thermal gradient over India is less. The thermal high over North America is at a little higher latitude and over west Africa at a lower latitude than over west Asia. At 500 and 300 mb a thermal ridge runs along 25° - 30°N with appreciable temperature gradient to the south at 300 mb. At 200 mb the thermal ridge is along 35° - 40°N with decrease in temperature to the south. Aloft, this thermal ridge disappears. At 150 and 100 mb, the temperature increases from the south to the north, from the Equator to the Pole.

6.4.2 Standard deviation of temperature is about 2°C at 700 and 500 mb, increasing to 2 to 5°C aloft. Standard deviations are higher in the north than in the south.

6.4.3 Tropopause is the highest between 25° and 30°N, where it is between 100 and 95 mb. The pressure at tropopause increases to the south being 120 mb at Port Blair and 115 mb at Trivandrum. To the north of 30°N also pressure at the tropopause increases. The temperature at the tropopause is uniform up to 30°N, being about 198°A.

6.4.4 Monsoon airmass prevails over most of the country where lapse rates are near the saturated adiabatic. However, the lapse rate of temperature in the lowest few hundred metres above the sea around India has been found in some of the available observations to be equal to or greater than the dry adiabatic lapse rate. Between 850 and 700 mb the lowest values are along the west coast and highest near Madras which has less rain. They are 5° to 6°C Km^{-1} between 700 and 500 mb and increase with height becoming a maximum at 300-200 mb or 200-150 mb where values of 7 to 8°C Km^{-1} are reached. Aloft, they decrease. Between 150 and 100 mb higher values are to the north, with 5.7°C Km^{-1} at Delhi and 2.1°C Km^{-1} at Trivandrum.

6.5.1 October is a month of very weak temperature gradient to the south of 25°N upto 300 mb, while the temperature decreases to the north. At 200 mb the temperature field is very flat all over Asia. At 150 mb the temperature increases towards north from 20°N latitude and at 100 mb from 15°N. At the last level increase in temperature from 15° to 30°N is 11°C.

6.5.2 Tropopause in October is at about 110 mb (temperature 198°A) over India and the polar tropopause occurs only to the north of 30°N.

6.5.3 Between 850 and 700 mb lapse rate is over 7°C Km^{-1} over northwest India and decreases to 6°C Km^{-1} in Assam and 5°C Km^{-1} at Trivandrum and Port Blair. Higher above, lapse rates are uniform over the country increasing from 5°C Km^{-1} between 700 and 500 mb to about 7°C Km^{-1} between 200 and 150 mb. Between 150 and 100 mb, lapse rates are less but increase northwards from 3°C Km^{-1} at Trivandrum to 4.5 to 5°C Km^{-1} near 23°N and again decrease towards higher latitudes.

6.5.4 Standard deviation of temperature is 2 to 3°C at 700 and 500 mb. Aloft, the range varies from 2° to 5°C. Higher values are in the north.

6.6 The annual range of mean temperature decreases appreciably from north to south up to 200 mb. Aloft, it is practically uniform. There is a tendency for the range to decrease with height from lower troposphere to about 500 mb and again increase slightly at 300 mb.

7. Upper Winds

7.1 The sub-tropical high pressure belt passes over and near India throughout the year. It is masked in the lower troposphere by the effect of continentality. In the middle and upper troposphere it is predominent and defines the wind distribution (Fig. 7.1 to 7.4).

7.2.1 In January by 900 mb the extension of the Siberian High into northern India is effaced, being a cold high. A weak anticyclonic cell is centred over the Peninsula at 21°N, 80°E as part of the subtropical ridge line running from Arabian Sea to southeast Asia between 20° and 30°N which forms separate cells over Arabia, India and southeast Asia. This ridge line shifts southward with height and is at about 8°N at 300 mb over India. At 900 mb except for easterlies over Assam, winds are West to Northwest to the north of the ridgeline and northeast to southeast to the south. From 850 mb winds are practically westerly at all levels to the north of the ridge line and speeds increase with height over northern India. A weak trough exists over Burma and Assam upto 800 mb. From 200 to 100 mb the anticyclonic cell from southeast Asia extends into South Bay.

7.2.2 The strongest westerlies are experienced between 25° and 30°N, at all heights from 500 mb upwards. The wind speed in this belt is over 40 kt at 500 mb, about 75 kt at 300 mb, and 85 kt at 200 mb, with speeds slowly decreasing aloft.

7.3.1 In April a trough line runs along 77°E at 900 mb over the Peninsula as at sea level. Weak high cells probably exist over the Central Bay and the Arabian Sea. The subtropical ridge appears over land near about 18°N at 850 mb and persists at 700 mb. Aloft, it gradually shifts southwards to 8°N at 200 mb. At this level the anticyclone from the east extends upto Sri Lanka. ~~Ceylon~~. A trough is also present over northeast India between 900 and 800 mb with axis along 87°E. Westerlies increase with height over northern India and the adjoining Peninsula. At 300 mb maximum speeds are about 40 kt near 25°N and 50 kt between 25° and 30°N at 200 mb decreasing slowly aloft.

7.3.2 In May a trough line runs from Gorakhpur to Kanyakumari at 900 mb, A weaker trough also runs from Multan to Badin. Winds all over the country are from some westerly direction. At 850 mb the only troughs are one over northeast India along 87°E and another roughly along 12°N in the Bay and the Peninsula. The latter trough persists upto 500 mb. Subtropical ridge from

Arabia reaches into the Peninsula at 800 mb and persists upto 500 mb at about the same position. Aloft, this ridge line shifts southwards reaching 14°N at 200 mb, but is again displaced northwards to near 20°N at 100 mb. From 200 mb the ridge over the Peninsula is an extension from the east rather than from the west. The westerlies over northern India are strongest between 200 and 150 mb, reaching 50 kt at 200 mb near 30°N and 50 to 60 kt at 150 mb. Speed decreases aloft. Easterlies over the Peninsula are not over 20 kt.

7.3.3 In June by the end of which the monsoon is established over practically the whole of the country, winds are westerlies at 900 mb. The monsoon trough over northern India between westerlies to the south and easterlies to the north is established only towards the end of the month. A trough is present over ~~West~~ Pakistan and adjoining Iran which persists upto 800 mb. Between 850 mb and 500 mb a trough line exists over the northeast India between 85° and 90°E. The sub-tropical ridge from the West begins extending into Rajasthan at 700 mb and reaches Gujarat by 500 mb. Weak easterlies appear at 300 mb south of ridge line along 22°N. The anticyclone from the east extends to 85°E at 300 mb and 70°E by 150 mb. The ridge line is at 25°N at 150 mb and near 28°N at 100 mb. Easterlies well to the south of this ridge line strengthen with height and are 50 kt over the Peninsula at 100 mb.

7.4 In July the monsoon trough runs from Delhi to Calcutta at 900 mb. Westsouthwest to westnorthwest winds prevail to the south of it and southeast winds to north. A weak trough is also present over ~~West~~ Pakistan and neighbourhood. Westerly winds over the Peninsula increase with height from ground and reach a maximum between 900 and 800 mb. This level is near 900 mb along the west coast and increases to 800 mb in the eastern Peninsula. Maximum speeds are between 20 and 25 kt. Similar wind maximum near 900 mb has been found in the Arabian Sea south of 20°N, particularly in the western portions. The monsoon trough shifts south with height and is near about 23°N at 700 mb but becomes diffuse by 500 mb. The trough over ~~West~~ Pakistan is not present at

700 mb and instead the sub-tropical high from the west extends into northwest India. Thus the warm surface low over West Pakistan and neighbourhood is replaced by the sub-tropical high at 700 mb. At 500 mb, this ridge, the easterlies over Northern India, and a trough over east central and southeast Arabian Sea are the chief features. Winds at this level are weak. At 300 mb apart from the western ridge along 30°N over northwest India and Pakistan, winds are easterly over the whole country. Between 200 and 100 mb another ridge from the east develops to the east of longitude 75°E (with ridge line at 30°N). Easterly winds strengthen with height from 200 mb reaching a maximum at 100 mb. Speeds are between 60 and 80 kt over the Peninsula at 150 and 100 mb and even at 200 mb over the extreme south.

7.5 During the course of October, the monsoon withdraws from most of the country. At 900 mb the sub-tropical ridge from the west extends to 88°E with a ridge line along 25°N. The ridge from the east extends into Assam. Westerlies are present south of 10°N and a trough runs along 12°N latitude, more prominently in the Bay. This trough persists with slight shift to south upto 700 mb. But at 500 mb the ridge is along 17°N with the westerlies to the north and easterlies to the south. Aloft, the westerlies over northern India strengthen with height, becoming 50 to 60 kt at 200/150 mb over northwest India and West Pakistan; but not to that extent over northeast India. Speed decreases at 100 mb. The easterlies to the south of the ridge line also increase in speed above 300 mb level, reaching a maximum at about 150 mb. From 300 mb upwards the ridge extending over the Peninsula is from the east. At 150 mb the ridge line is at 18°N and at 100 mb 20°N.

7.6 Zonal westerlies of the non-monsoon months are very steady north of 15°N. In middle troposphere winds are very unsteady in July and August but the upper tropospheric zonal easterlies of the southwest monsoon are very steady south of 25°N. In transitional layers between different wind regimes, winds are unsteady.

7.7 Diurnal variation in upper winds of the order of 5 kt occur even upto 500 mb. Some interesting changes from morning to evening are described below. In January westerlies increase in the afternoon over the Indo-Gangetic plains. At 700 mb the 'high' circulation over Deccan weakens and aloft, shifts south. In April at 900 mb wind vector changes form a clockwise circulation centred round the Bihar Plateau. Near 500 mb they form a 'high' over Deccan. In July at 900 mb the wind vector changes are from south as between a 'high' to the east of Assam and a 'low' over Pakistan. In October upto 500 mb westerlies increase over the Northern India and easterlies decrease over the Peninsula.

7.8 Along the west coast from morning to afternoon wind vector changes from west are prominent at 900 mb in January, April and October. 'Return vectors are noticed aloft upto 700 mb. Such 'return vectors' commence along the east coast at 900 mb. In July along both coasts 'wind vector change' from sea-side is noticed upto 800 mb.

8. Westerly Jet Streams

8.1 The sub-tropical Westerly Jet Stream is present over northern India from October to May. In January the jet stream runs between 25° and 30°N at about 200 mb (12 km). Winds are practically westerly and upto 95 kt. Within 5° of the core of the jet stream there does not appear to be confluence or diffluence of streamlines at this level. Jodhpur (27°N 72°E) has a mean speed of 95 kt at 12 km, Gauhati (26°N 92°E) 95 kt at 10.5 km and 90 kt at 12 Km and Allahabad (25°N 82°E) 80 kt at 10.5 and 12.0 Km. The weakening of the speed near Allahabad may suggest two maxima, one to the east and another to the west. The Jet stream lies within the troposphere. A speed of 50 to 60 kt has come to be accepted as the lower limit to be designated as a jet stream. Mean speed of 60 kt or more is found north of 20°N. At this southern limit this limiting speed is only at 12 km while further north it is in a deep layer. North of 23°N this speed commences at 9 km and in Assam even at 7 km. In these latitudes the speed is more than 60 kt upto about 14 km. Horizontal wind shear is generally more than 0.05 hr^{-1} (i.e., 5 kmph per 100 km) south of the jet stream. Vertical shear is 20 hr^{-1} (i.e., 20 kmph per km) at a level 3 km below the jet maximum.

8.2 From the surface upto 300 mb strong temperature gradient exists towards north, particularly at 500 and 300 mb. The consequent thermal wind builds up the jet stream and the wind speeds reach a maximum near 200 mb, at which level meridional thermal gradient is slack, before reversing aloft. Lapse rates are more to the south of the jet stream than to the north both below and above the jet level (from 300 to 100 mb), in conformity with the reversal of the meridional temperature gradient near the jet level. At heights below 300 mb, lapse rates on both sides are about the same. The lower lapse rates to the north near the level of the jet stream are associated with the occurrence of polar type of tropopause. Wind and temperature data are insufficient to derive the vertical circulation near the jet.

8.3 The position of the jet is about the same till April. The jet strengthens at Delhi, Allahabad and Gauhati in February. Otherwise speeds decrease from January to April, maximum speed being less than 60 kt in April. In May the jet shifts to near 30°N with speed of 50 kt.

8.4 The westerly jet stream disappears from the Indian latitudes during the southwest monsoon period of June to September. It reappears in October near 30°N with speed of 50 to 60 kt at 12 km. In November it is still near 30°N but shifts to 25 to 30°N in December. Speeds are over 70 kt in November and 80 kt in December.

9. Easterly Jet Stream

9.1 Near 100 mb, strong easterlies blow to the south of 25°N in the southwest monsoon period, which are called the Easterly Jet Stream. These strong easterly winds near the tropopause are a characteristic of Asia and Africa in summer and are not to be found over the Atlantic or the Pacific. In July winds are easterly 10 to 20 kt at 300 mb south of 27°N and westerly to the north of 32°N with transition in Between. As the temperatures decrease to the south from 25°N, easterlies strengthen over the Peninsula to 40 to 50 kt by 200 mb. At 200 mb the temperature decrease southwards starts at 30°N itself. At 150 and 100 mb, the temperature gradient south of 20°N is very flat but southward decrease persists to the north. This northward increase of temperature extends almost upto the Pole. This is a global feature. However, the steep gradient is between 20° and 50°N. On account of the effect of the thermal wind, the easterlies increase with height upto about 150/100 mb over the Peninsula at which level they are a maximum. At Madras mean wind is 085°/80 kt at 16 km while at 14 km it is 085°/60 kt and at 18.0 km 080°/25 kt. From the available scanty data the core of the easterly jet over India appears to be near about the latitude of Madras (13°N) at 100 mb. However, at Trivandrum (08° 30' N) maximum speed is at 14.0 km (150 mb), being 080°/65 kt higher than that at Madras at that level. Aloft, speed is less than at Madras. At Gan Island (1°S) maximum speed of 55 kt is at 150 mb as at Trivandrum and decreases sharply to 25 kt by 100 mb. At Bombay (19°N) speeds at 14, 16 and 18 km are respectively 55, 70 and 70 kt. The speed at 18 km is higher than that at Madras. Thus while the core of the easterly jet is near 13°N at 100 mb, the highest speeds at 150 mb are further to the south and above 100 mb further to the north.

9.2 Even at 100 mb strong temperature gradient prevails over northern India. Hence easterly winds increase with height even above 100 mb. New Delhi (28° 30' N) shows increase of speed from 10 kt at 14 km to 35 kt at 24 km. The easterlies may not be extending to north of 30°N in the upper troposphere as the few available winds at Ambala (30° 30'N) show westerlies between 14 and 18 Km. The easterlies above 18 Km over Delhi may be a part of the global stratospheric easterlies in summer.

9.3 The easterly jet stream over the Peninsula is the effect of the southward decrease of temperature over the region in the entire troposphere. This thermal gradient is effective in reversing the moderately strong westerlies of the lower troposphere and building speeds of 80 kt by 100 mb. Basically this is the effect of the sun's position north of 20°N at this time of the year. The heating of the Tibetan plateau and transfer of heat to free atmosphere may have relatively minor influence as no strong temperature gradient develops in its vicinity to south until the 200 mb level or higher. At 150 and 100 mb strong decrease in temperature towards south is present even in January on account of the polar and tropical tropopauses.

9.4 The horizontal shear at 100 mb to the south of the jet between Madras and Trivandrum is 0.09 hr^{-1}. To the north, between Madras and Visakhapatnam it may be of the order 0.07^{-1} The Easterly Jet seems to have a very sharp vertical profile. The vertical shear between 9 and 16 km varies between 15 and 20 hr^{-1}, the maximum shear being about 5 km below the core. Above the core, between 16 and 18 km the shear is about 22 hr^{-1}.

9.5 As in the case of the westerly jet stream, temperature and wind data are too scanty to reliably picture the vertical circulation near the jet stream. The same is the case regarding diffluence and confluence in the jet stream. The direction of winds at 100 mb is within five degrees of 85° at places to the south of 23°N.

9.6 In June, Madras, Port Blair, Nagpur and Bombay show increase in the speed of the easterlies from 14 to 18 km. The maximum speed is likely near 18 km at about 15°N, though its merger in the stratospheric easterlies is not totally unlikely. Trivandrum shows maximum speed of 60 kt at 14 km, speed being higher than at Madras at this level. Ambala has fairly strong westerlies between 14 and 18 km. Between 25° and 30°N westerlies occur at some stations at 14 km and even at 16 km. Easterlies which commence at 18 km at Delhi are weak. The Easterly Jet in June is thus confined a little more to the south in India and is at a higher level in the Peninsula than in July. Speeds are less to the north of 15°N in June but more at some levels to the south.

9.7 Conditions in August are similar to July except that the speed increases upto 18 km over Madras and even upto 21 km at Nagpur. In September strong easterlies are confined to south of about 21°N, speeds are less and westerlies appear at levels like 14 km north of 25°N. At Madras a maximum speed of 50 kt is at 14 km and 16 km.

10. Meridional Circulation

10.1 Mean meridional components are usually weaker than the zonal winds and are not prominently seen on the mean wind charts. In view of their importance for exchange of heat, momentum etc. between different latitudes, meridional circulation over India is separately discussed.

10.2 Fig 10 presents a vertical cross-section of the mean meridional components for the mean Indian Longitude in January and July. In January, over India to the south of about 30°N, northerlies of the direct cell prevail from the surface upto 300 mb and southerlies aloft. Towards the Equator these meridional components are stronger, much to the south of the centre (12°N) of the direct cell as found on global scale. Two types of direct circulation have been recognised. Of these the type associated with the predominent easterly trades has a layer of southerlies at the middle level of the northerlies, the main layer of southerlies being much higher above. The Indian data in January also show either weak southerlies or weakening of northerlies at the middle of the layer of northerlies. Along 50°E, upper tropospheric southerlies are absent at Aden and Bahrein where northerlies reach upto the tropopause.

10.3 In July between 12°N and 26°N a simple circulation of southerlies below and northerlies aloft is found over the Indian region, which may be called the monsoon cell. The usual direct cell is very much shrunk in its latitudinal extent, between 26° and 40°N. But its presence at 30°N is clear from the northerlies in mid-troposphere and southerlies aloft, though weak southerlies of the monsoon cell extend so far in the lowest layers of the troposphere. In this month Aden and Bahrein exhibit both the lower northerlies and upper tropospheric southerlies of the direct cell. South of 10°N in the Indian area there is a deep layer of northerlies commencing almost from the surface, southerlies above and a marked layer of northerlies aloft.

11. Monsoon Effect

11.1 The reversal of winds from northeast in winter to southwest in summer, in the Arabian Sea, the Bay of Bengal and neighbourhood has come to be referred as the monsoon, derived from the Arabic word mausim". In January the winds in the seas around India are from northeast while in July they are from southwest to west. The northeasterly winds prevail from November to March and southwest or westerlies from May to September while in other months winds differ between the northern and southern parts. The period of northeasterly winds is generally dry except in the south Peninsula, compared with the copious rains over almost all parts of the country during the southwesterly wind regime. On account of the importance of the rains, in common parlance, monsoon has come to mean the southwest monsoon and only its rains and not the southwest winds which commence much earlier than the rains. In the Madras State where much of the rain is during the period of the northeasterly wind regime, the northeast monsoon has come to mean the rainy season.

11.2 The winds of the northeast monsoon are not basically different from the northeast trades. The southwesterlies of summer are however a unique feature of the Indian area in their strength and latitudinal and vertical extent. Summer southwesterlies elsewhere (or northwesterlies in the southern hemisphere) are of limited extent and weaker. In the period July to September the meridional temperature gradient is also reversed in the lower troposphere from that in winter. Temperature increases to north in the former period while it decreases in the latter.

* * * * * * * *

REFERENCES

1. Ananthakrishnan, R. 1965: 'General circulation of the atmosphere over the Indian Ocean and adjoining areas'. Proceed. Sympos. met. results of IIOE, pp.105-114.

2. Ananthakrishnan, R. and Ramakrishnan, A.R. 1964: 'Vertical variation of the constancy of upper winds over India'. Ind. Jour. Met. and Geophys. Vol. XV pp.359-368.

3. Ananthakrishnan, R., Srinivasan, V. and Ramakrishnan, A.R. 1968: 'Climatology of India and neighbourhood', Forecasting Manual, Part I - 1.

4. Balakrishnan, T.A.S. F/Lt. 1950: 'An elementary note on Indian Climate'. Ind. Met. Dept. Tech. notes No. 28.

5. Banerjee, A.K. and Sharma, K.K. 1966: 'Seasonal oscillation of daily mean maximum temperature in India and neighbourhood'. IJMG Vol.XVII, pp.443-450.

6. Banerjee, A.K. and Sharma, K.K. 1967: 'A study of the seasonal oscillations in the upper air temperatures over India'. IJMG Vol.XVIII pp. 69-74.

7. Bartholomew, J.G. and Herbertson, A.J. 1899: 'Atlas of Meteorology'.

8. Bedi, H.S. and Parthasarathy, B. 1967: 'Cold waves over northwest India and neighbourhood'. IJMG Vol. XVIII pp. 371-378.

9. Bunker, Andrew, F. 1965: 'Interaction of the summer monsoon air with the Arabian Sea'. Proceed. Sympos. met. results of IIOE, pp.3-16.

10. Desai, B.N. 1967: 'Circulation over India and neighbourhood during the Southwest monsoon season'; IJMG Vol. XVIII, pp.459-464.

11. Dhar, O.N. and Narayanan, J. 1965: 'A study of precipitation distribution in the neighbourhood of Mount Everest'. IJMG Vol.XVI pp.229-240.

12. Doraiswamy Iyer, V. 1958: 'High maximum temperatures on the north Konkan Coast', IJMG Vol. IX pp.259-266.

13. Flohn, H. 1954: 'Scientific Proceedings of the International Association of Met. Rome', pp.431-441.

14. Flohn, H. 1958: 'Monsoon winds and General circulation', Symposium on Monsoons of the World, pp.65-74.

15. Flohn, H. 1958: 'Recent investigations on the mechanism of the "Summer Monsoons" of Southern and Eastern Asia', Symposium on Monsoons of the World, pp.75-88.

16. Goldie, N., Moore, J.G. and Austin, E.E. 1958: 'Upper air temperatures over the world', Geophys. Memo (London) No. 101.

17. Gupta, R.G. 1966: 'A study of winds upto 32 km over Hyderabad Deccan'. IJMG Vol. XVII pp.199-206.

18. Heastie, H. and Stephenson, P.M. 1960: 'Upper winds over the world' Parts I and II, Geophys. Mem. (Lon) No. 103.

19. India Meteorological Department. 1945: 'Climatic charts of the Indian monsoon area'.

20. India Meteorological Department. 1943: 'Climatic charts of India and neighbourhood for Meteorologists and Airmen'.

21. Jagannathan, P. 1957: 'Seasonal oscillation of air temperatures in India and neighbourhood'. IJMG Vol. VIII pp.155-168.

22. Jagannathan, P. and Khambete, N.M. 1963: 'Seasonal oscillation of the diurnal range of temperature in India and neighbourhood'. IJMG Vol. XIV pp.389-402.

23. Joseph, P.V. and Raman, P.L. 1966: 'Existence of low-level westerly jet stream over peninsular India during July', IJMG Vol.XVII pp.407-410.

24. Koteswaram, P. 1958: 'The easterly jet stream in the tropics'. Tellus, Vol.X pp.43-57.

25. Koteswaram, P. 1958: 'The Asian Summer Monsoon and the General circulation over the tropics'. Symposium on Monsoons of the World, pp.105-110.

26. Koteswaram, P. and Chakravarthy, K.C. 1950: 'Distribution of temperature lapse rates in the upper air over India during different months'. IJMG Vol.I, pp.167-170.

27. Koteswaram, P. and Parthasarathy, S. 1954: 'The mean jet stream over India in the pre-monsoon seasons and vertical motions associated with sub-tropical jet streams'. IJMG Vol.V pp.138-156.

28. Koteswaram, P., Raman, C.R.V. and Parthasarathy, S. 1953: 'The mean jet stream over India and Burma in winter', IJMG Vol.IV, pp.111-122.

29. Krishna Rao, P.R. 1952: 'Some high sounding balloon ascents and upper air temperatures upto 35 km over India', IJMG Vol.III pp.173-185.

30. Krishna Rao, P.R. 1930: 'Distribution of temperature in the lower stratosphere', India Met. Deptt. Scientific Notes, Vol. I No. 10.

31. Krishna Rao, P.R. and Ganesan, V. 1953: 'Characteristics of the upper troposphere, tropopause and lower stratosphere over Trivandrum'. IJMG Vol. IV pp.193-204.

32. Krishna Rao, P.R. 1952: 'The probable regions of 'jet' streams in the upper air over India', Current Science, Vol.XXI, pp.63-64.

33. Mooley, D.A. 1956: 'Zonal wind circulation and vertical temperature distribution along the Indian longitudes during the monsoon and winter seasons', IJMG Vol.VII, pp.113-128.

34. Malurkar, S.L. 1945: 'Quasi-stationary low pressure areas in and near India', India Met. Deptt. Tech. Notes No. 20.

35. Mukherjee, A.K. and Ghosh, S.K. 1965: 'Orographical influence on the air flow over Brahmaputra valley'. IJMG Vol.XVI pp.203-336.

36. Parthasarathy, S. and Narayanan, J. 1953: 'The diurnal variation of upper winds over the Indian sub-continent', IJMG Vol.IV, pp.205-219.

37. Pisharoty, P.R. and Asnani, G.C. 1958: 'Flow patterns over India and neighbourhood at 500 mb during the monsoon', Symposium on Monsoons of the World, pp.112-117.

38. Raghavan, K. 1966: 'A climatological study of severe heat waves in India', IJMG Vol.XVII pp.581-586.

39. Raghavan, K. 1967: 'A climatological study of severe cold waves in India', IJMG Vol.XVIII pp.91-96.

40. Ramachandran, G. 1967: 'Rainfall distribution in relation to latitude, longitude and elevation', IJMG Vol.XVIII pp.227-232.

41. Ramakrishnan, K.P., Sreenivasaiah. B.N. and Venkiteswaran, S.P. 1958: 'Upper Air Climatology of India and neighbourhood in the monsoon seasons', Symposium on Monsoons of the World, pp.3-34.

42. Ramamurti, K.S. Unpublished - "Reduction of temperature to standard level".

43. Raman, C.R.V. 1965: 'Cyclonec vortices on either side of the Equator and their implication'. Proceed. Sympos. Met. results of IIOE, pp.155-163.

44. Raman, C.R.V. and Dixit, C.M. 1964: 'Analysis of mean monthly resultant winds for standard pressure levels over the Indian Ocean and adjoining continental areas'. .. India Met. Deptt., IMC Bombay.

45. Ramanathan, K.R. 1931: 'The structure of sea breeze at Poona', India Met. Deptt. Scientific Notes Vol.III No. 30.

46. Ramanathan, K.R. 1958: 'Monsoons and the general circulation of the atmosphere - A review', Symposium on Monsoons of the World, pp.53-64.

47. Ramanathan, K.R. and Ramakrishnan, K.P. 1933: 'The Indian southwest monsoon and structure of depressions associated with it'. India Met. Deptt. Mem., Vol. XXVI, pPart II.

48. Ramanathan, K.R. and Ramakrishnan, K.P. 1938: 'The general circulation of the atmosphere over India and its neighbourhood'. India Met. Deptt. Memo., XXVI, Part X.

49. Rangarajan, S. and Srivastava, G.P. 1965: 'Temperature and humidity distribution in the atmosphere over the Indian seas', Proceed. Sympos. Met. results of IIOE, pp.17-26.

50. Rao, Y.P. 1962: 'Meridional circulation associated with the monsoons of India'. IJMG Vol.XIII pp.157-166.

51. Rao, Y.P. and Raghavendra, V.K. 1967: 'Variation of pressure, wind, cloudiness and rainfall across the Equator in the Indian Ocean' (to be published in the proceedings of the Symposium on Indian Ocean).

52. Roy, A.K. and Mahalingam, L.S. 1942: 'Inversion and isothermal layers in the free atmosphere over south India'. India Met.Deptt.Sc.Notes,Vol.X No.117.

53. Sastry, P.S.N. and Narasimhan, A.L. 1966: 'Some characteristics of tropopause over India'. IJMG Vol.XVII pp.567-572.

54. Seshadri, N. 1966: 'Radar upper wind measurements at New Delhi using Decca wind finding radar-Type W F 2'. IJMG Vol.XVII, pp.225-232.

55. Sharma, K.K. 1966: 'A study of annual oscillations of the tropopause over India'. IJMG Vol.XVII, pp.479-480.

56. Thiruvengadathan, A. and Ananthakrishnan. R. 1965: 'Vertical structure of the high level easterlies over Trivandrum and Minicoy during the southwest monsoon season'. IJMG Vol.XVI pp.137-140.

57. Venkiteswaran, S.P. 1950: 'The upper winds at 10 km and above over India and its neighbourhood'. India Met. Deptt. Mem., Vol.XXVIII, Part II.

58. ....1949: 'Monthly Meteorological charts of the Indian Ocean'London: H.M.S.O.

59. .... - 'Indian Ocean' Koninklijk Nederlands Meteorologisch Institut.

DIAGRAMS

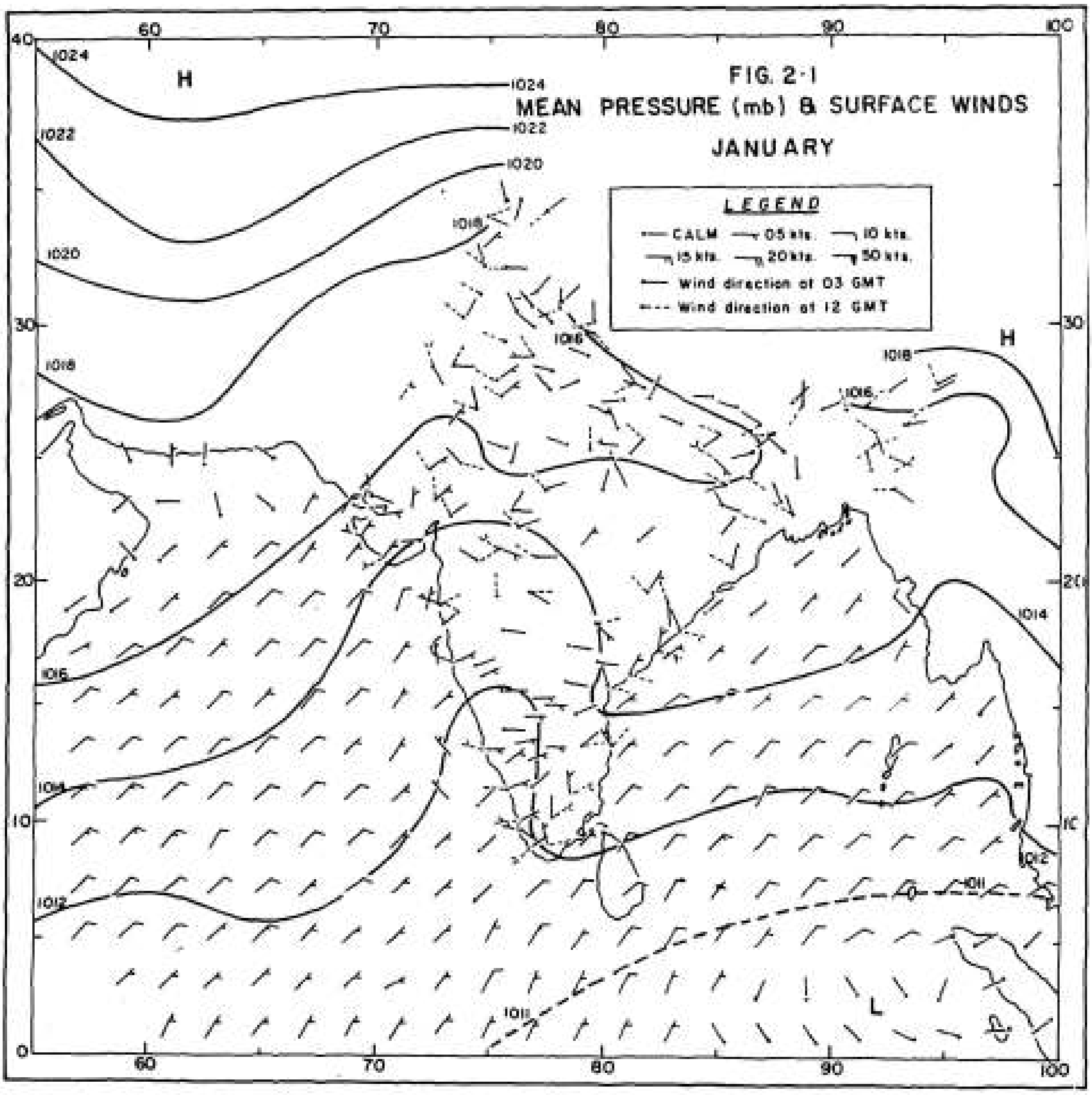


FIG. 2-1
MEAN PRESSURE (mb) & SURFACE WINDS
JANUARY

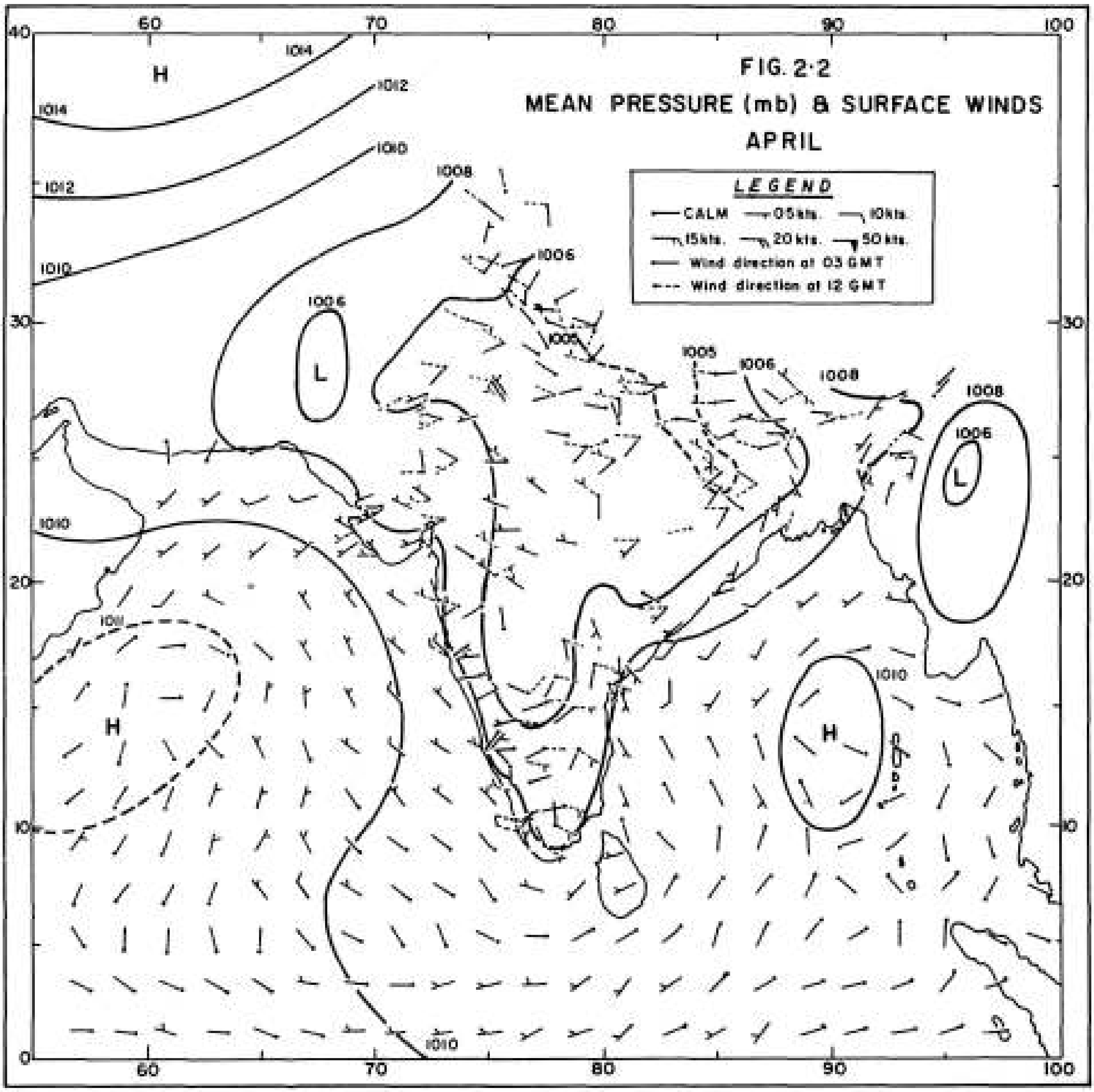


FIG. 2·2
MEAN PRESSURE (mb) & SURFACE WINDS
APRIL

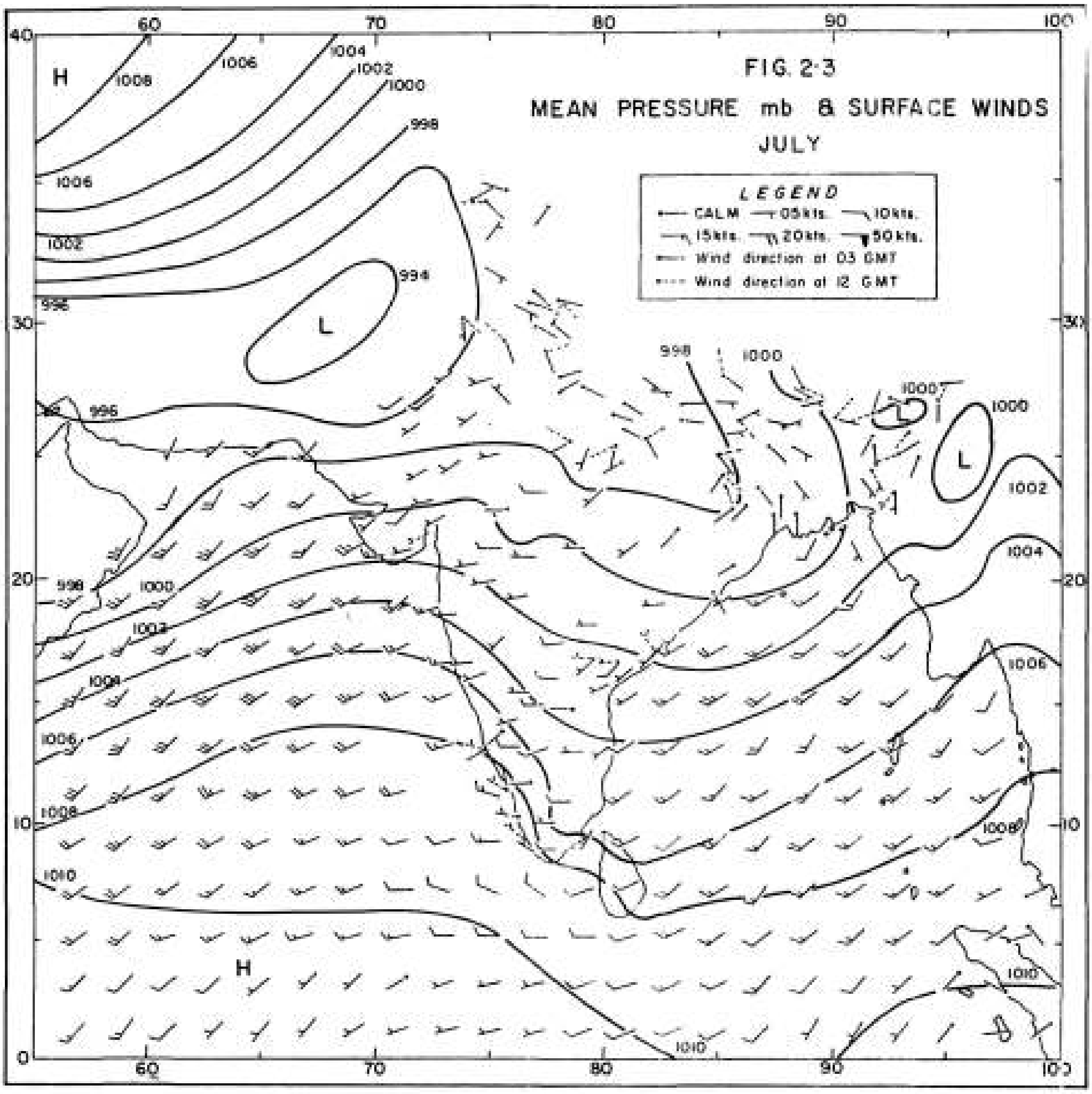


FIG. 2-3
MEAN PRESSURE mb & SURFACE WINDS
JULY

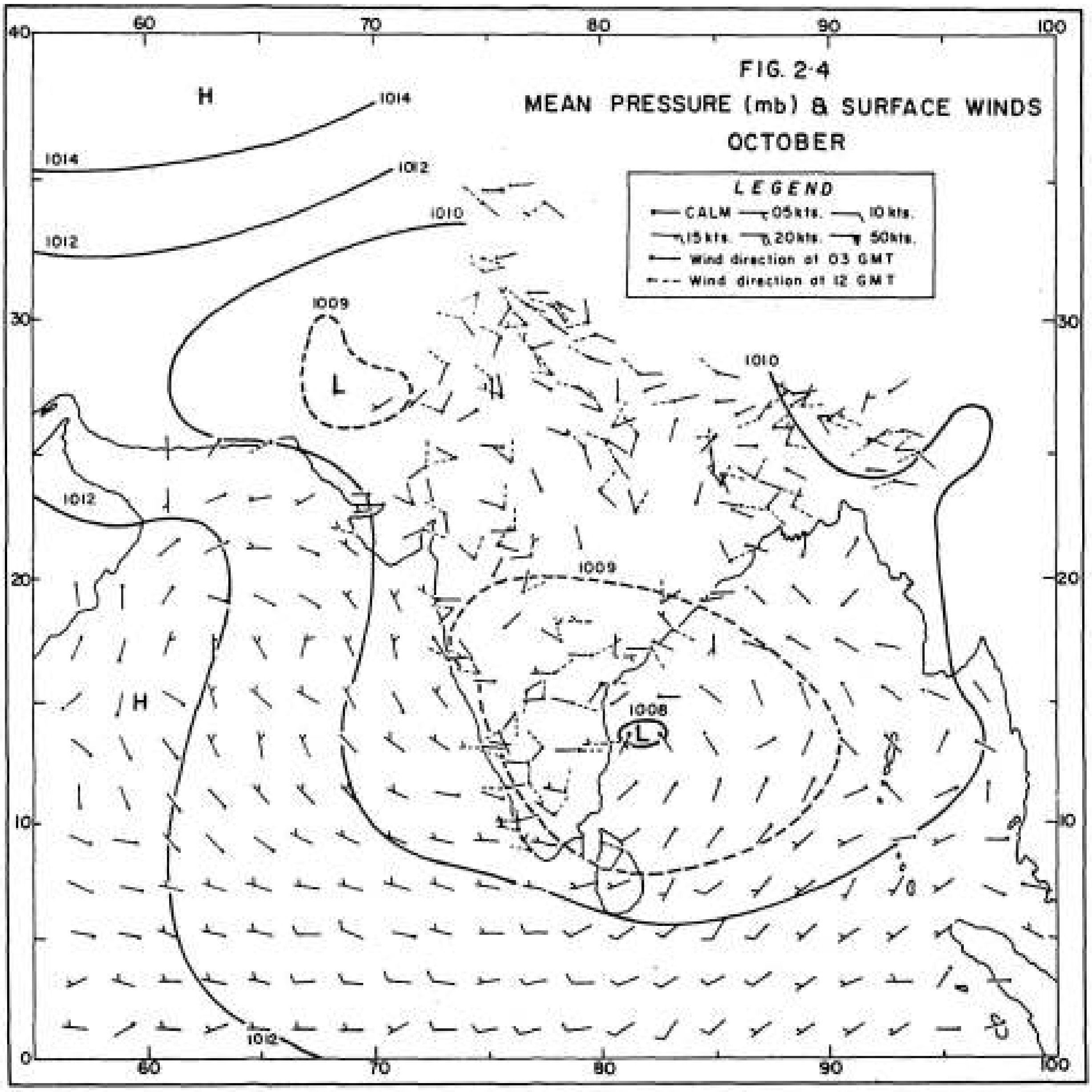


FIG. 2·4
MEAN PRESSURE (mb) & SURFACE WINDS
OCTOBER

FIG. 4·1 MEAN DAILY TEMPERATURE IN °C
(Reduced to sea level at adhoc lapse rate of 6°c/km)

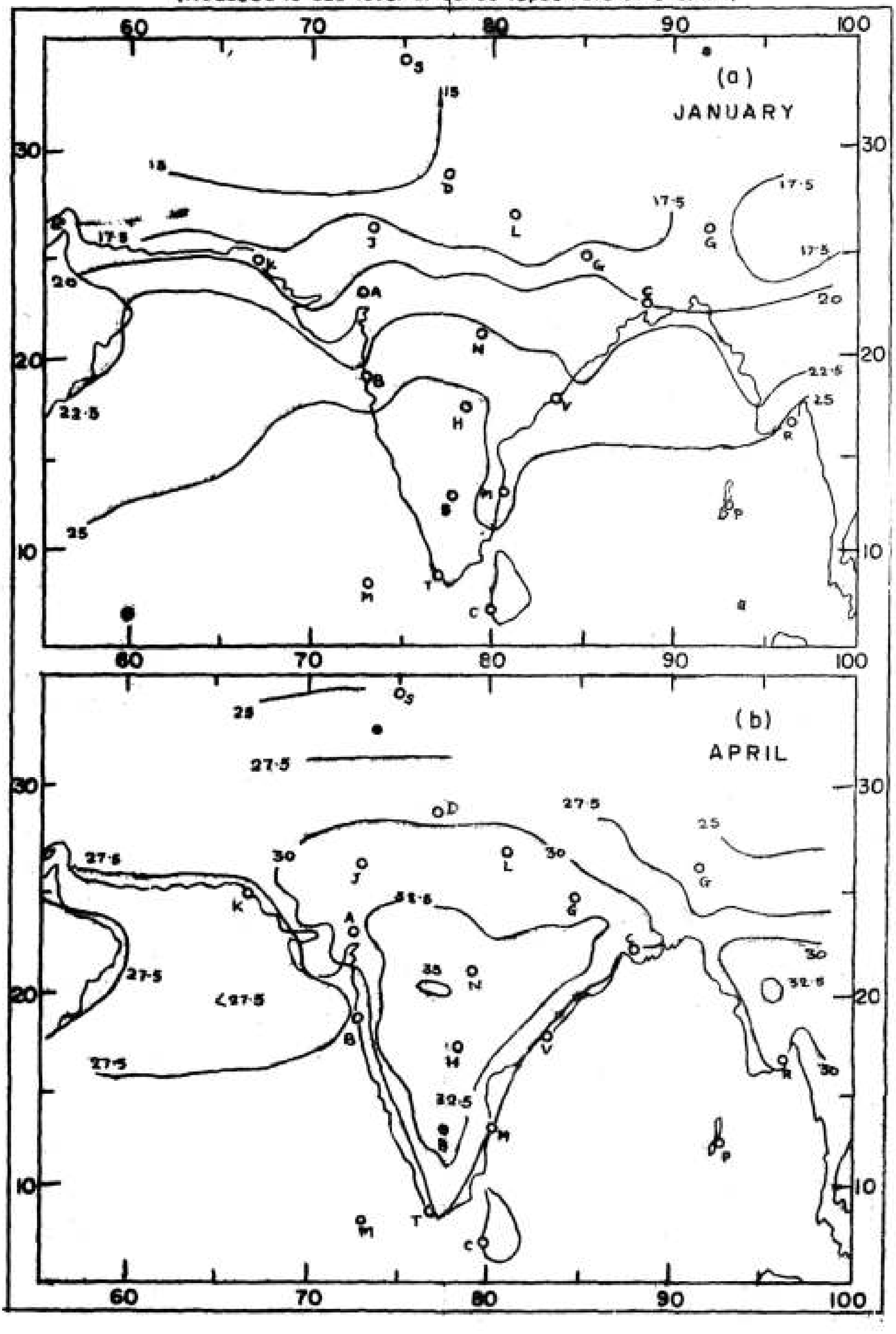


FIG. 4·1 MEAN DAILY TEMPERATURE IN °C
(Reduced to sea level at adhoc lapse rate of 6°c / km)

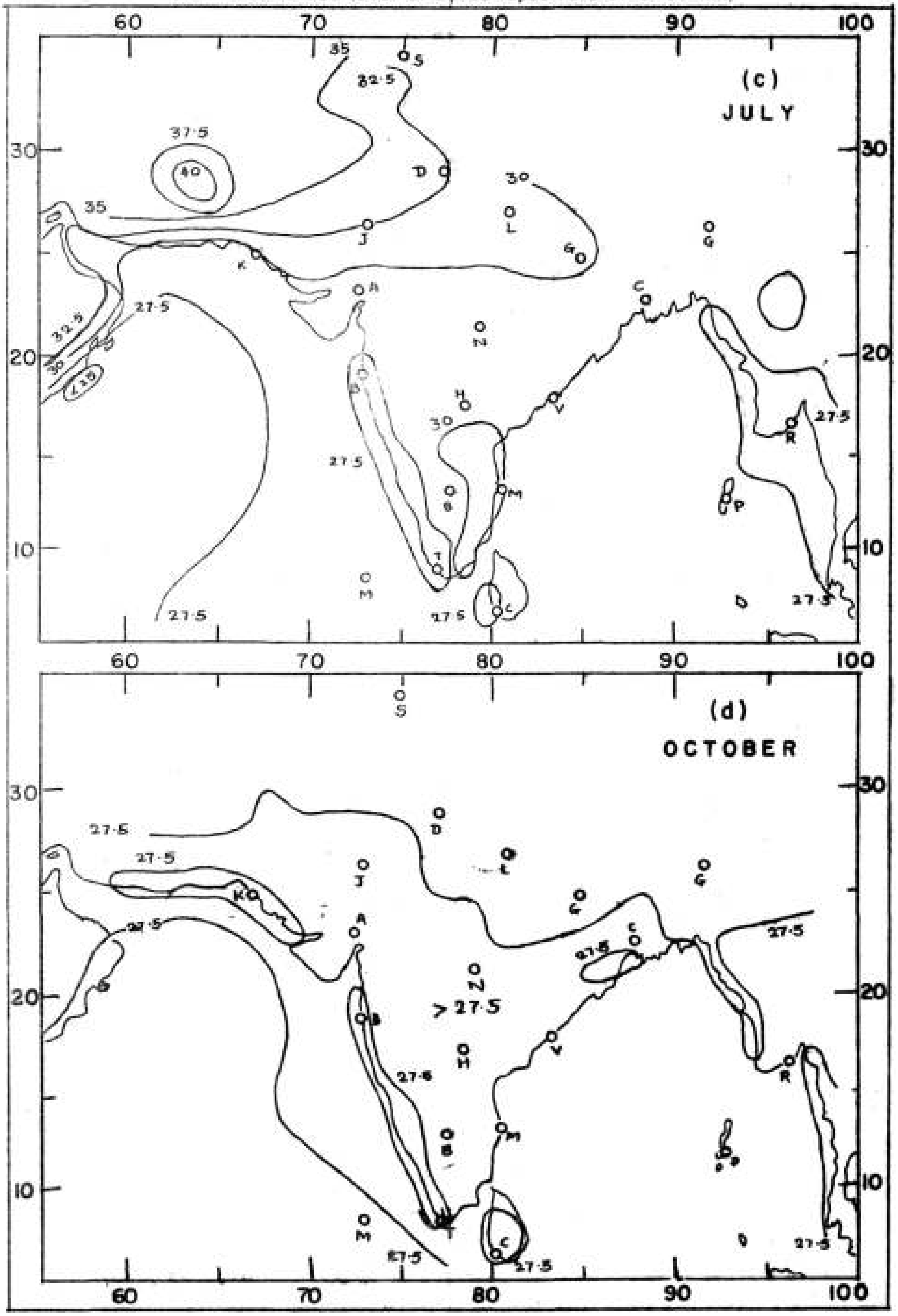


FIG.4·2 MEAN MAXIMUM TEMPERATURE IN °C

(Reduced to sea level at adhoc lapse rate of 6°c/km)

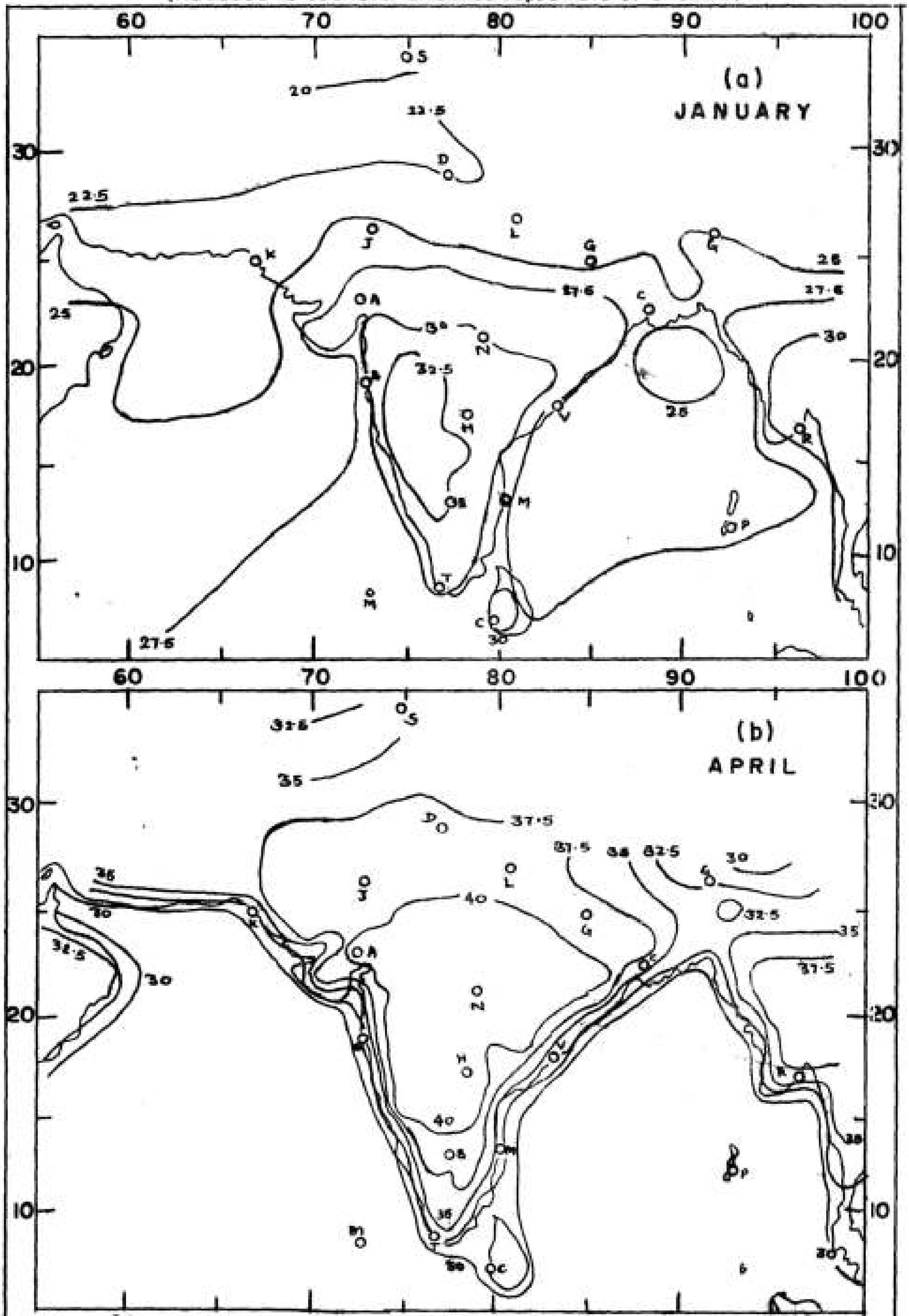


FIG.4·2 MEAN MAXIMUM TEMPERATURE IN °C

(Reduced to sea level at adhoc lapse rate of 6°c/km)

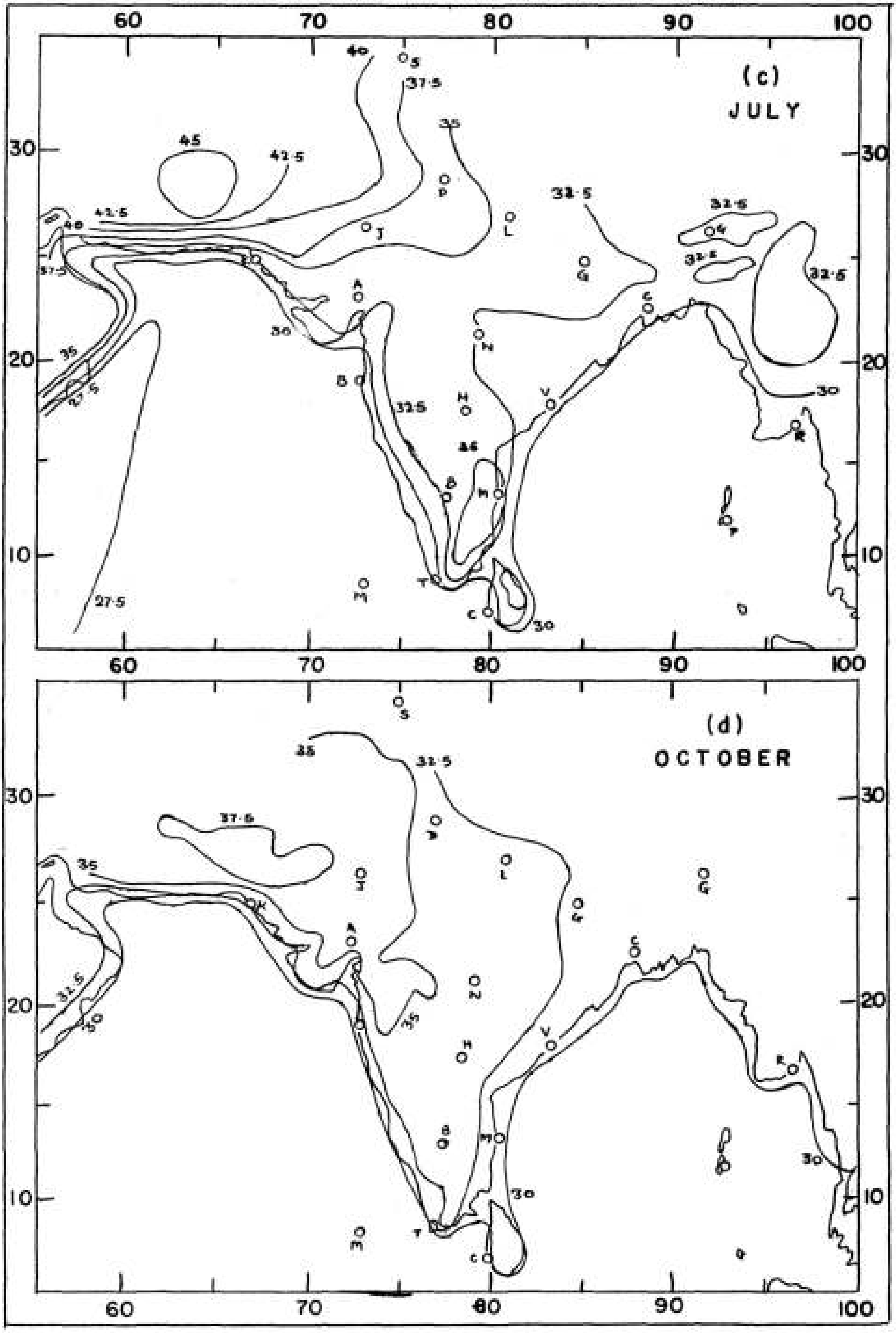


FIG. 4-3 MEAN MINIMUM TEMPERATURE IN °C

(Reduced to sea level at adhoc lapse rate of 6°c/km)

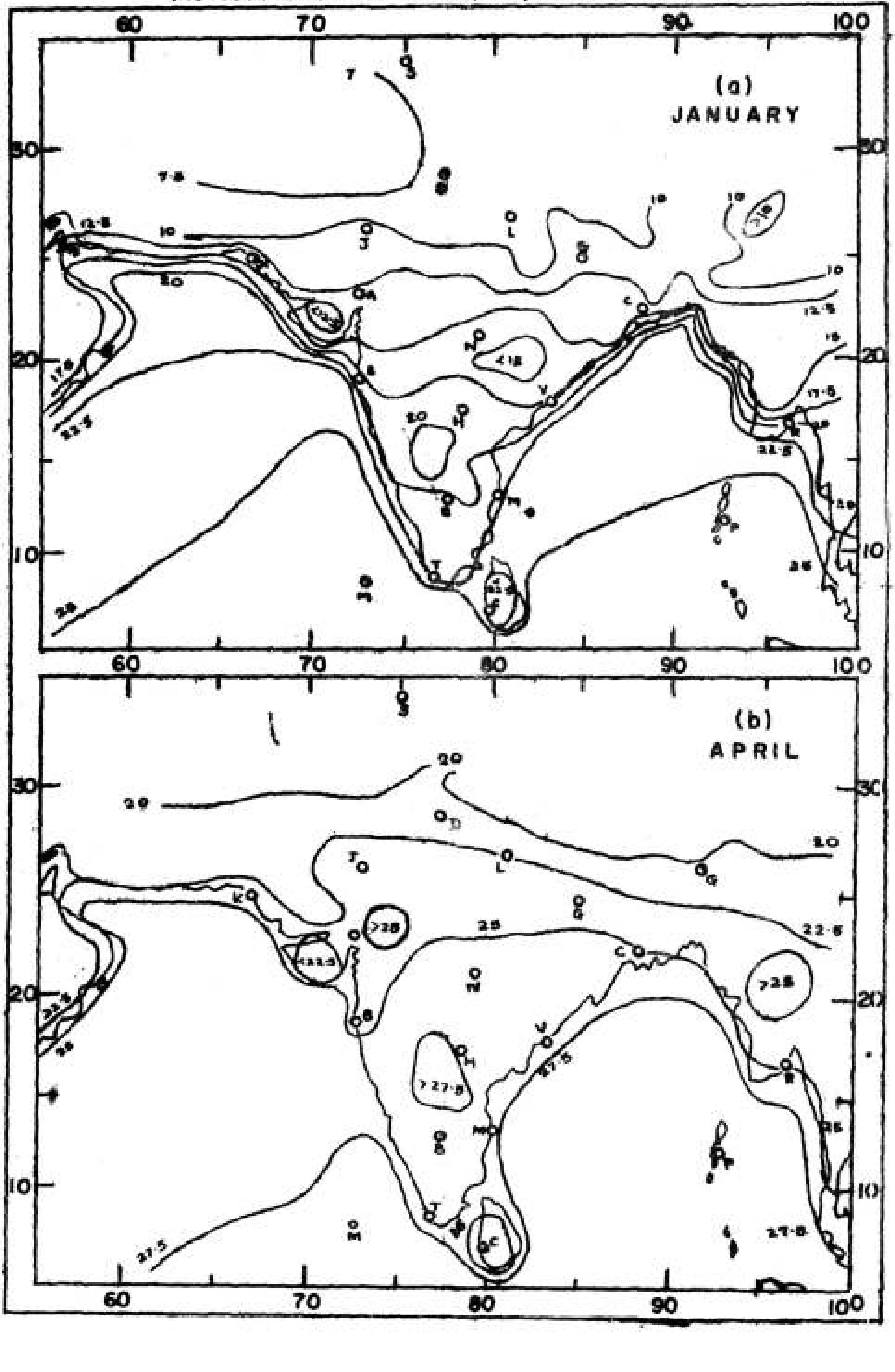
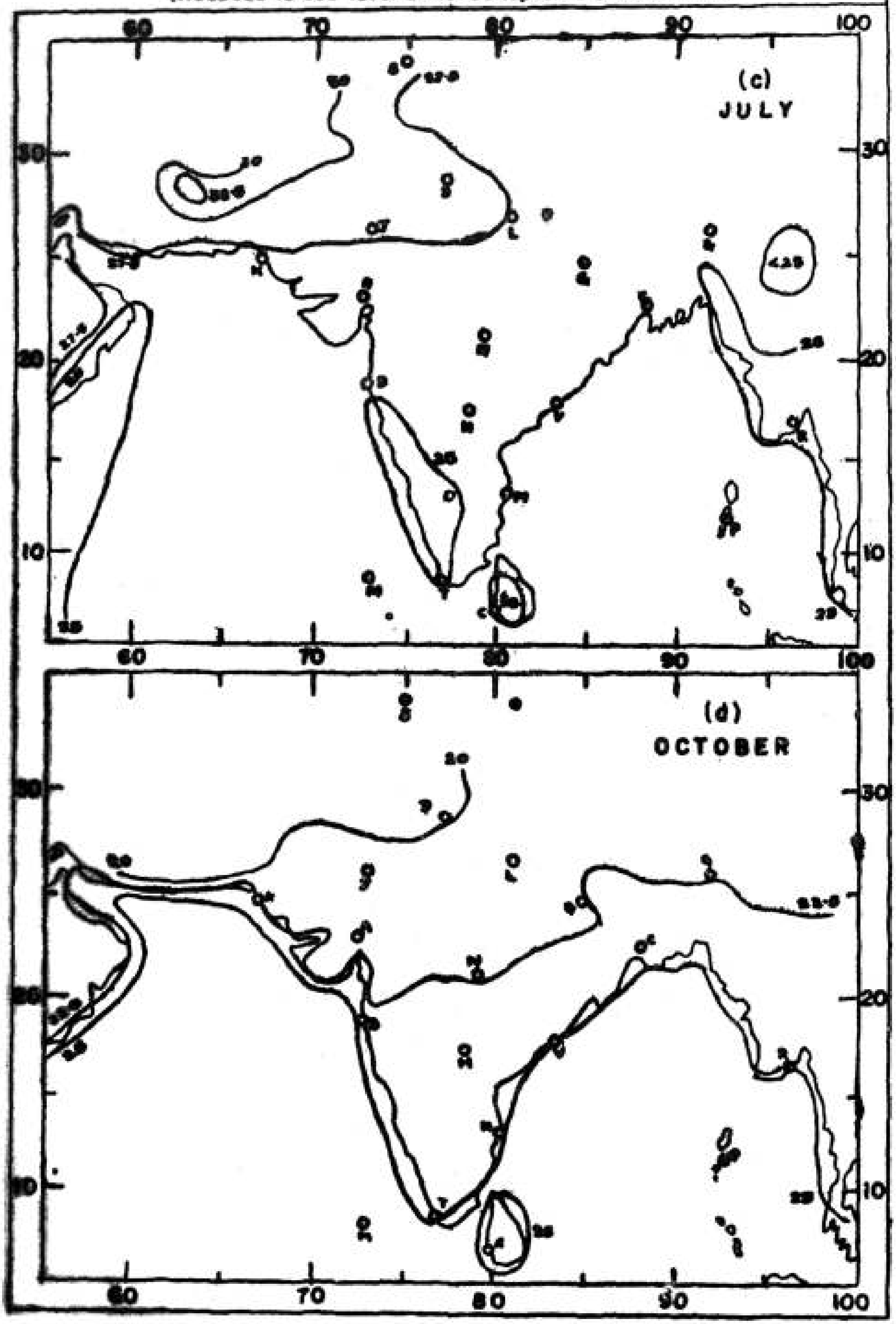
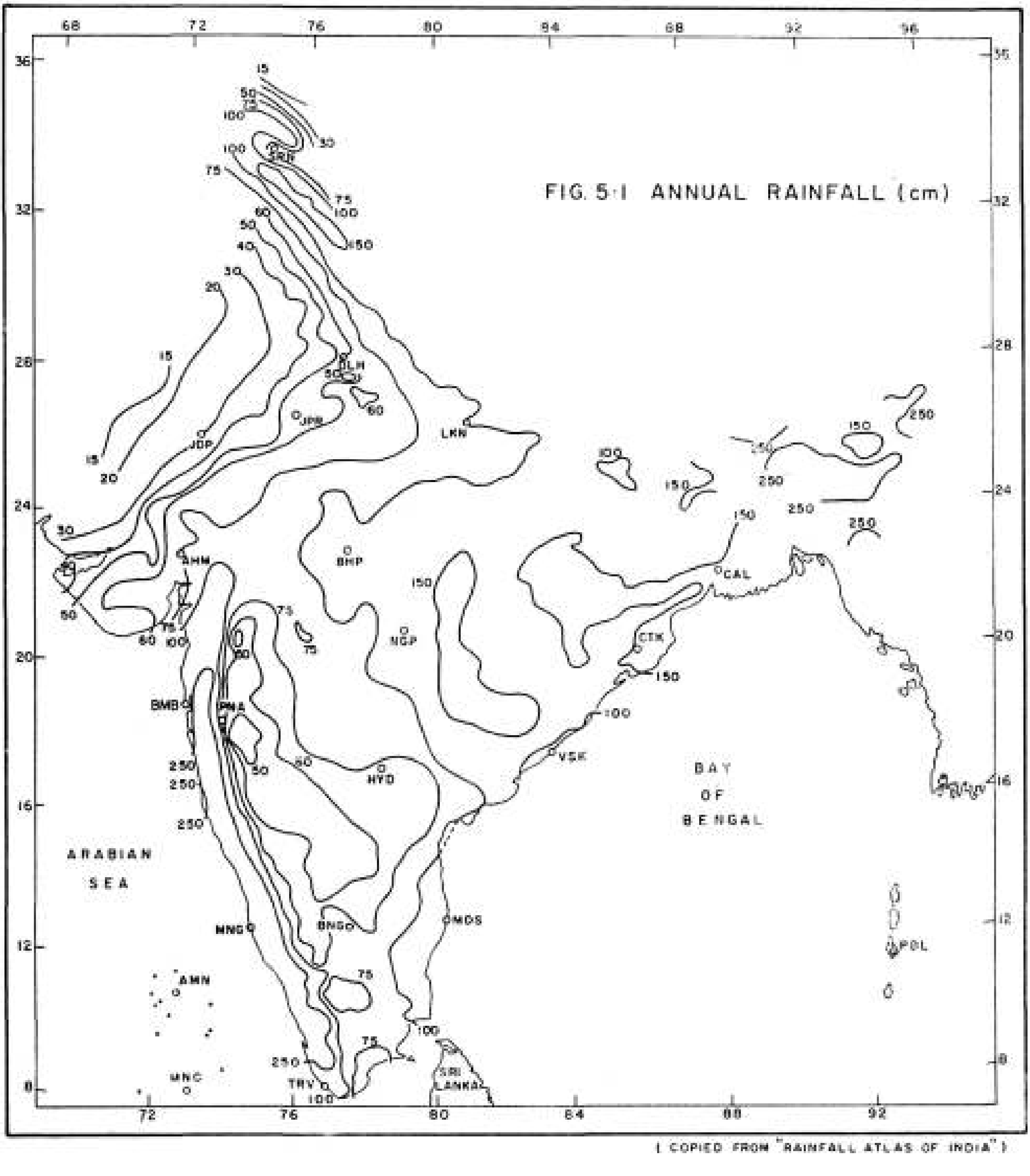


FIG. 4.3 MEAN MINIMUM TEMPERATURE IN °C
(Reduced to sea level at adhoc lapse rate of 6° c/km)





(COPIED FROM "RAINFALL ATLAS OF INDIA")

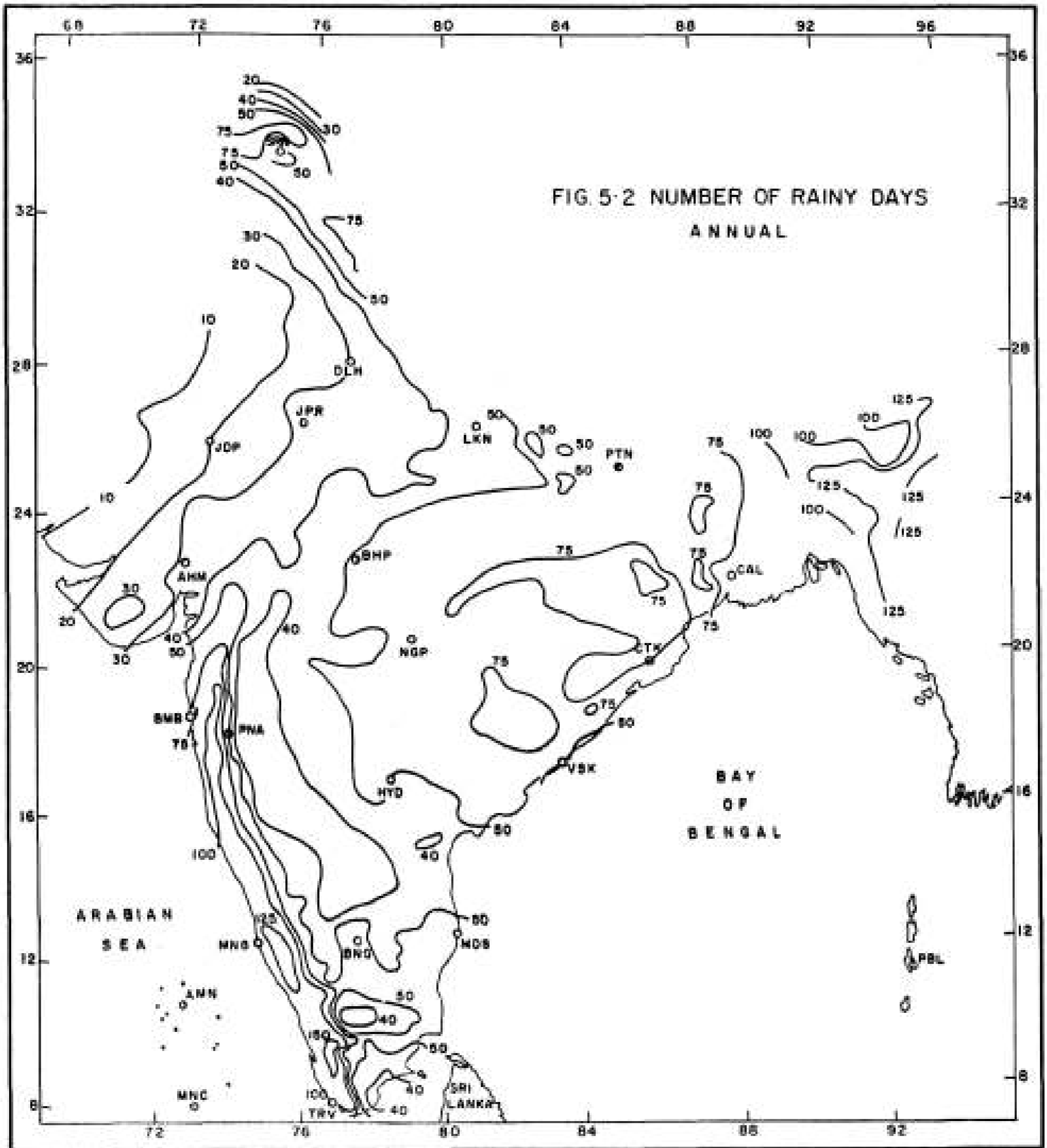
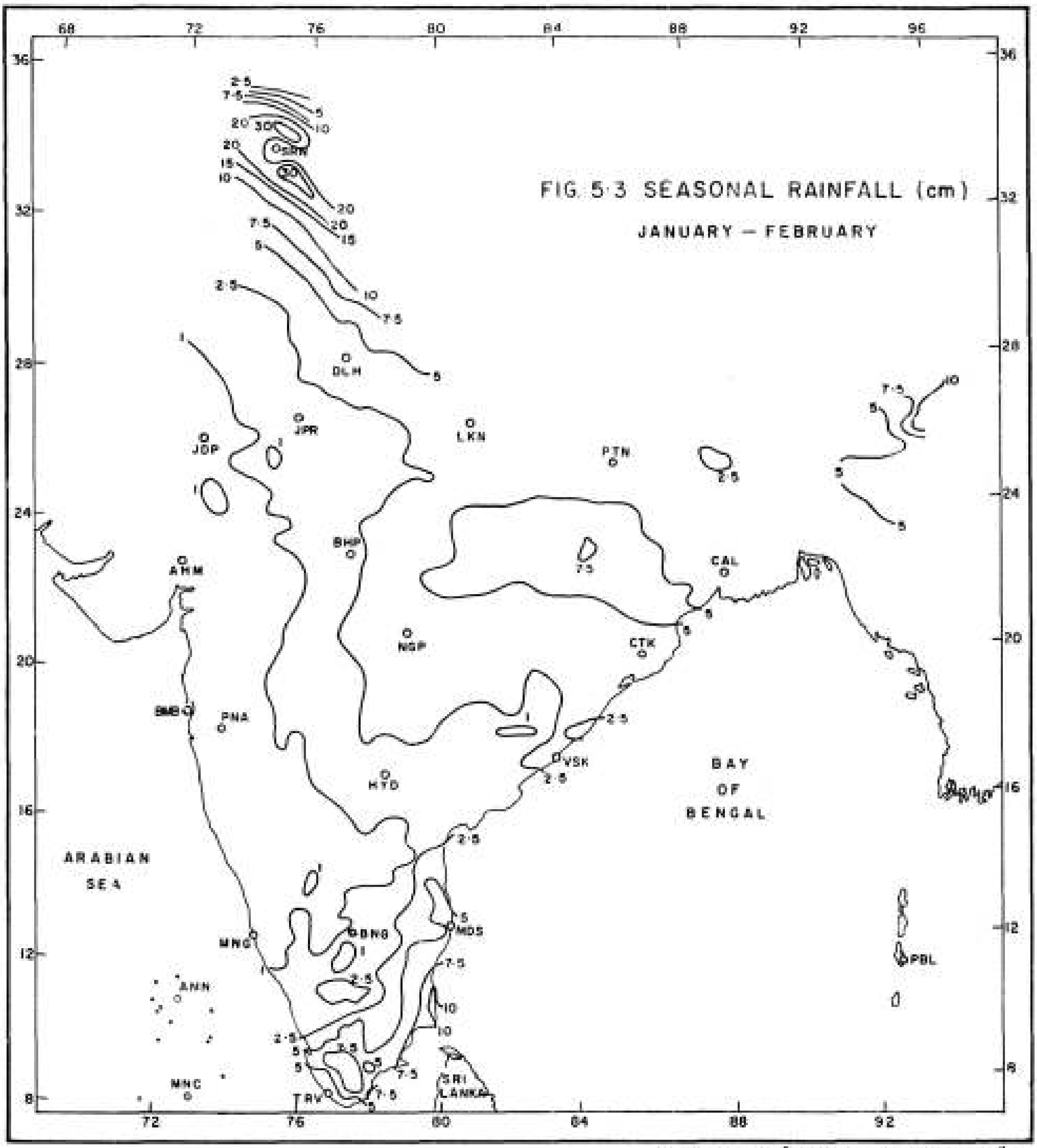


FIG. 5·2 NUMBER OF RAINY DAYS
ANNUAL

(COPIED FROM "RAINFALL ATLAS OF INDIA")



(COPIED FROM "RAINFALL ATLAS OF INDIA")

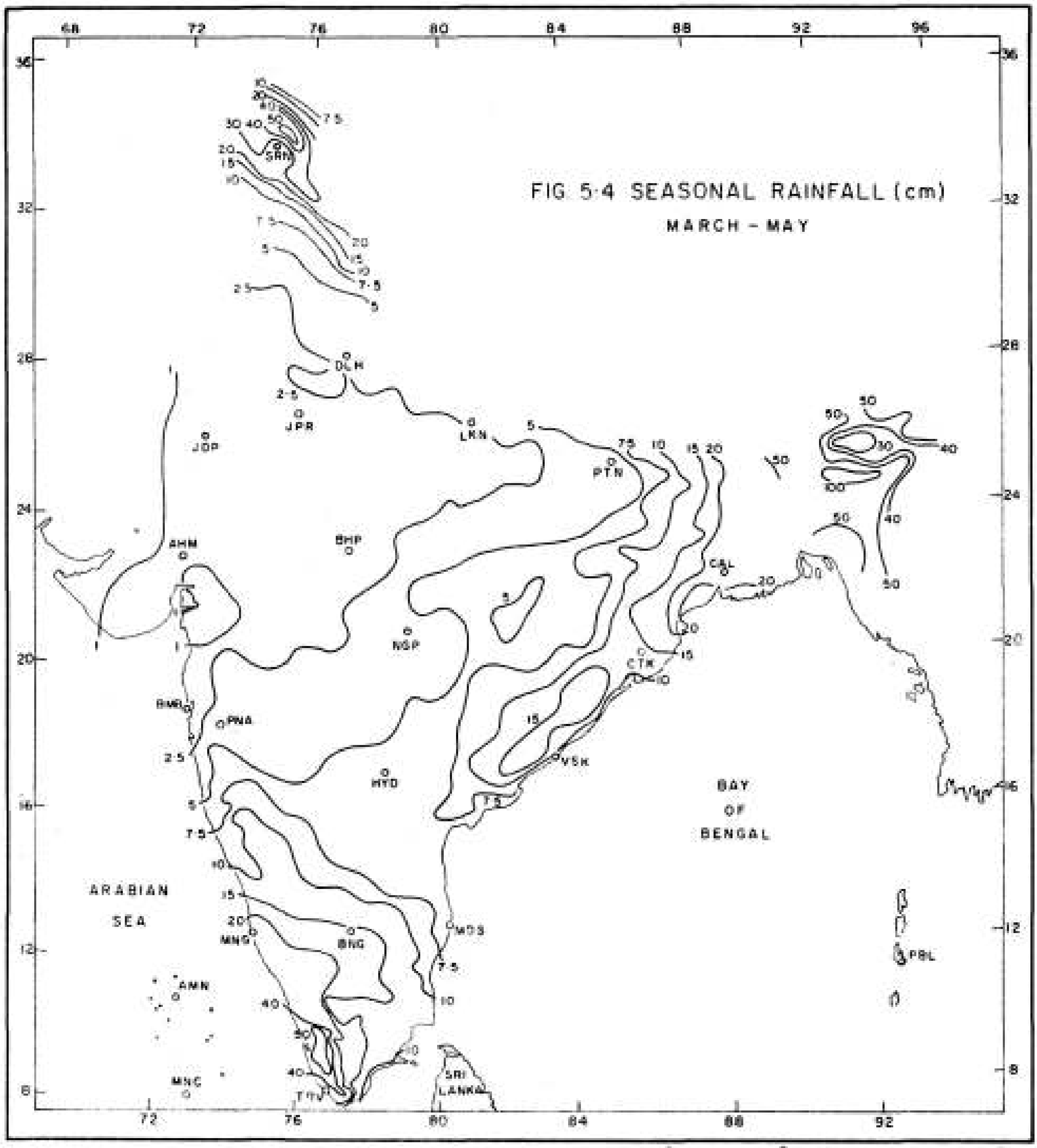
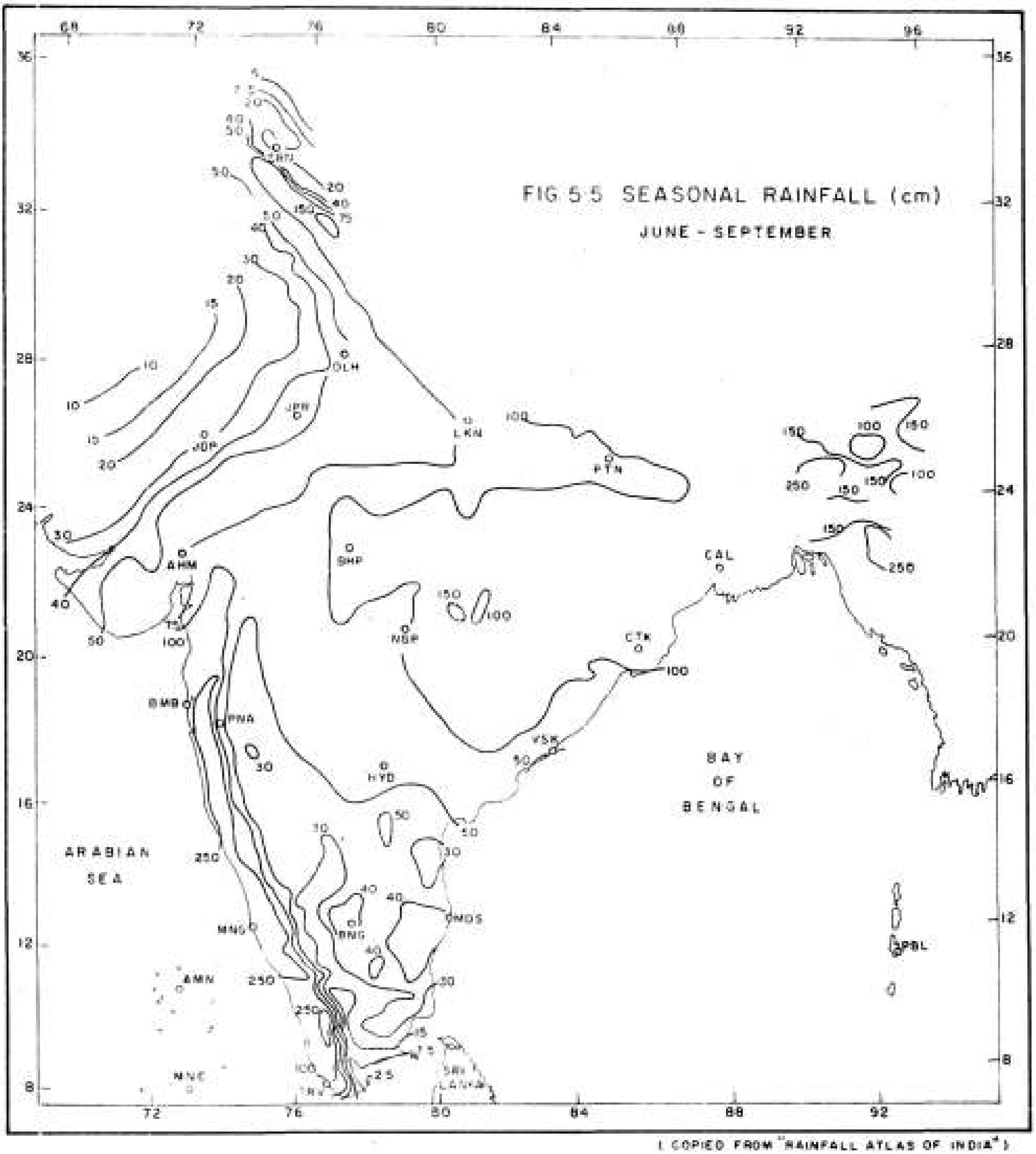
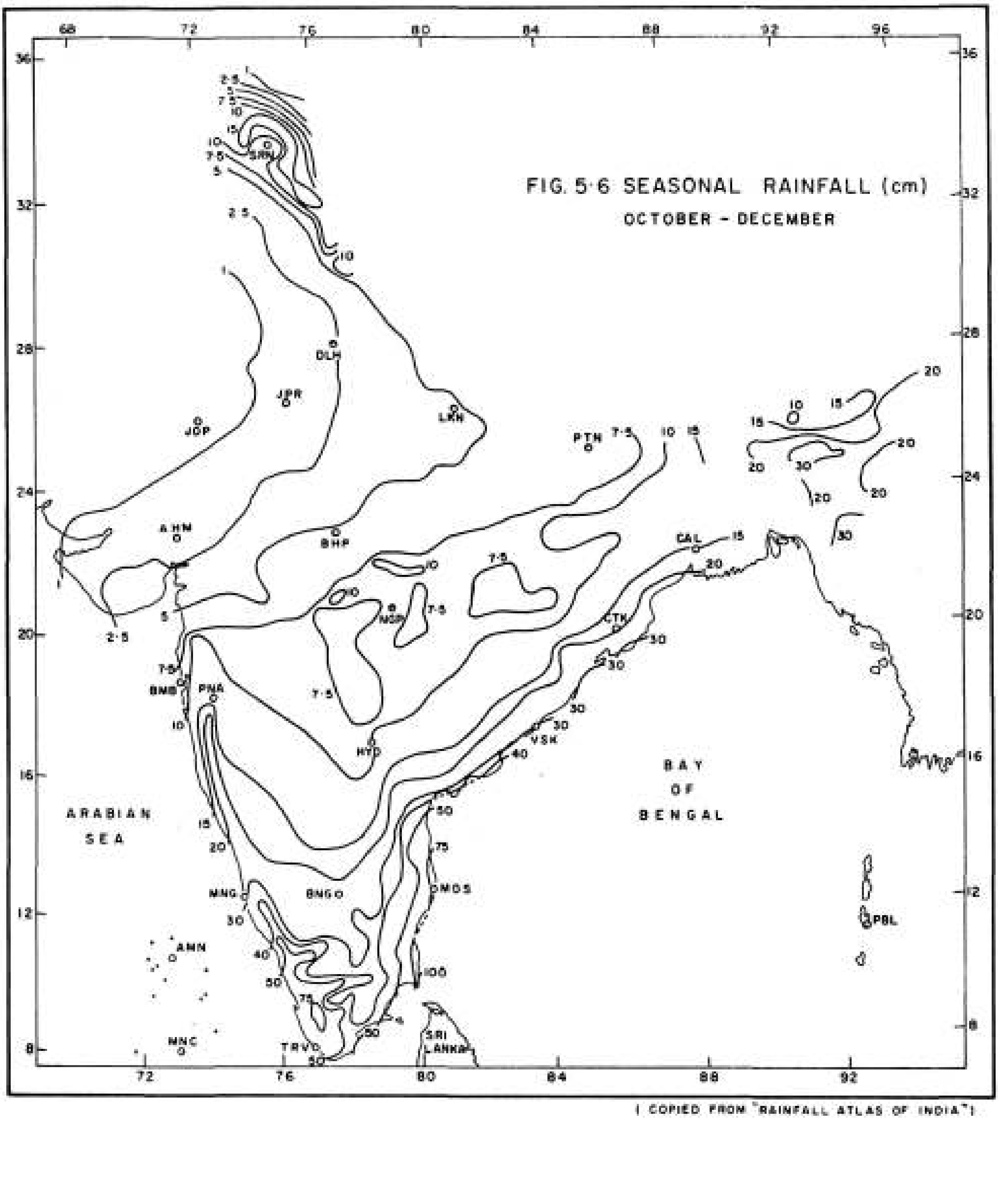


FIG 5·4 SEASONAL RAINFALL (cm)
MARCH – MAY

("COPIED FROM "RAINFALL ATLAS OF INDIA")



(COPIED FROM "RAINFALL ATLAS OF INDIA")



(COPIED FROM "RAINFALL ATLAS OF INDIA")

FIG. 6·1 UPPER AIR ISOTHERMS (°C) : JANUARY

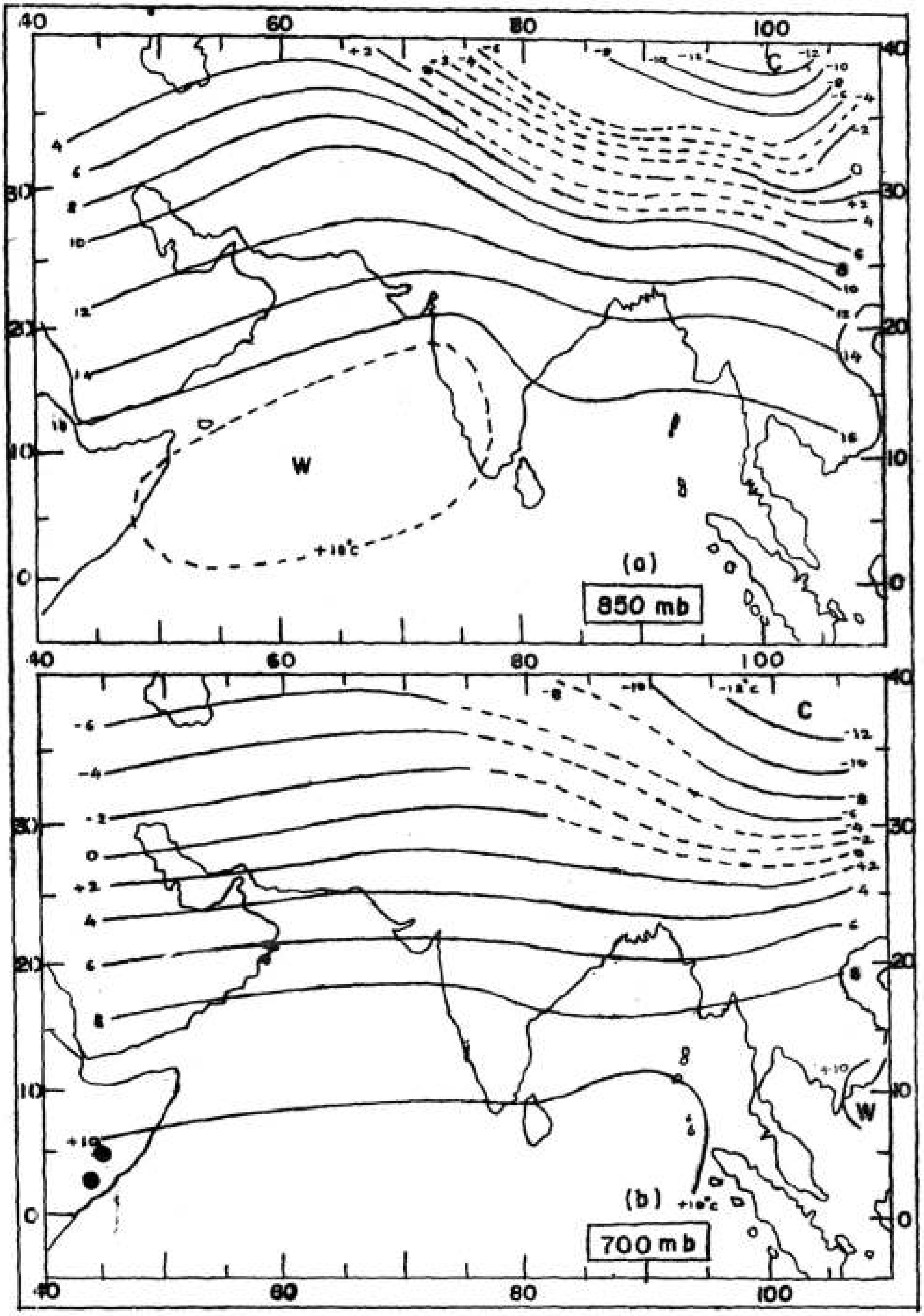


FIG. 6·1 UPPER AIR ISOTHERMS (°C) : JANUARY

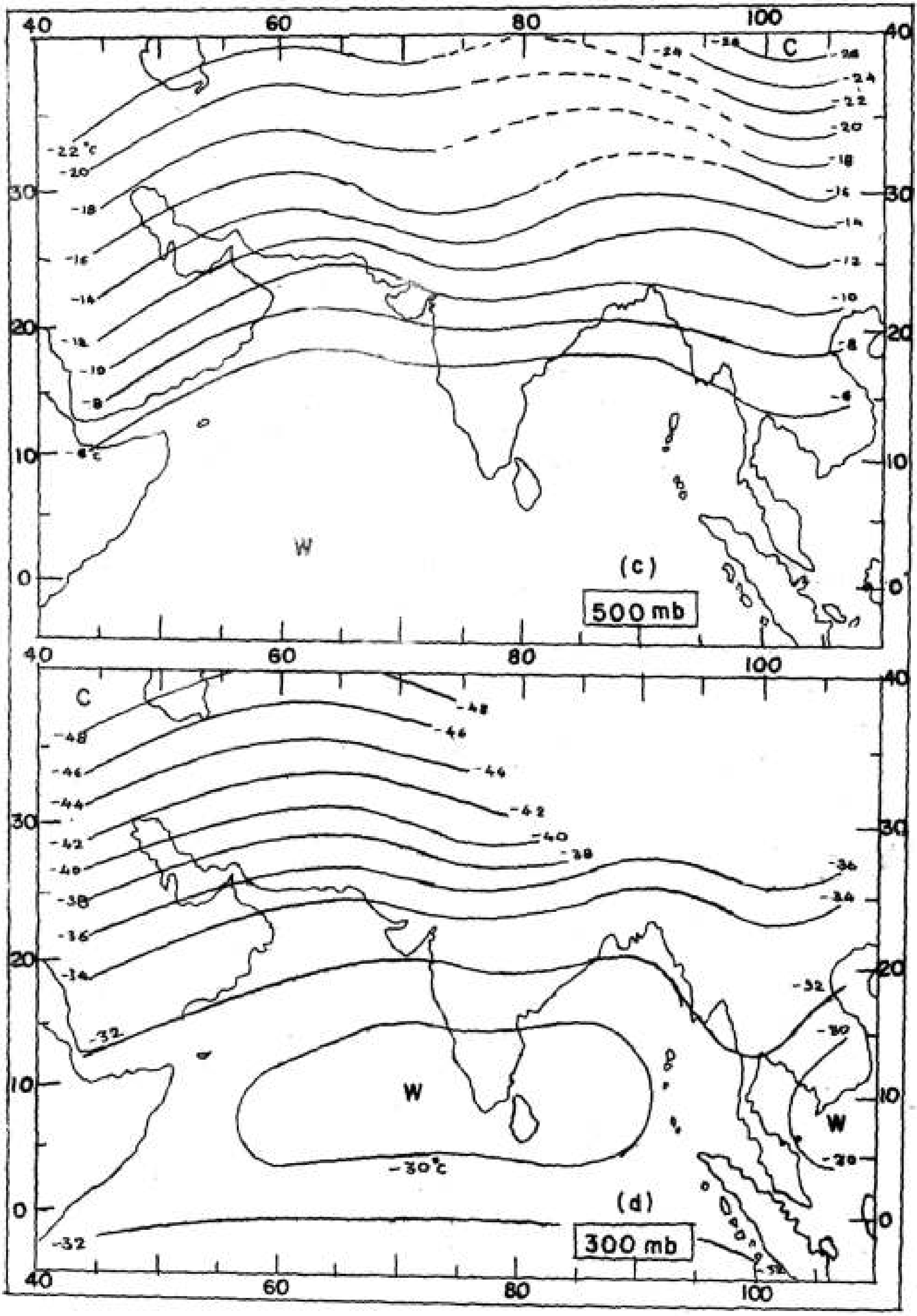


FIG. 6·2 UPPER AIR ISOTHERMS (°C) : APRIL

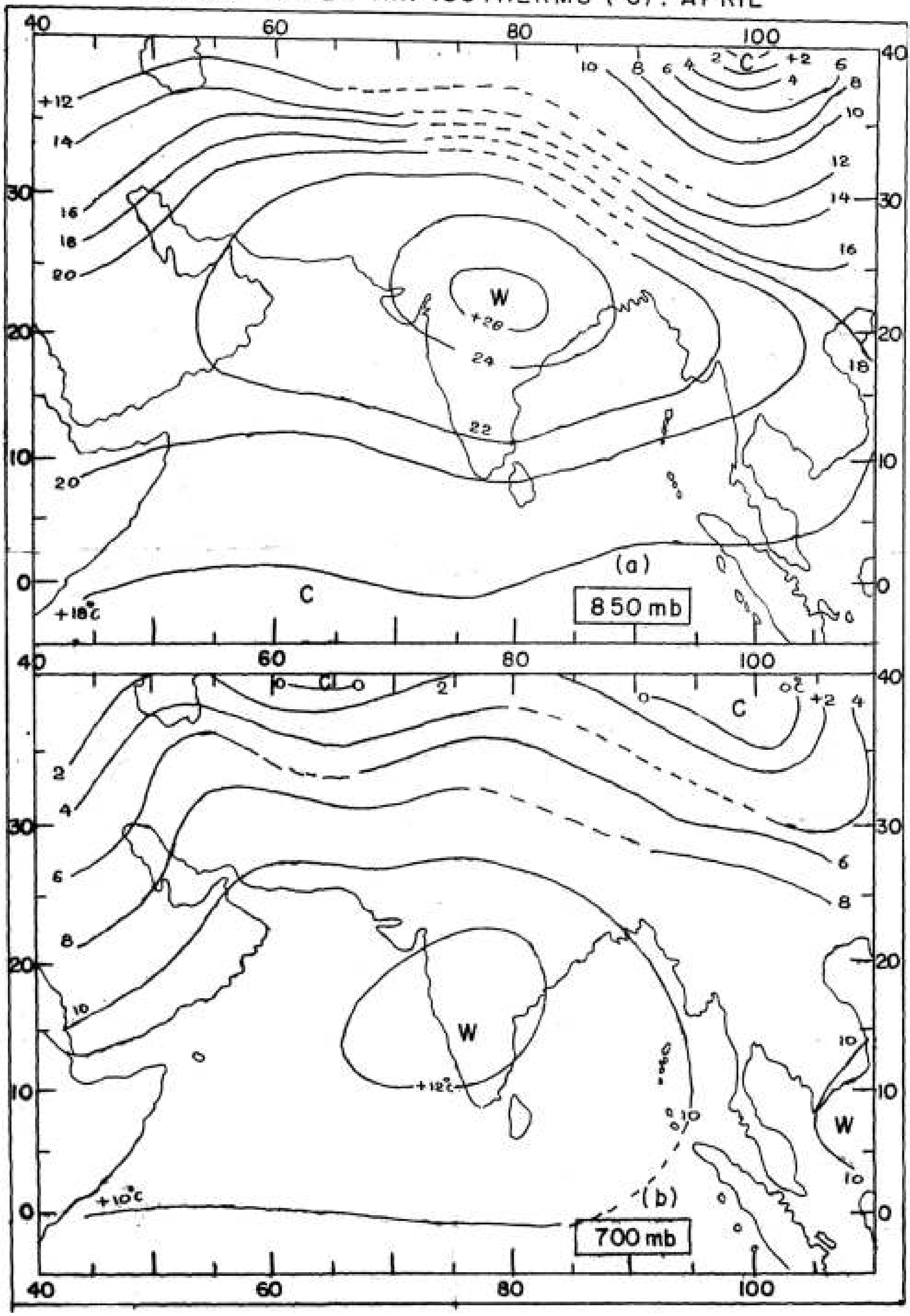


FIG. 6·2 UPPER AIR ISOTHERMS (°C) : APRIL

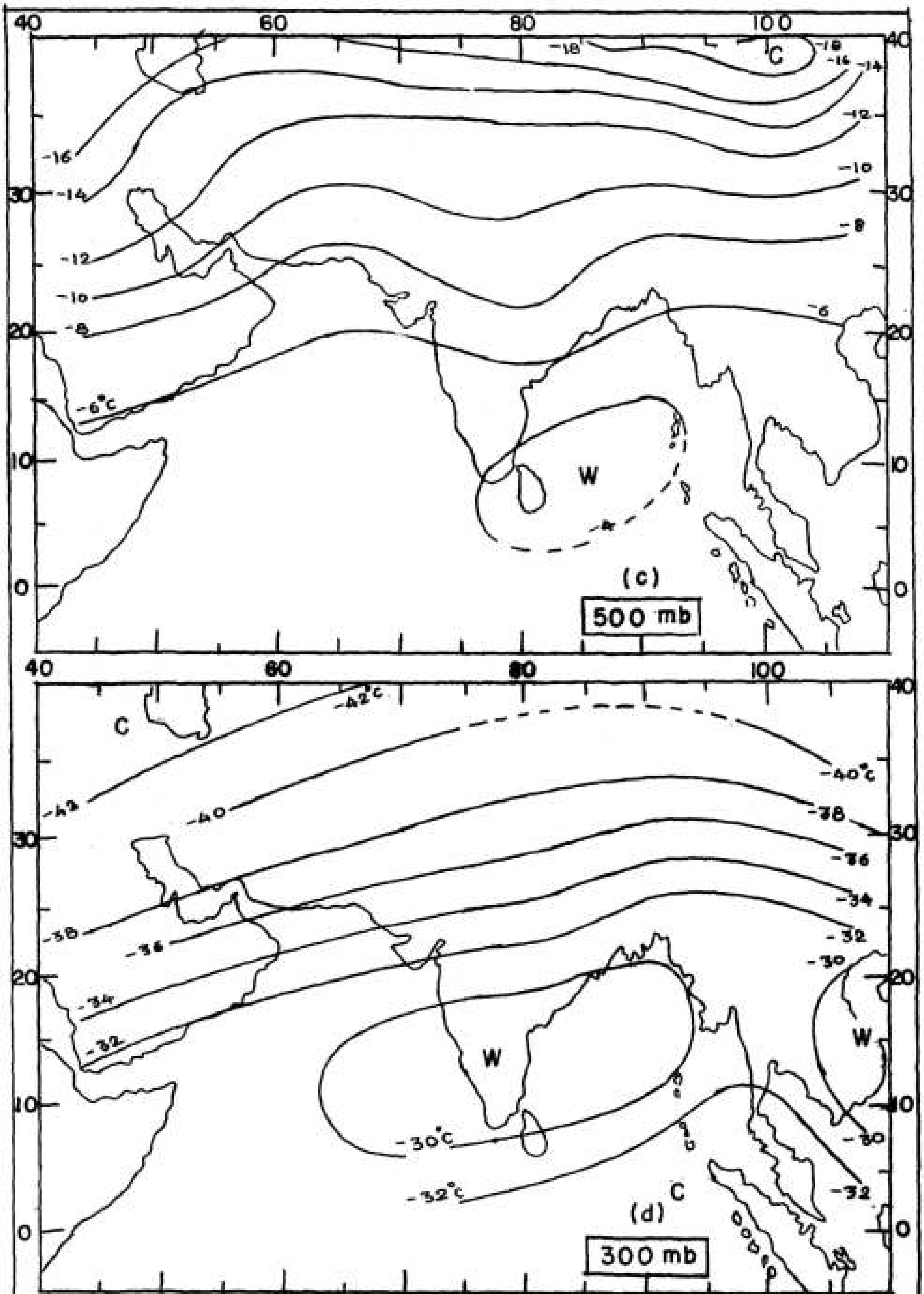


FIG. 6·3 UPPER AIR ISOTHERMS (°C) : JULY

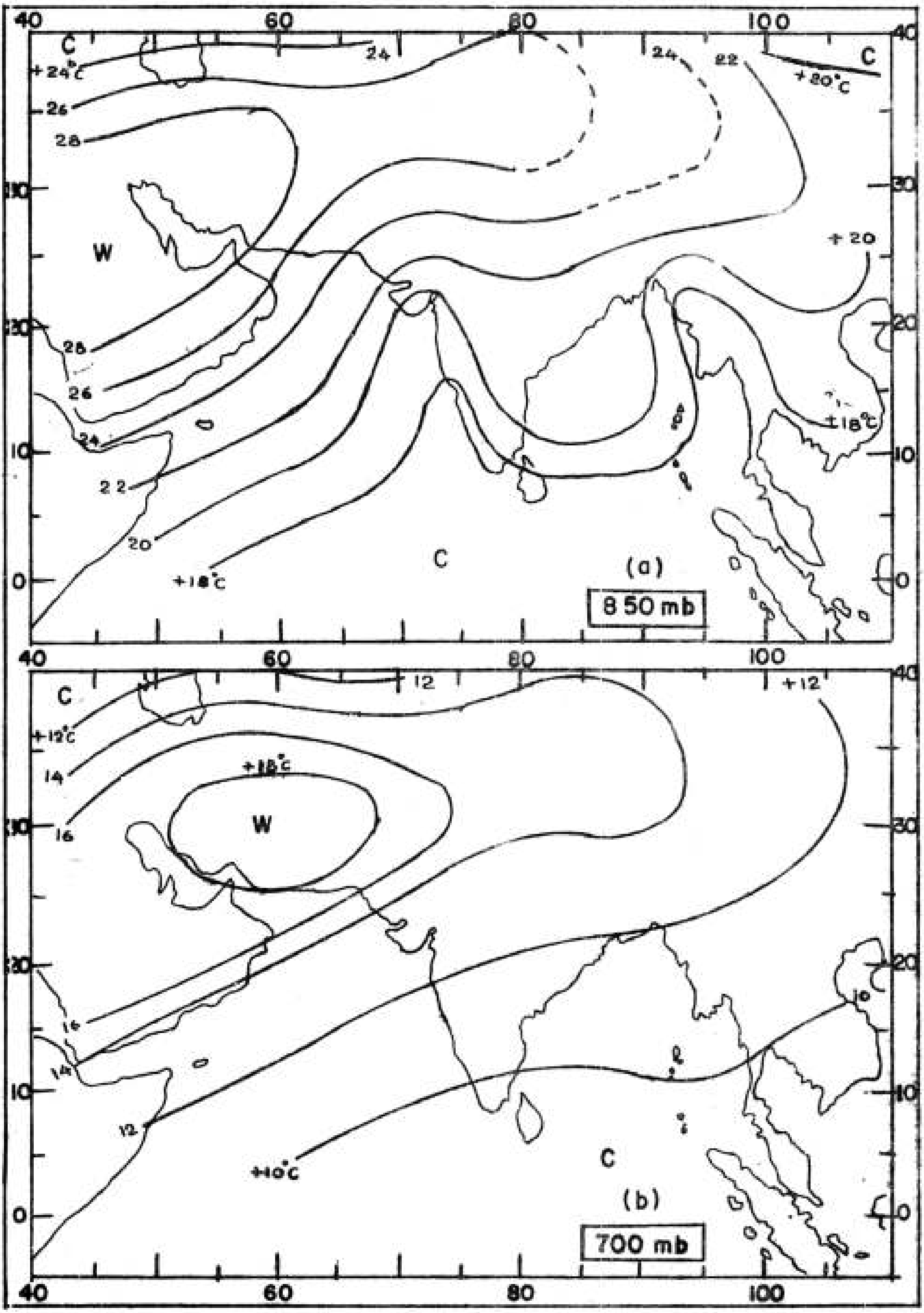
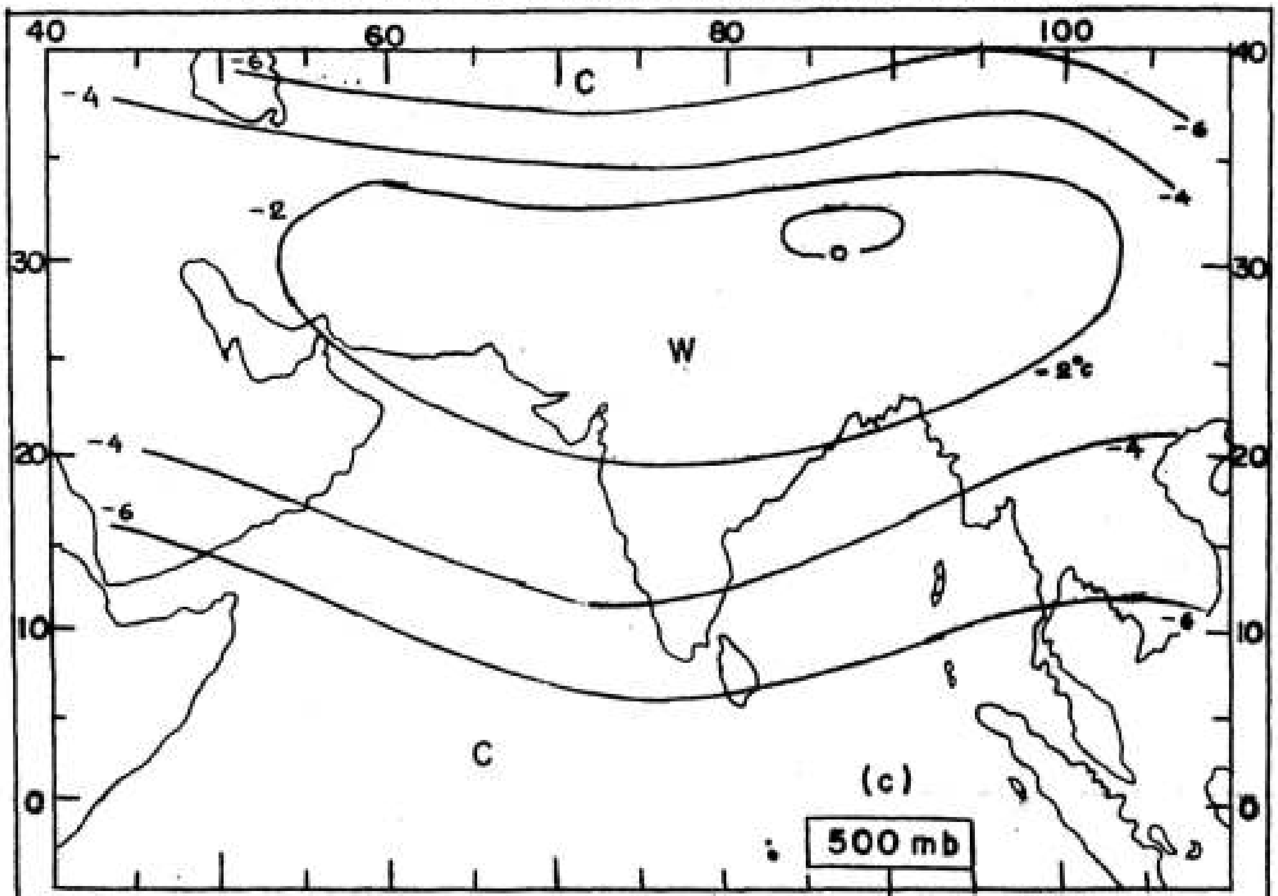


FIG. 6·3 UPPER AIR ISOTHERMS (°C) : JULY



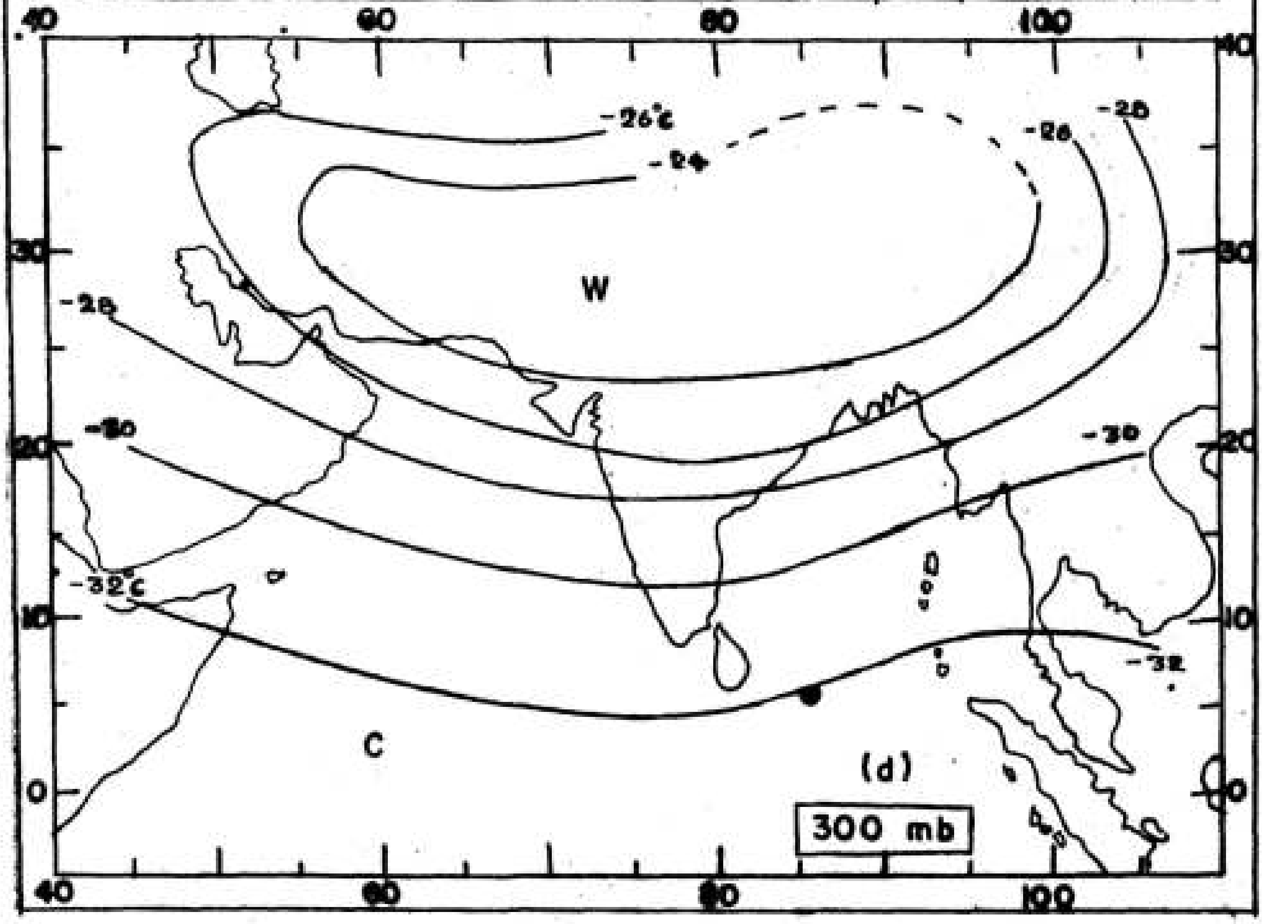


FIG. 6·4 UPPER AIR ISOTHERMS (°C) : OCTOBER

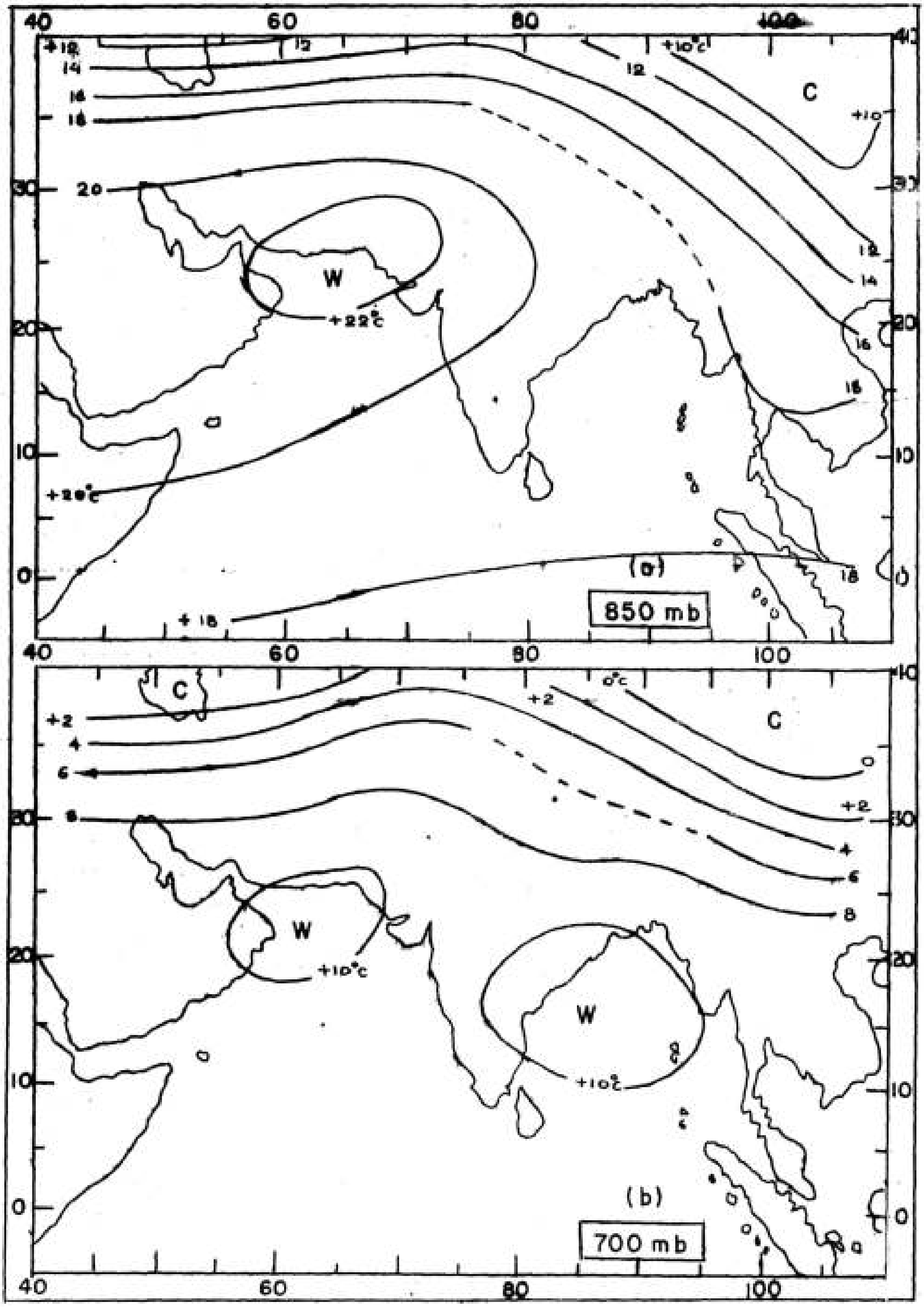
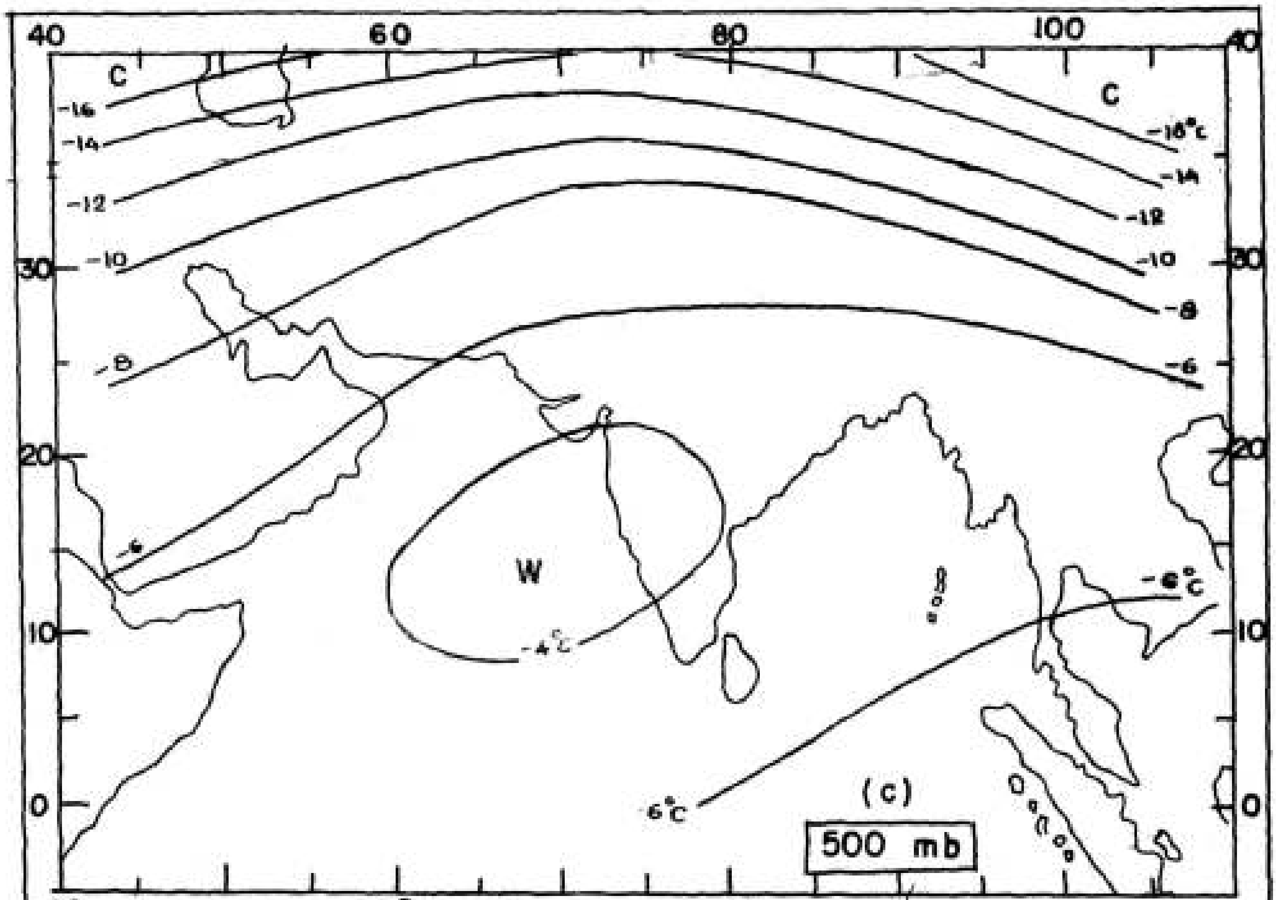


FIG. 6·4 UPPER AIR ISOTHERMS (°C) : OCTOBER



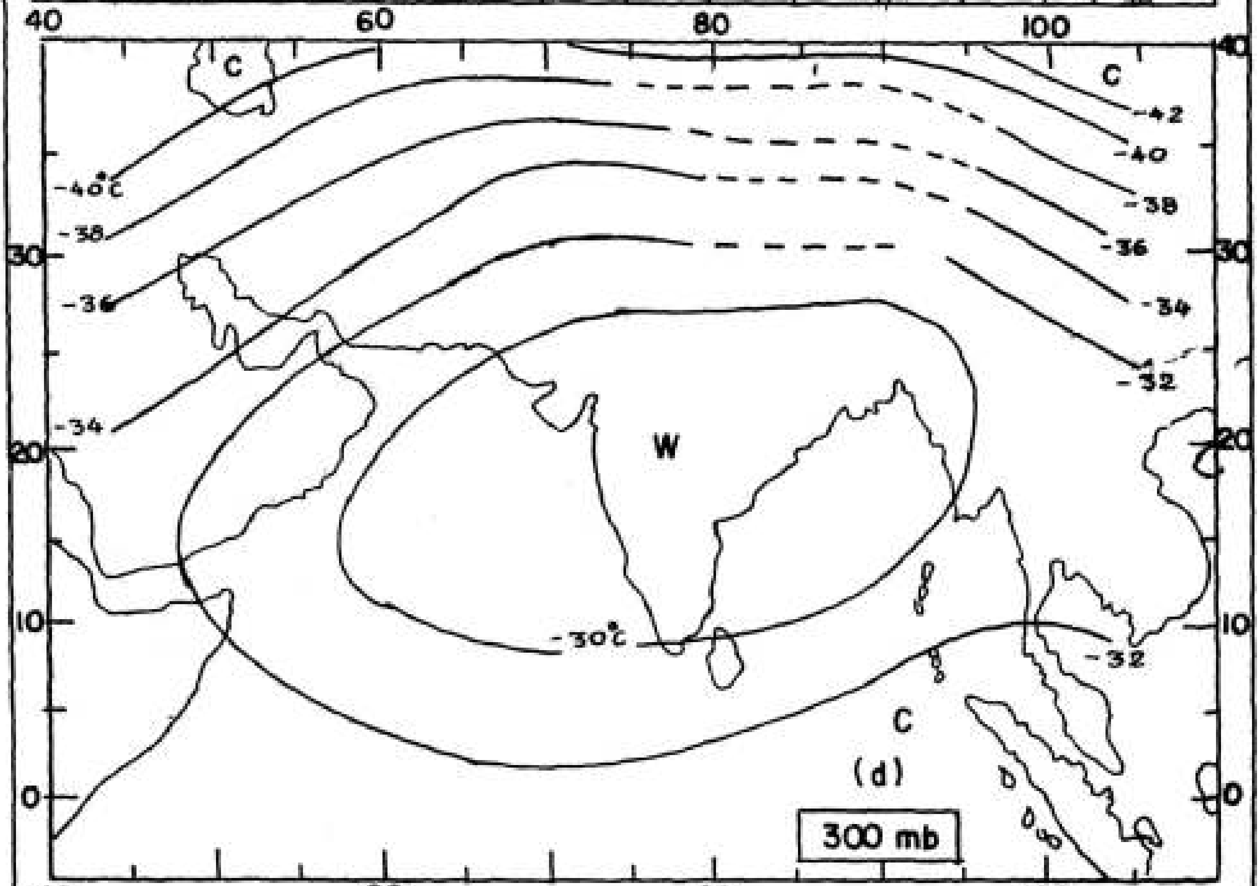


FIG. 7·1 UPPER WINDS: JANUARY

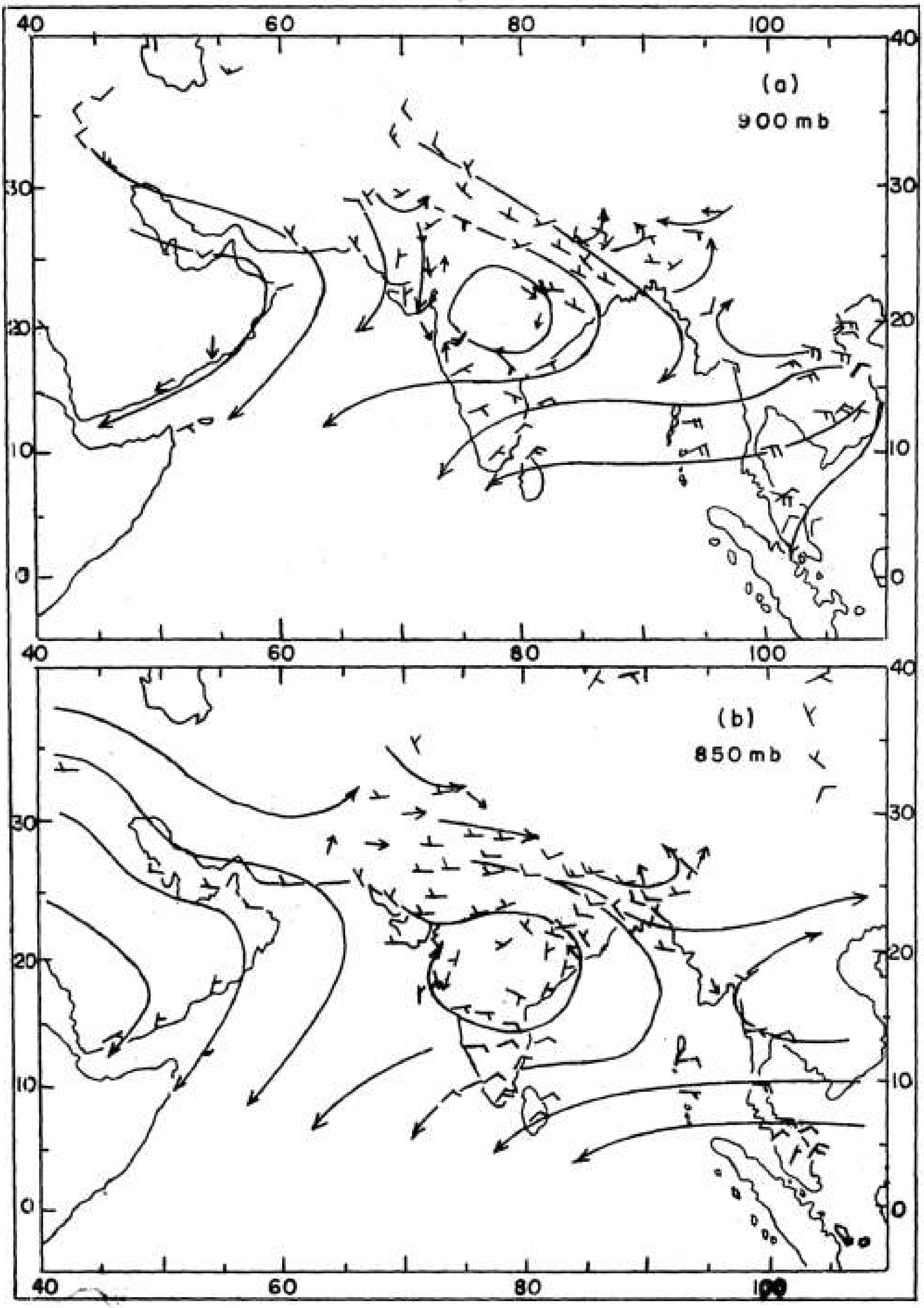


FIG. 7·1 UPPER WINDS : JANUARY

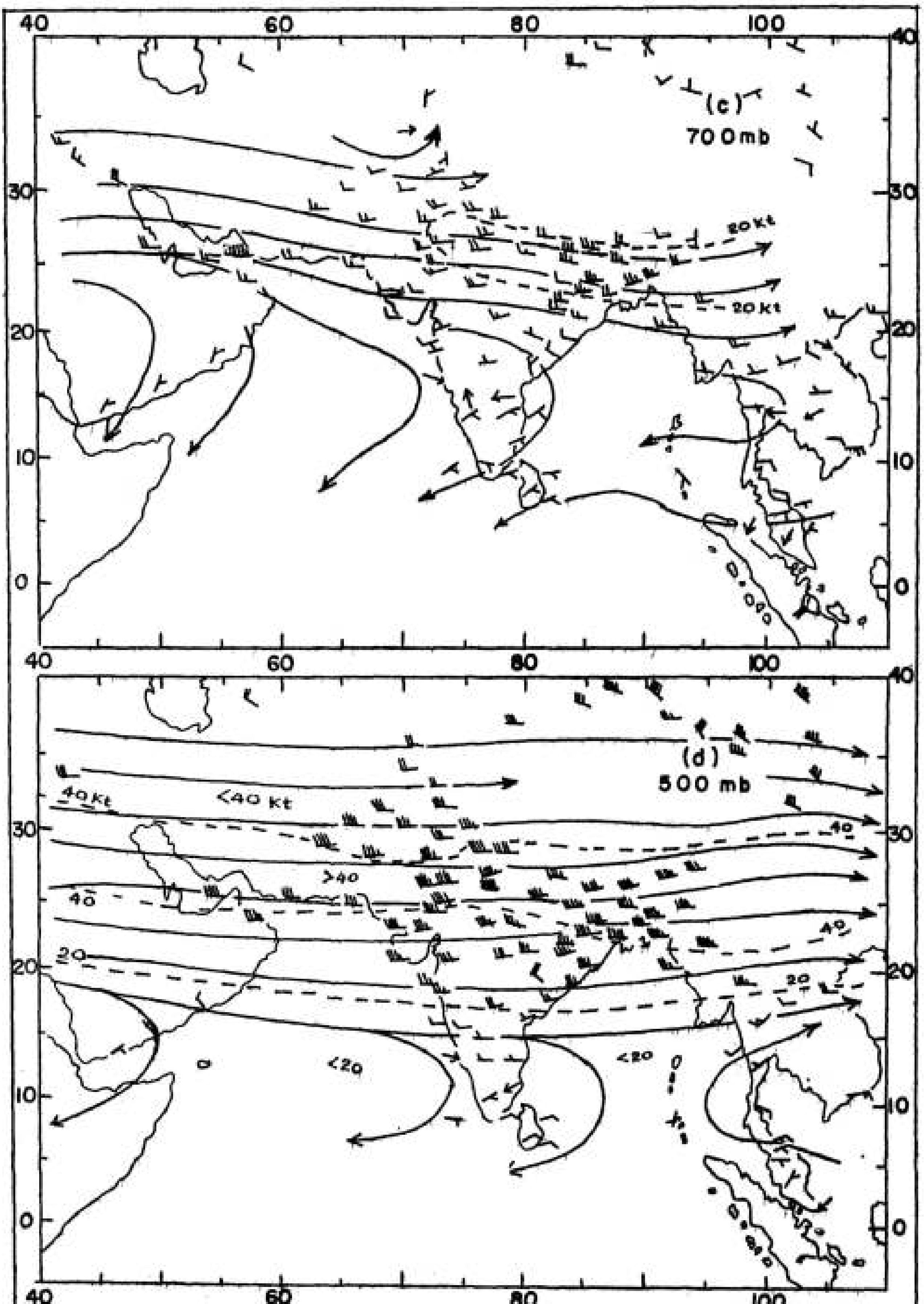


FIG. 7·1 UPPER WINDS : JANUARY

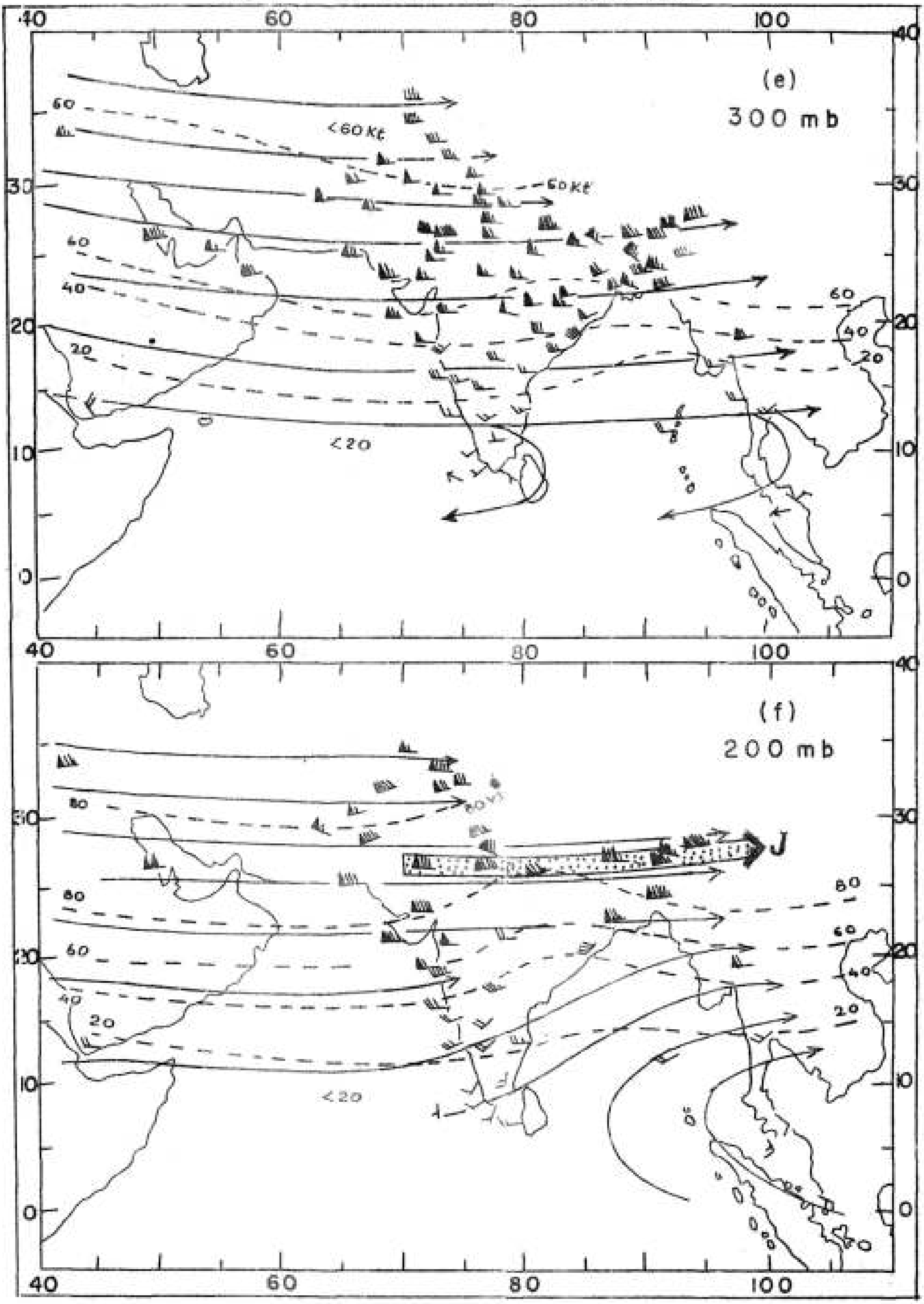


FIG. 7·1 UPPER WINDS : JANUARY

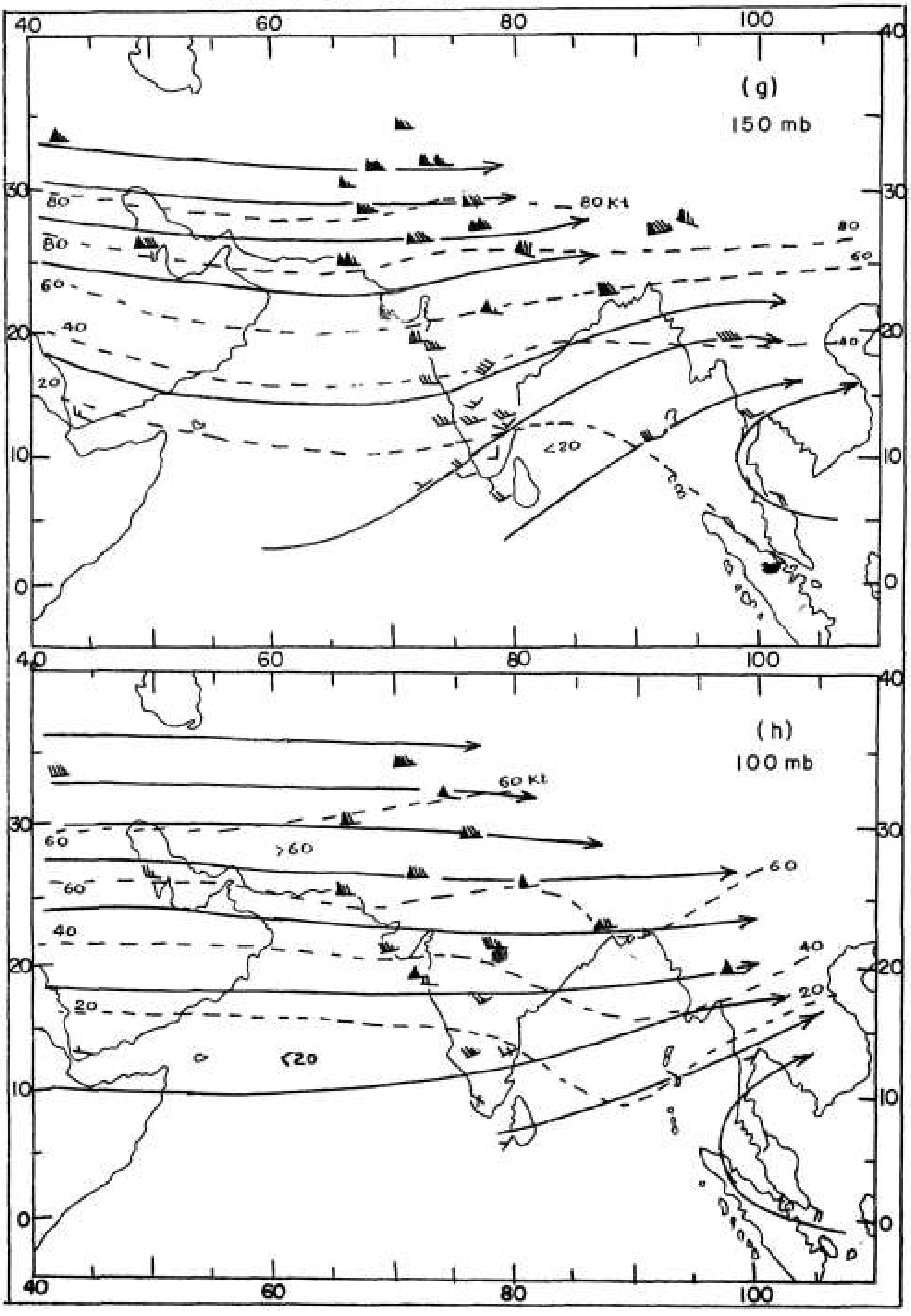


FIG. 7·2 UPPER WINDS : APRIL

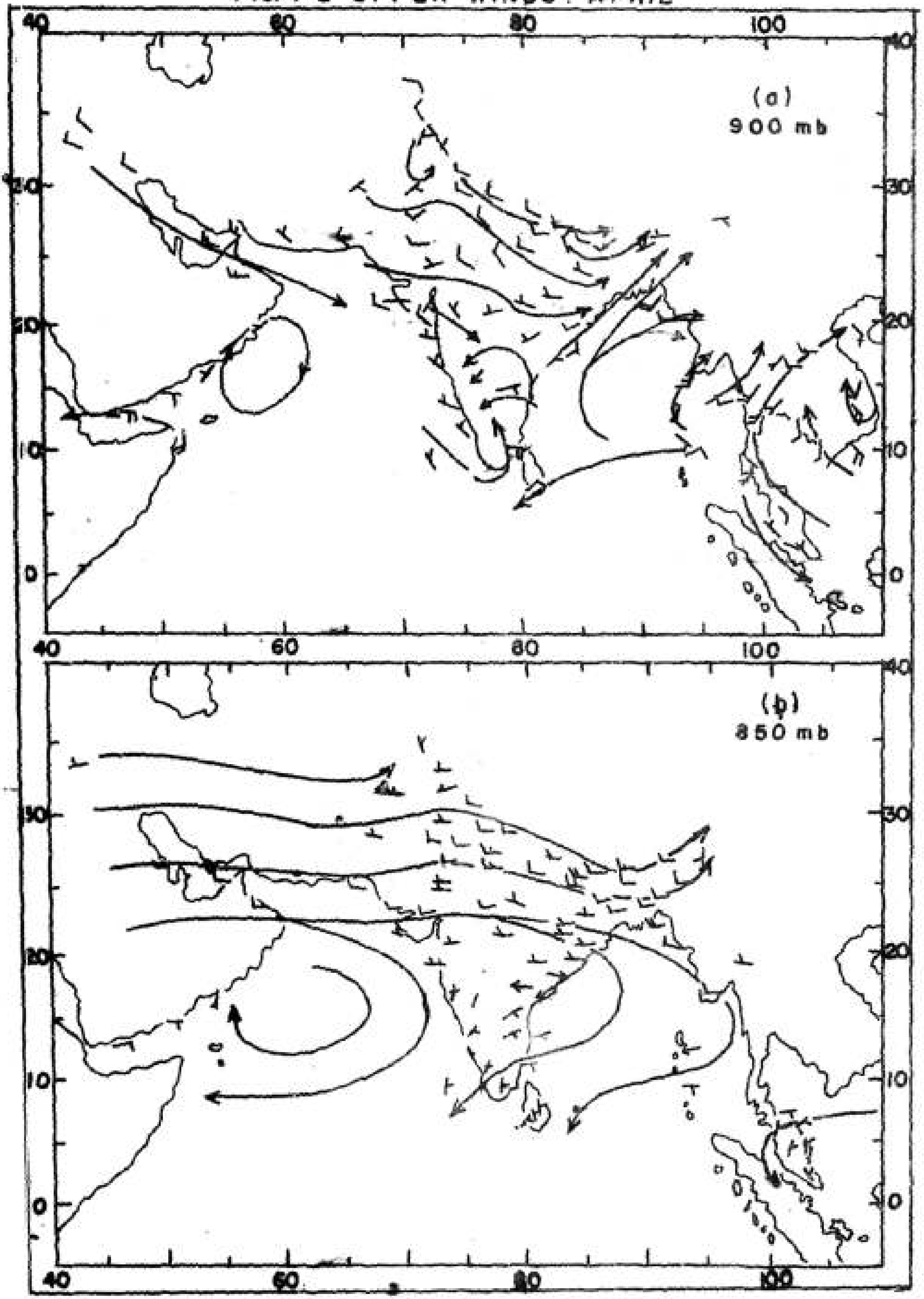


FIG. 7·2 UPPER WINDS : APRIL

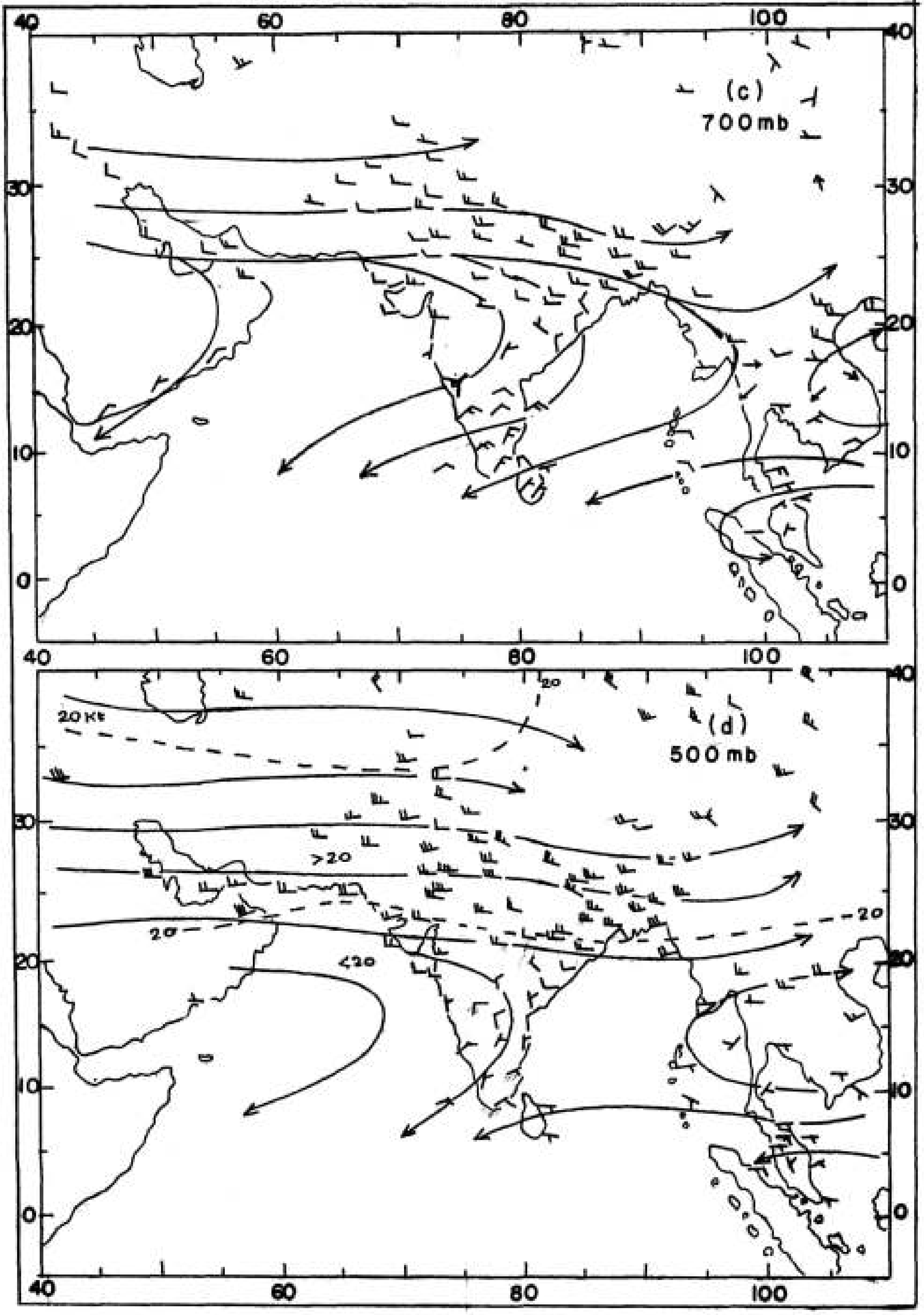


FIG. 7·2 UPPER WINDS : APRIL

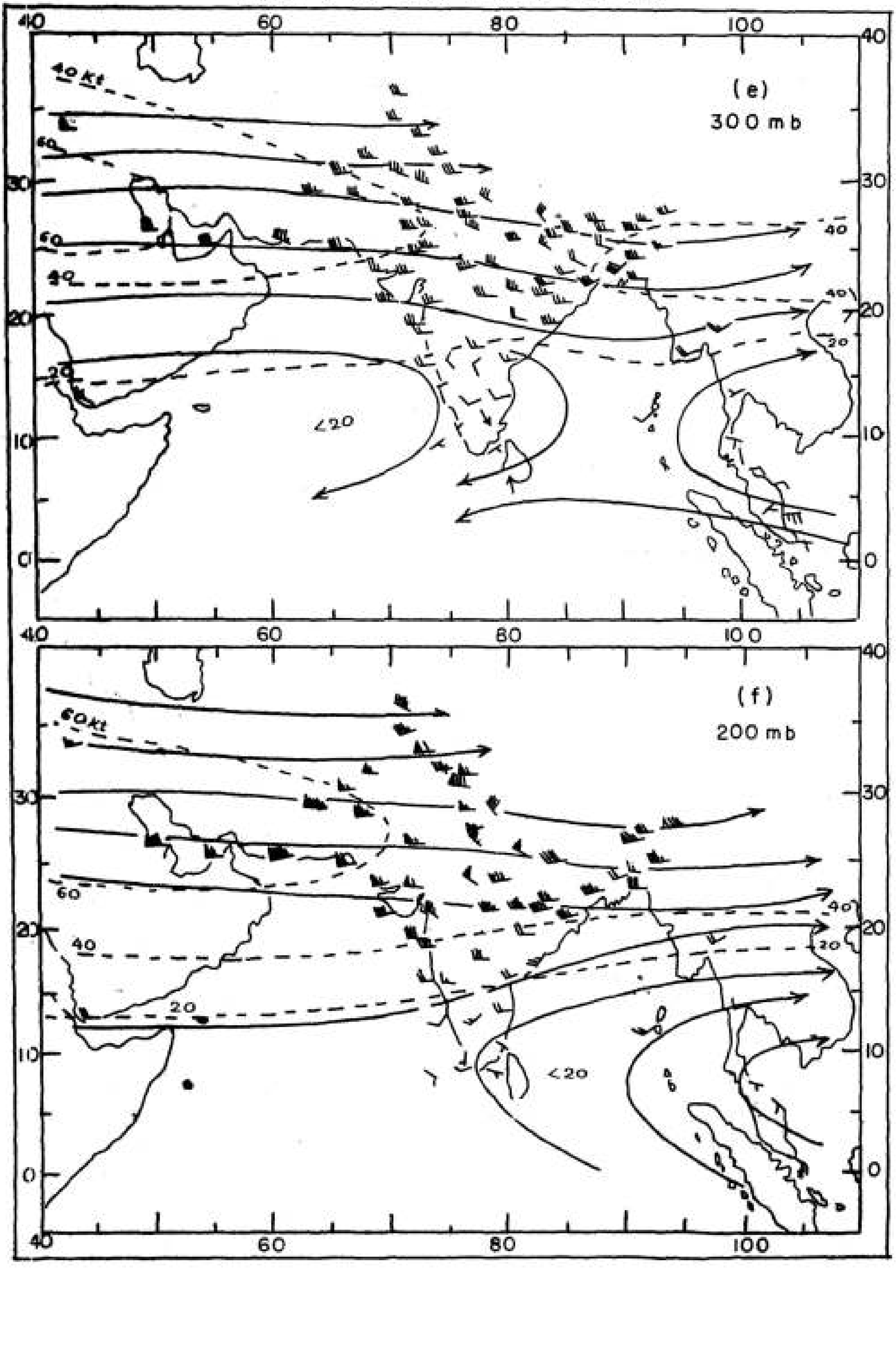


FIG. 7·2 UPPER WINDS : APRIL

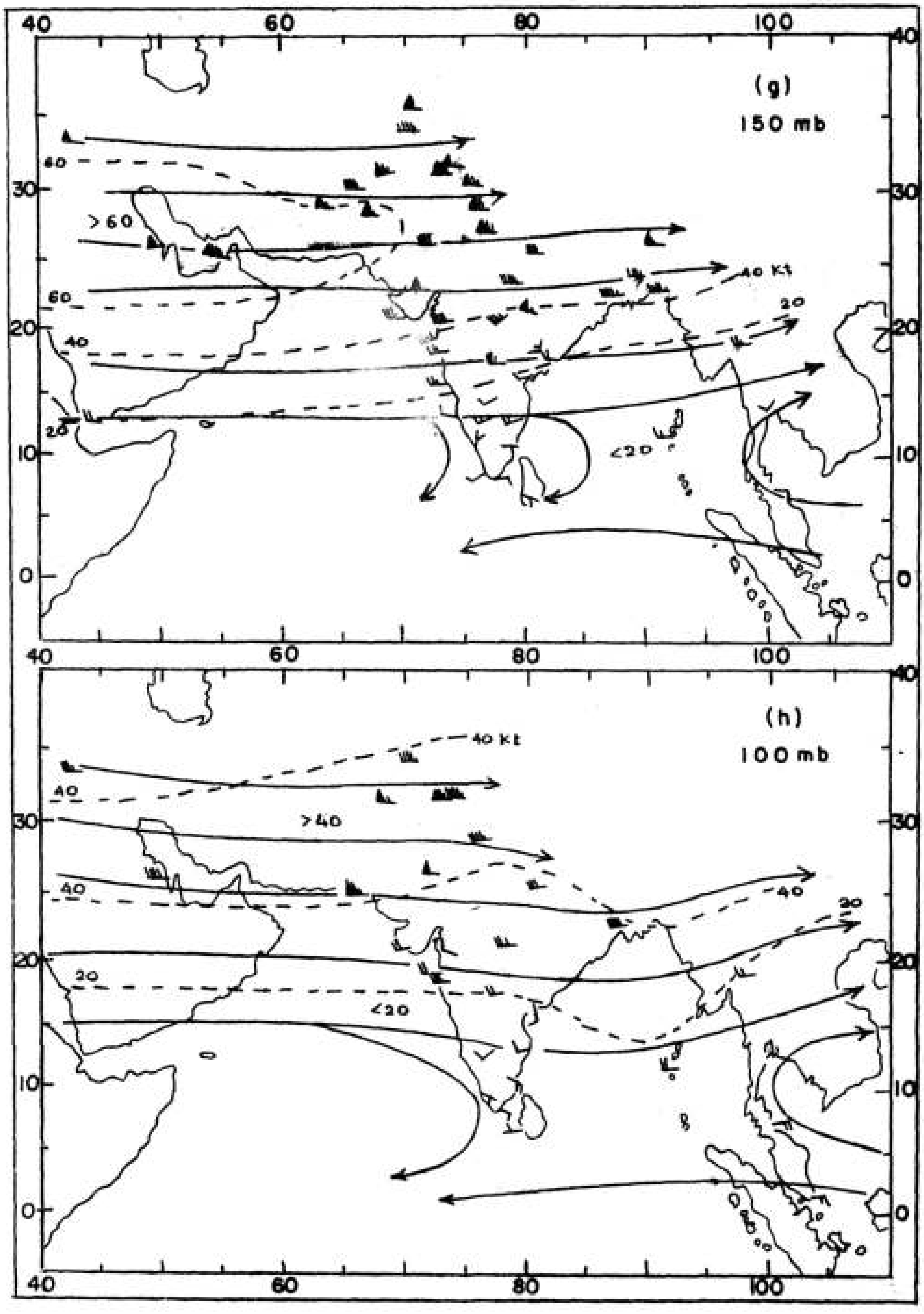


FIG. 7·3 UPPER WINDS : JULY

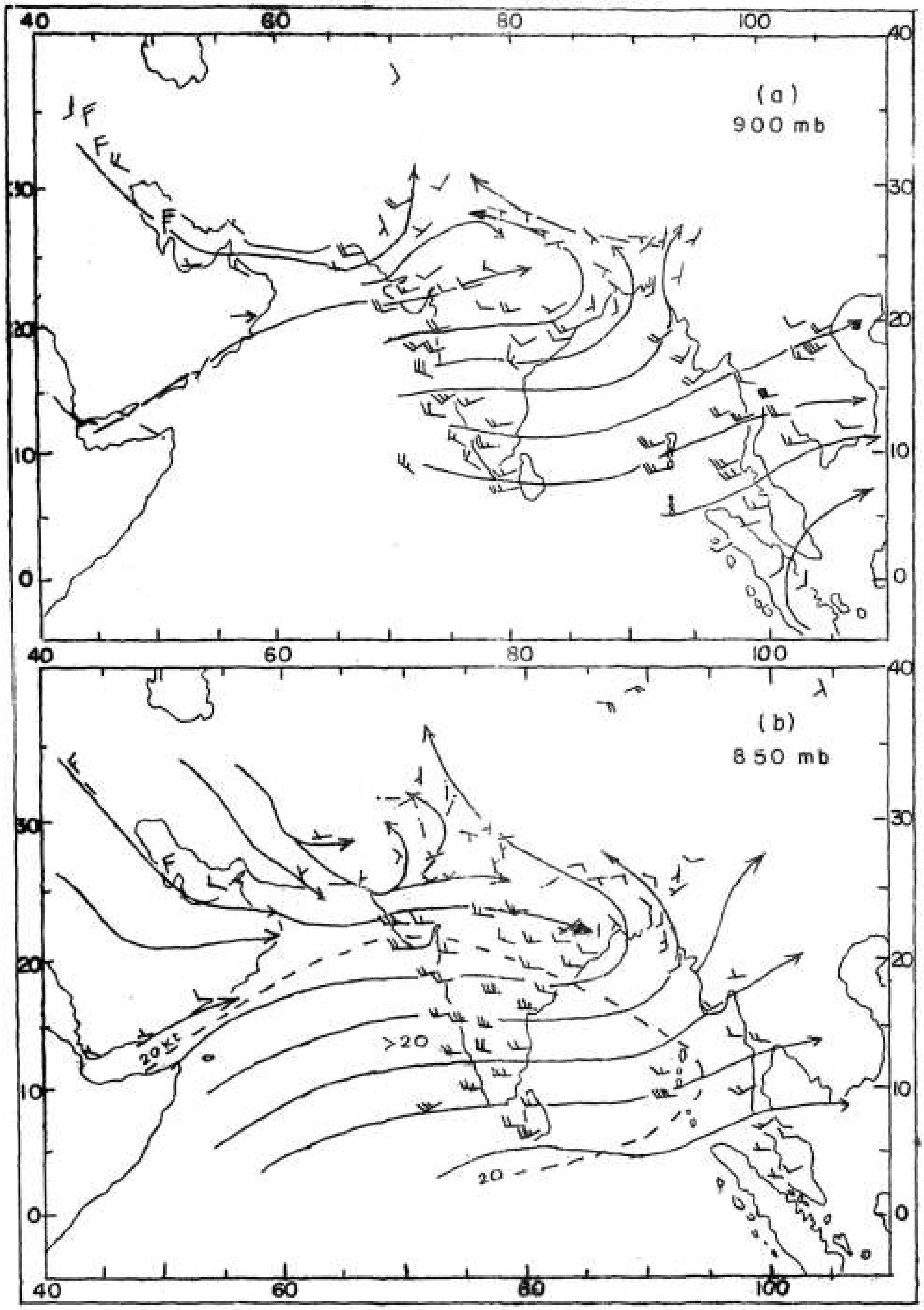


FIG. 7·3 UPPER WINDS : JULY

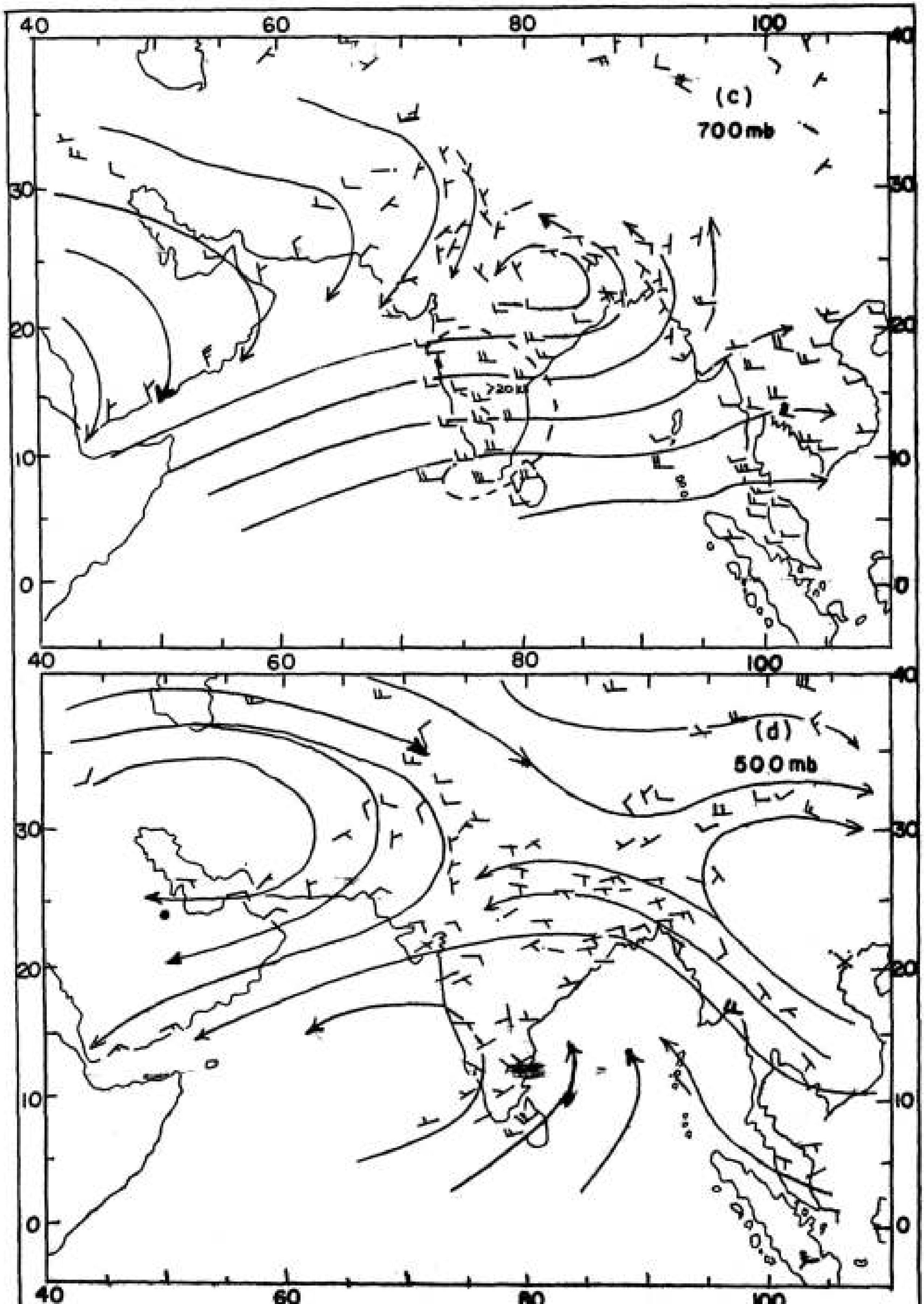


FIG. 7·3 UPPER WINDS : JULY

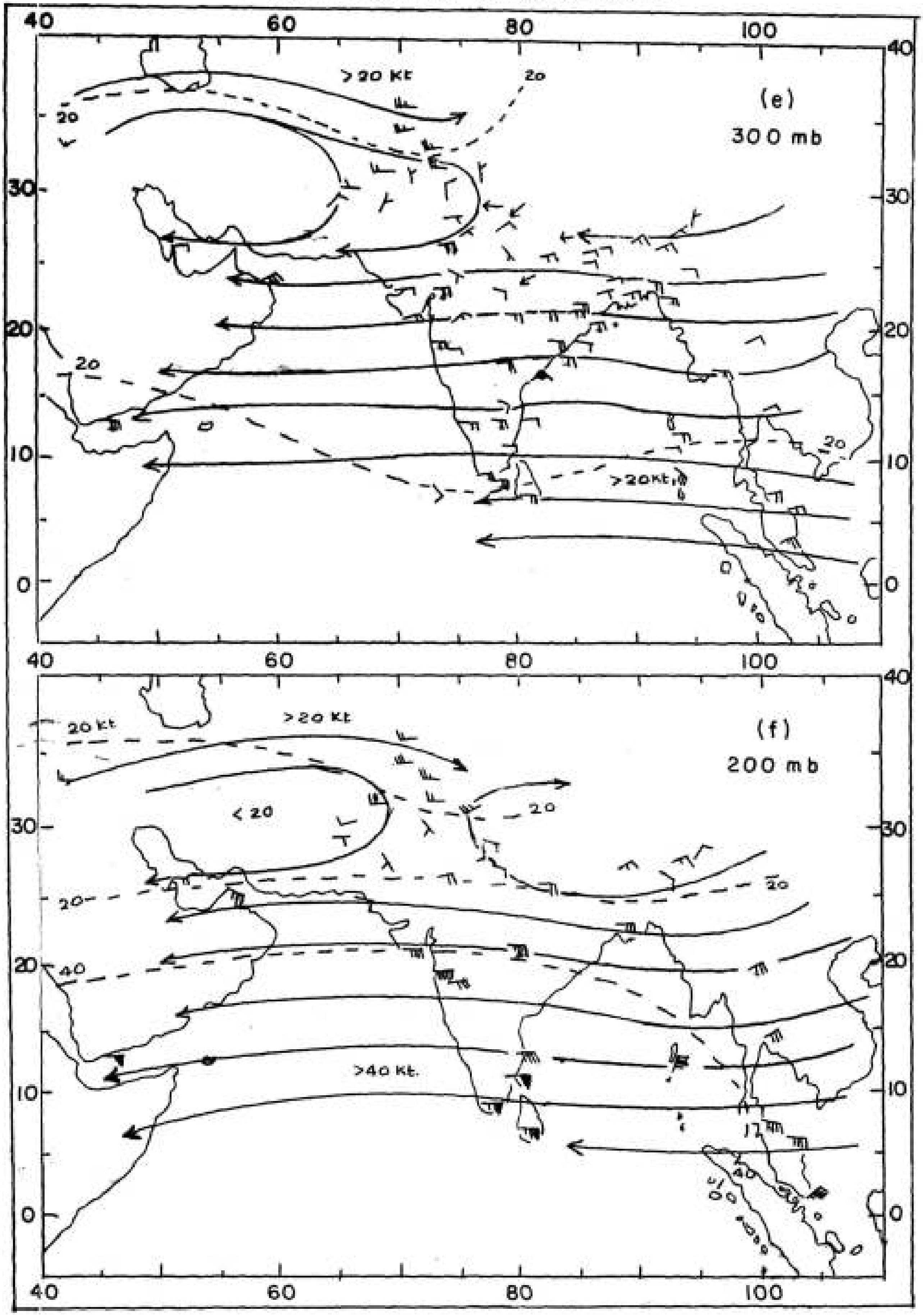


FIG. 7·3 UPPER WINDS: JULY

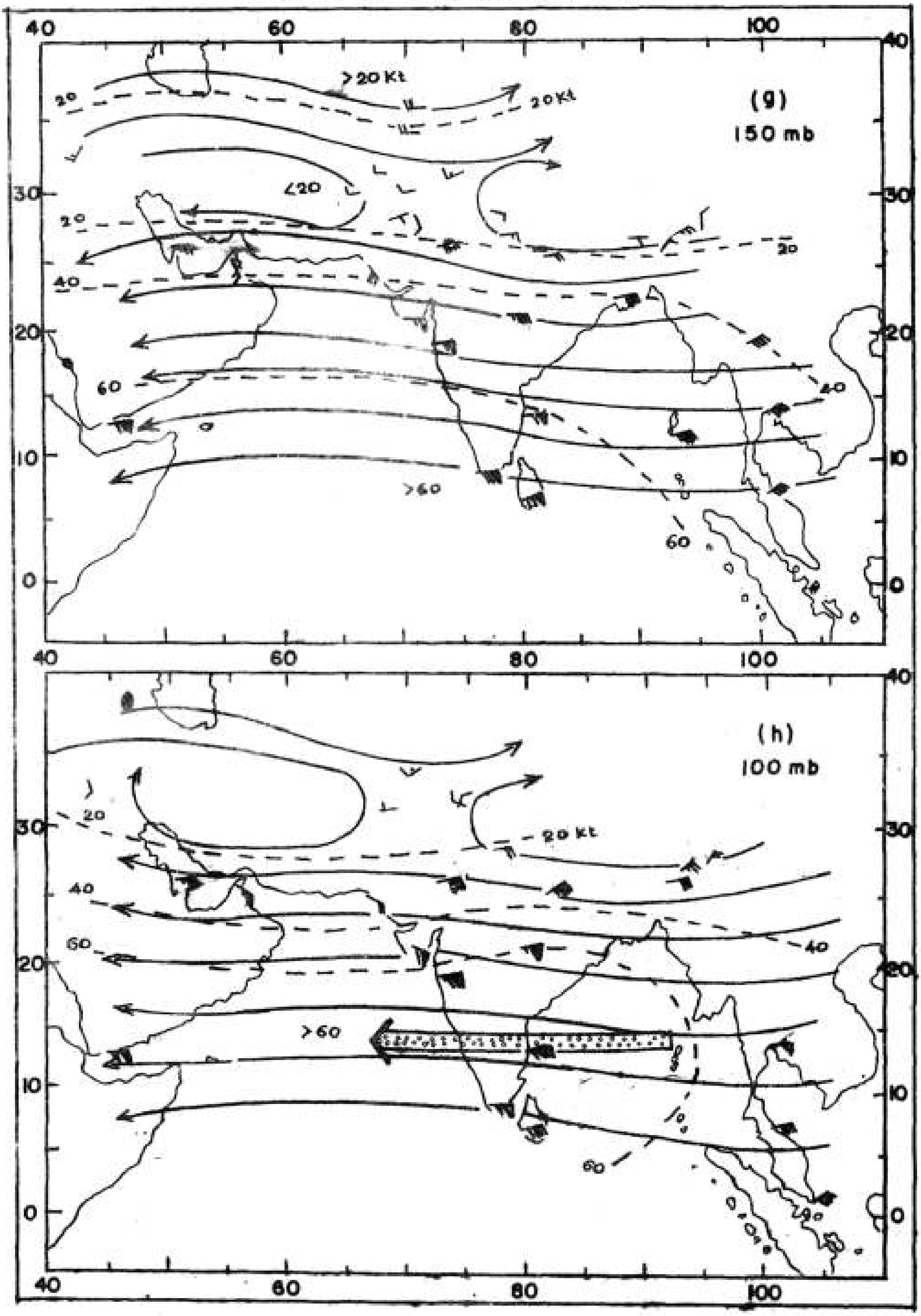


FIG. 7·4 UPPER WINDS : OCTOBER

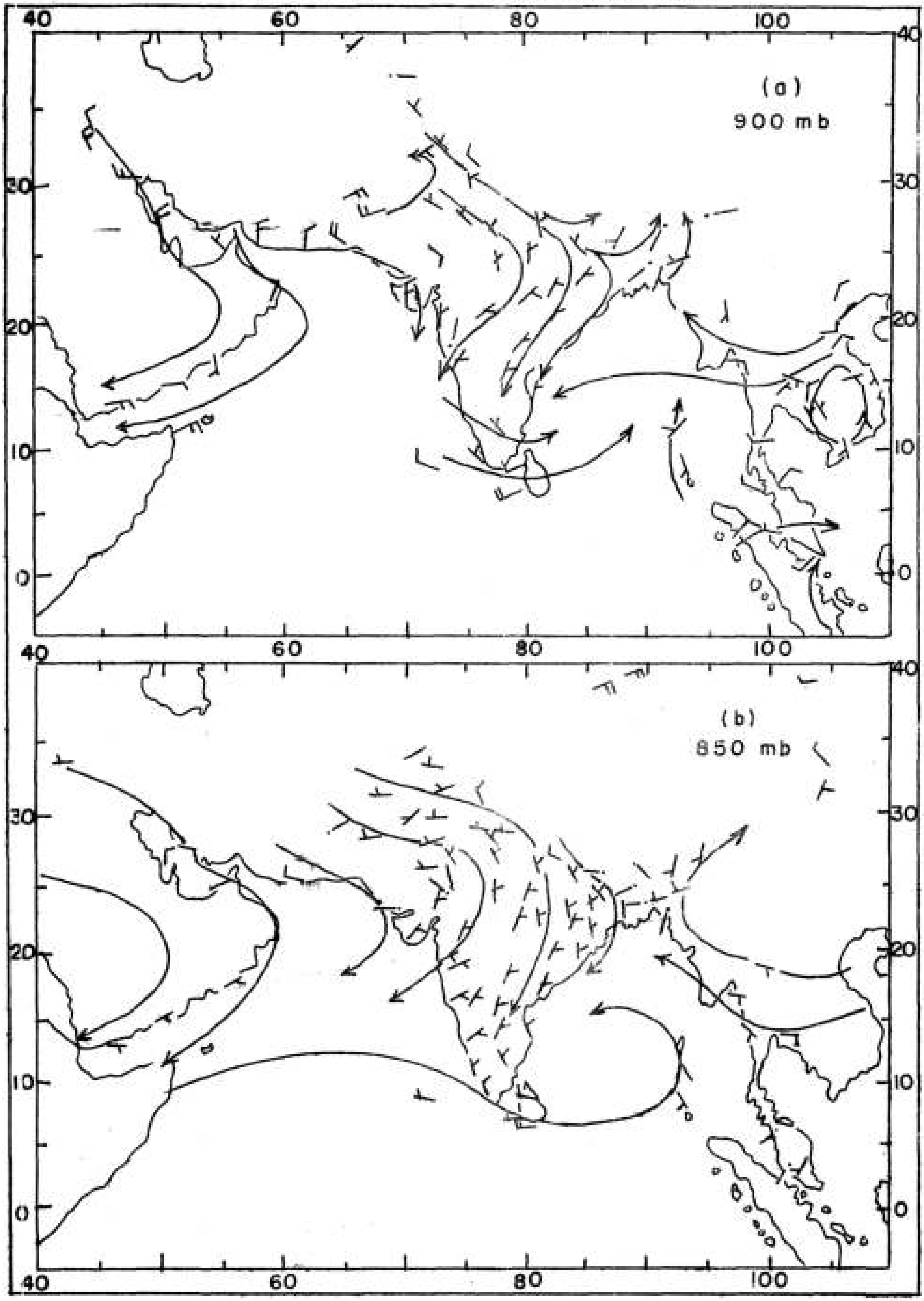


FIG. 7·4 UPPER WINDS : OCTOBER

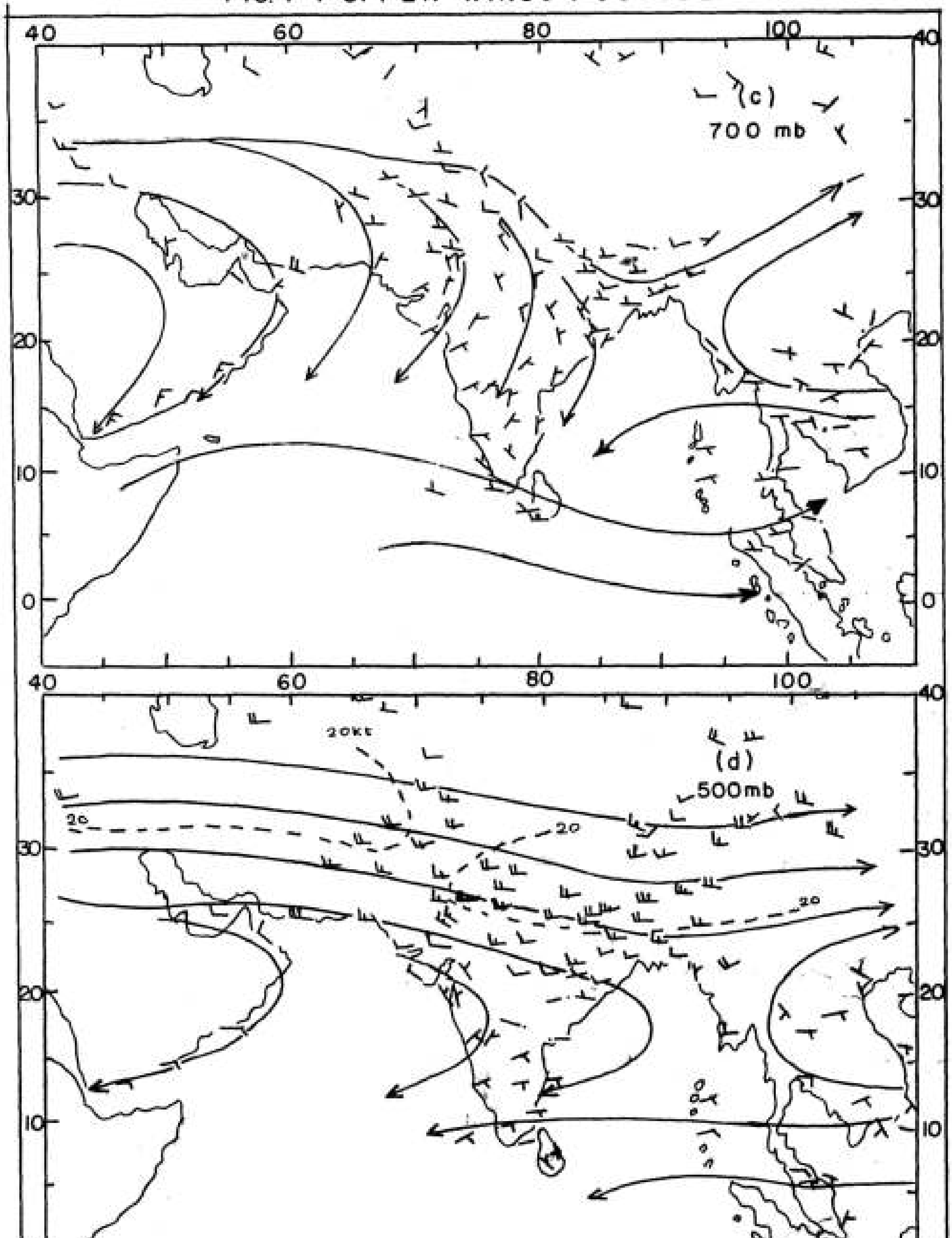


FIG. 7·4 UPPER WINDS : OCTOBER

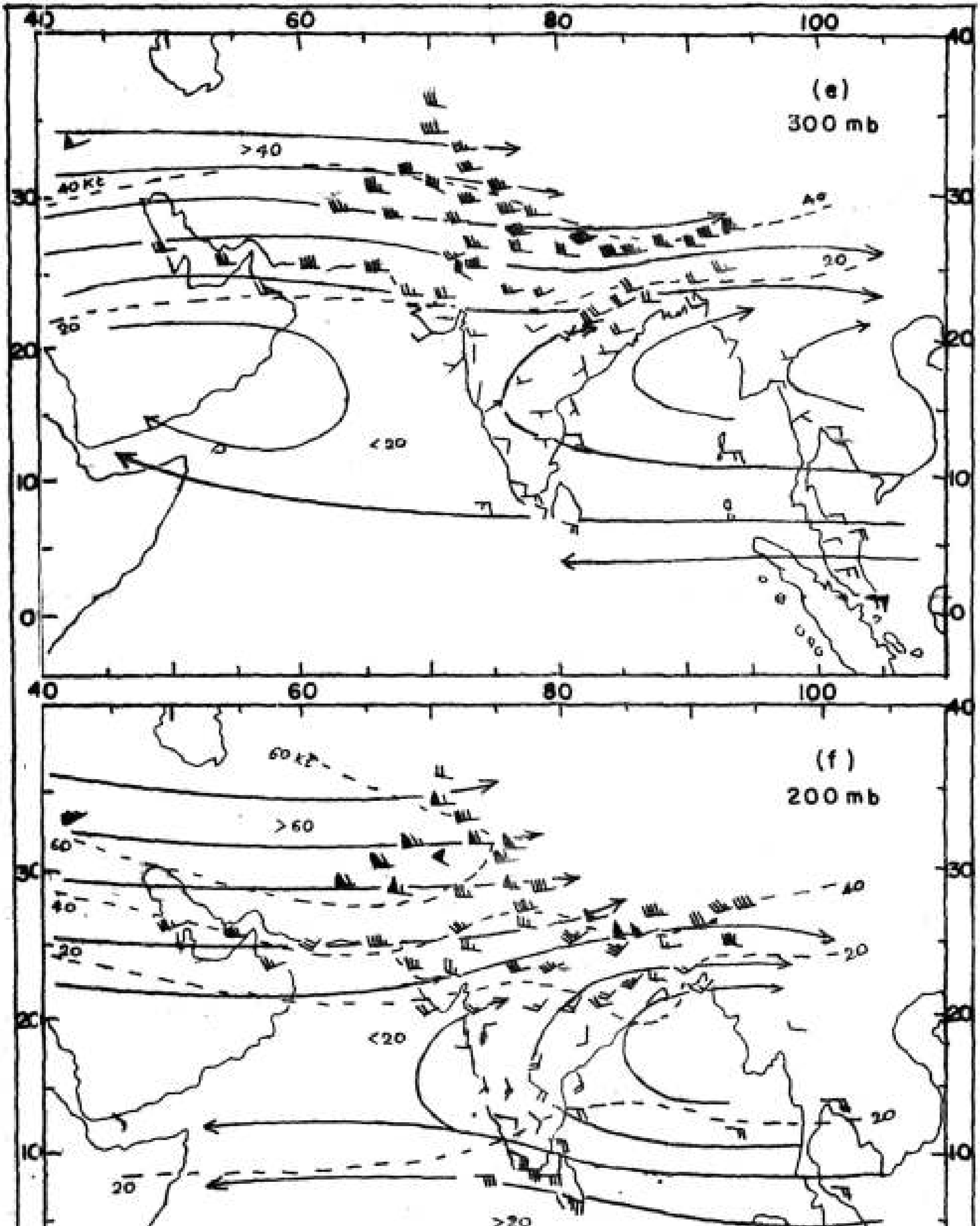


FIG. 7·4 UPPER WINDS : OCTOBER

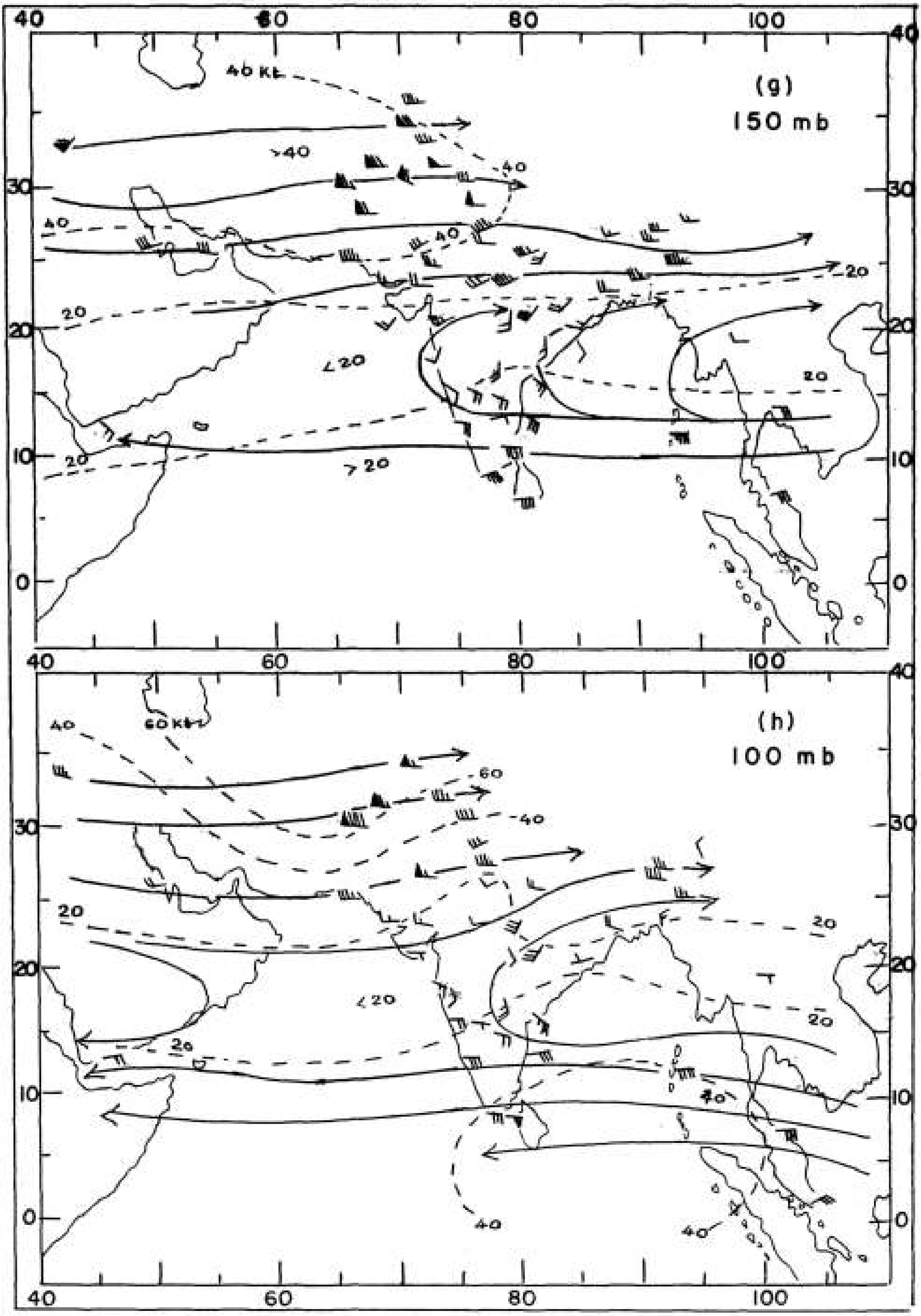
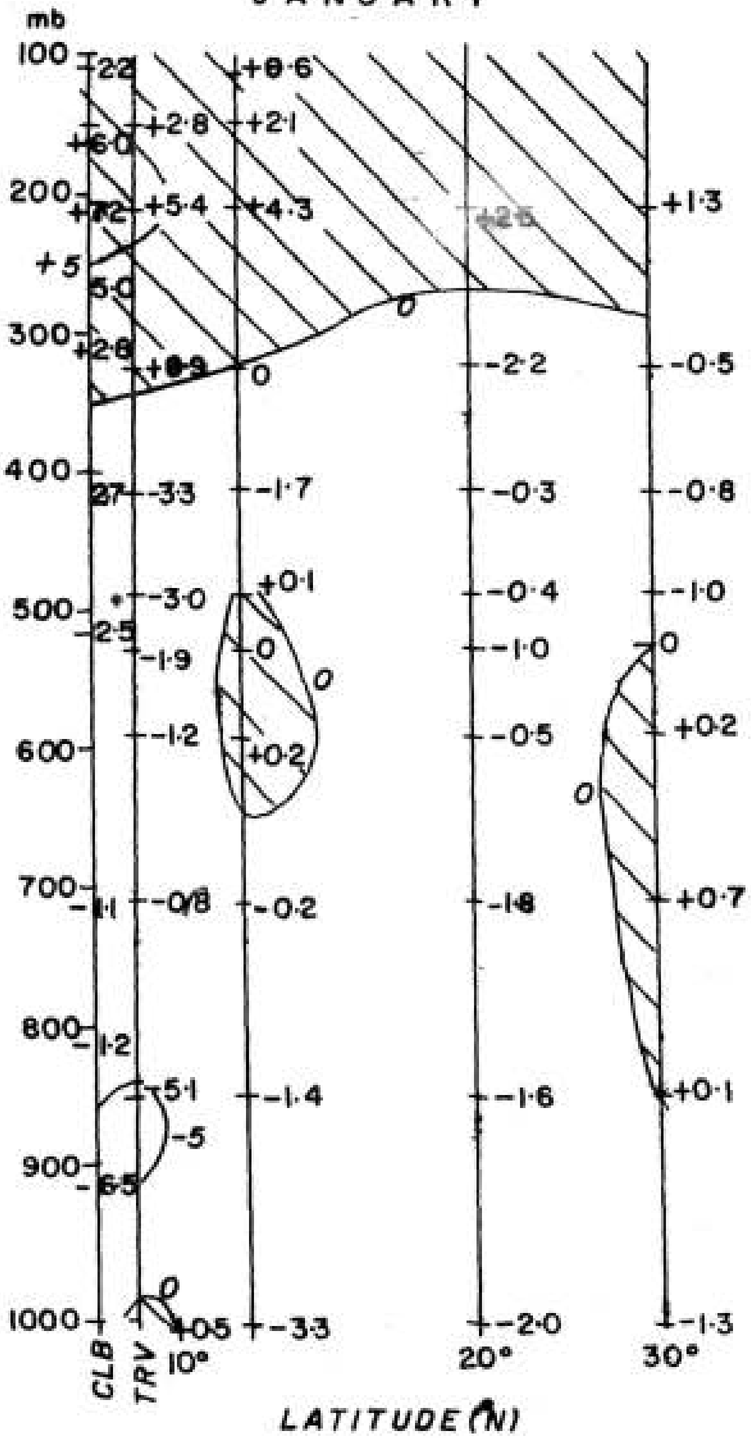


FIG. 10(a) MEAN MERIDIONAL CIRCULATION OVER INDIA

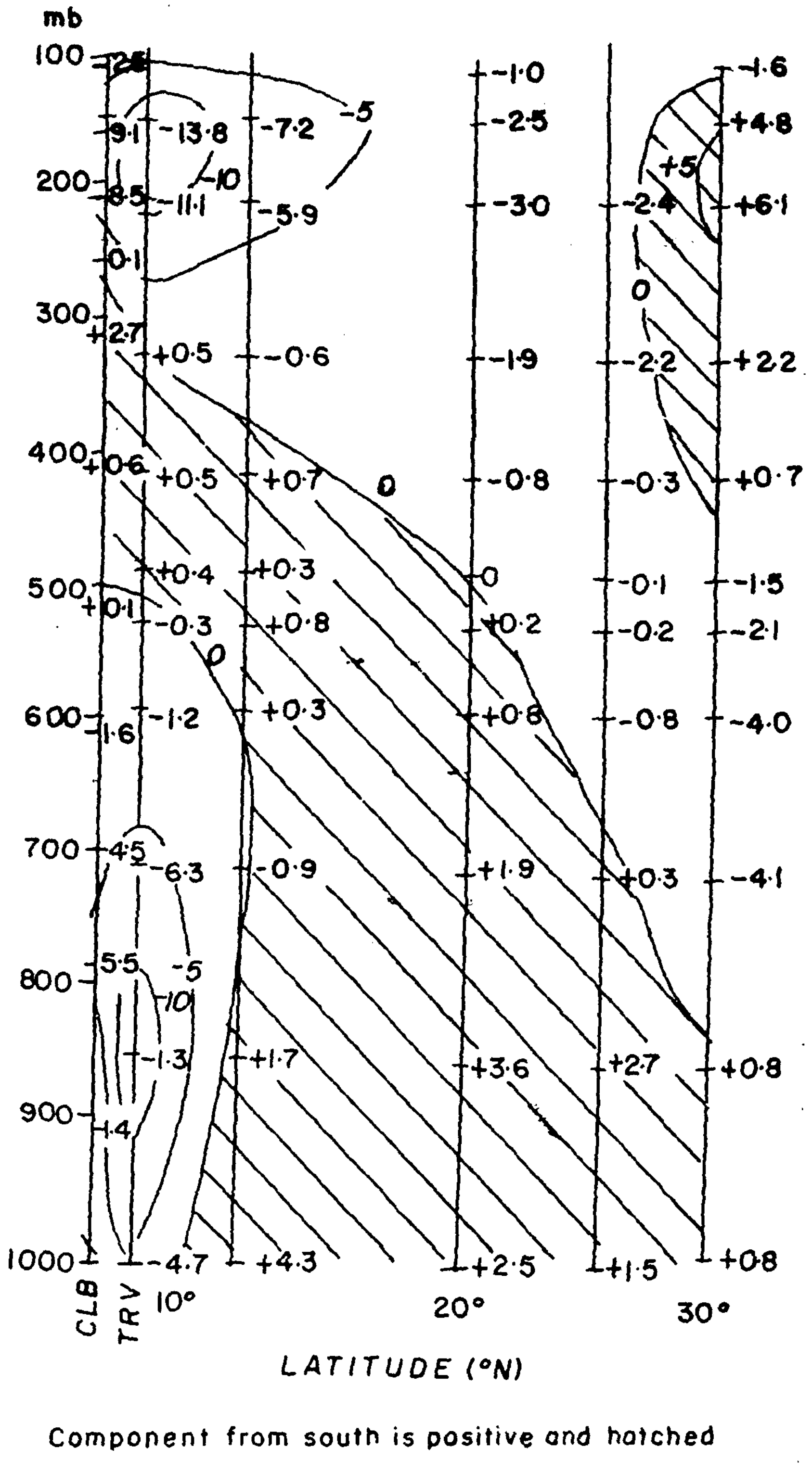
JANUARY



Component from south is positive and hatched

FIG. 10(b) MEAN MERIDIONAL CIRCULATION OVER INDIA

JULY



Component from south is positive and hatched

FORECASTING MANUAL REPORTS

No. I-1	Monthly Mean Sea Level Isobaric Charts - R.Ananthakrishnan, V. Srinivasan and A.R. Ramakrishnan.
No. I-2	Climate of India - Y.P. Rao and K.S. Ramamurti.
No. II-1	Methods of Analysis: 1. Map Projections for Weather Charts - K. Krishna
No. III-1.1	Discussion of Typical Synoptic Weather Situations: Winter - Western Disturbances and their Associated Features - Y.P. Rao and V. Srinivasan.
No.III-3.1	Discussion of Typical Synoptic Weather Situations: Southwest Monsoon: Active and Weak monsoon conditions over Gujarat State - Y.P. Rao, V.Srinivasan, S.Raman and A.R.Ramakrishnan.
No.III-3.2	Discussion of Typical Synoptic Weather Situations: Southwest Monsoon: Active and Weak monsoon conditions over Orissa - Y.P. Rao, V. Srinivasan, A.R. Ramakrishnan and S. Raman.
No. III-3.3	Discussion of Typical Synoptic Weather Situations: Southwest Monsoon: Typical Situations over Northwest India - M.S.V.Rao, V. Srinivasan and S. Raman.
No.III-3.4	Discussion of Typical Synoptic Weather Situations: Southwest Monsoon: Typical Situations over Madhya Pradesh and Vidarbha - V. Srinivasan, S. Raman and S. Mukherji.
No.IV-13	Rainfall of India - P. Jagannathan.
No.IV-16	Microseisms and Weather - A.N.Tandon and S.N.Bhattacharya.
No.IV-17	Medium Range Forecasting - K.R. Saha and D.A. Mooley.
No.IV-18.1	On the Criteria for declaring the onset of the southwest monsoon over Kerala - R. Ananthakrishnan, U.R.Acharya and A.R. Ramakrishnan.
No.IV-18.2	Monsoons of India: Synoptic Features associated with onset of Southwest Monsoon over Kerala - R. Ananthakrishnan, V. Srinivasan, A.R. Ramakrishnan and R. Jambunathan.
No.IV-18.3	Some aspects of the "Break" in the Indian Southwest Monsoon during July and August - K. Ramamurthy.
No.IV-20	Evaporation - N. Ramalingam.
No.V-1	Techniques of High Level Analysis and Prognosis: 1. Organisation and Methods of Analysis - P.K. Das, N.C. Rai Sircar and D.V. Rao.