towards the low pressure areas over the heated landmass. Under the extreme low pressure condition on land, the wind from the southern part of the Indian Ocean (south of Equator) is attracted towards the subcontinent of India. The air coming from oceans towards land is warm and moist. When land barriers like mountain ranges and plateaus come in the way of the moisture-laden winds, they ascend and result into saturation, condensation, and precipitation (**Fig. 4.3**).

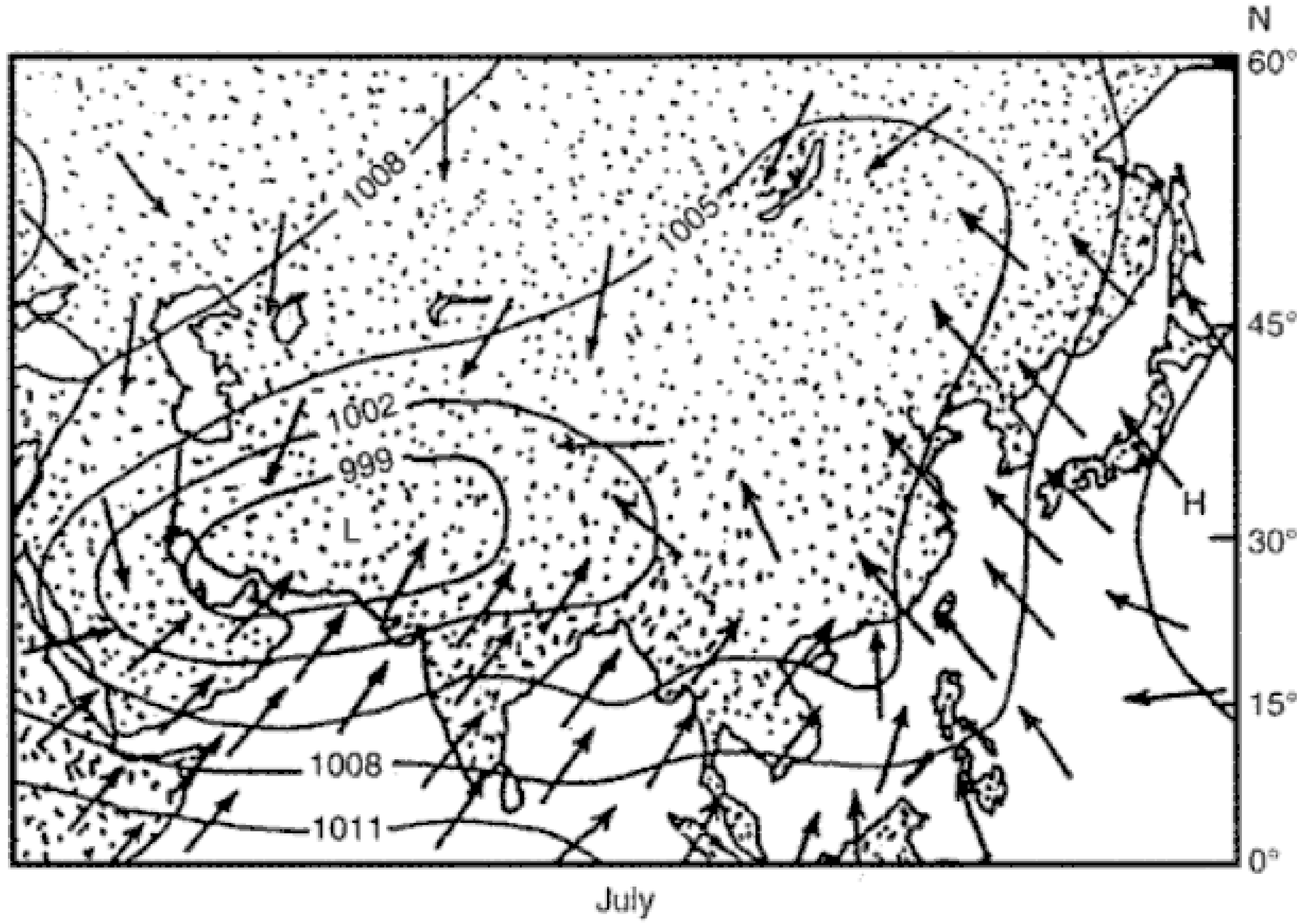

Fig. 4.3 The Summer Monsoon

Contrary to this, in the Northern Hemisphere during winter season, there develops high pressure areas near Baikal Lake (Siberia), and Peshawar (Pakistan). As compared to these high pressures, the Indian Ocean and the Pacific Ocean (south of Japan) remain relatively warm, having low pressure areas. Consequently, there is an outflow of air from the high pressure of the land to the low pressure areas of the oceans. The air blowing from high pressure areas of land towards the sea is cold and dry. This cold and dry air is incapable of giving precipitation unless it comes into contact with some water body (ocean/sea) (**Fig. 4.4**)

The thermal concept about the origin of monsoon has, however, not been accepted universally as it fails to explain the intricacies of monsoon. Besides differential heating, the origin and development of monsoon are also influenced by the shape of the continents, orography, and the conditions of air circulation in the upper troposphere. The Halley's concept has been criticised on more than one count as follows:

1. The low pressure areas that develop over the continents during the summer season in the Northern Hemisphere are not stationary. These low pressure areas change their position (location) suddenly. This sudden change in the low pressure areas are not exclusively related to low thermal conditions. The low pressure areas stabilises in June in the north-eastern parts of the subcontinent. In fact, they represent the cyclonic lows associated with the dynamic factors, and therefore, these low pressure areas cannot be termed as only thermally induced.

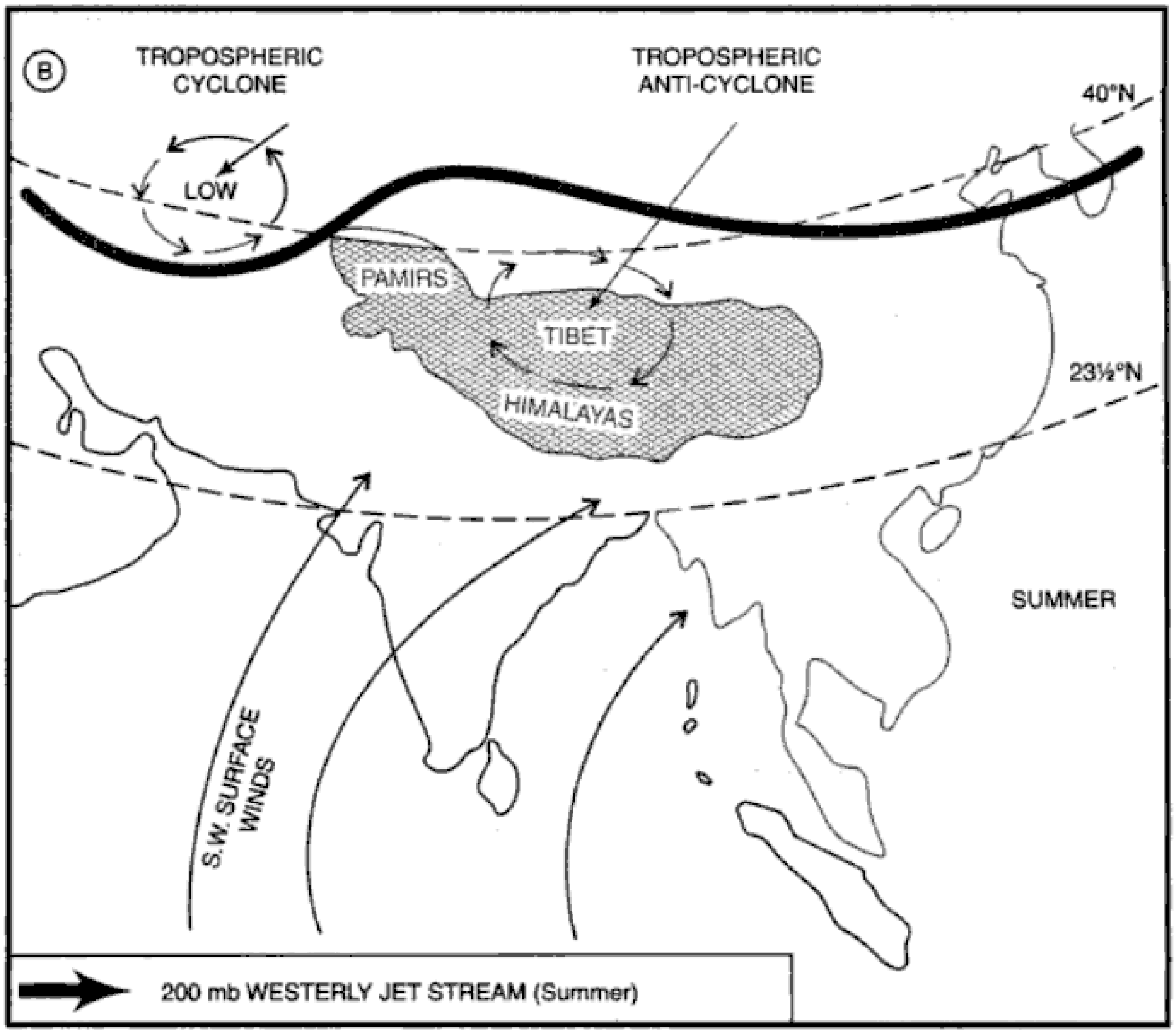

Fig. 4.8 Monsoon and the Tibetan-Himalayan Highlands

According to Maung Tun Yin, the Tibetan Plateau acts as a physical barrier. At the beginning of June, the subtropical jet stream disappears completely over northern India **(Fig. 4.7).** At this time, the jet stream shifts to the north of the Himalayas and Tibet, and takes up a position at about 40° N. Yin considers that there is a correspondence between the shifting of the jet and the slowing down of the westerlies over the whole of Eurasia. In fact, the plateau of Tibet becomes very cold in winter, and proves to be the most important factor in causing the advance of the jet far to the south in the middle of October. Thus, he opines that the abrupt onset of summer monsoon at the beginning of June is prompted by the hydro-dynamic effect of the Himalayas and not by the thermally induced low pressure centre over northwest India. In the middle of October, the plateau proves to be the most important factor in causing the advance of the jet south of the Himalayas or bifurcate it into two parts **(Fig. 4.7).**

The summer-time heating of the Tibetan Plateau makes it a high-level heat source. This 'Heat Engine' produces a thermal anticyclone over this region. A warm core anticyclone (high pressure) is formed over this plateau during the summer monsoon period. The formation of this anticyclone takes place in the middle part of the troposphere at 500 mb level. It is the result of a process called anti-cyclogenesis. However, on the southern side of this upper air anticyclone, the direction of air flow is from east to west. In fact, these easterly winds blowing in the mid-troposphere are known as tropical easterly jets. **Fig. 4.8** shows the meridional cross section of the Indian summer monsoon and its relationship with the Tibetan-Himalayan Highlands.

The abrupt arrival of monsoon is of great climatic and social significance to the people of the subcontinent of India. The onset of monsoon puts an end to the scorching weather and the local hot winds *(loo)* in the northern plains of India. The relative humidity increases in the atmosphere tremendously. The arrival of monsoon is also the beginning of agricultural operations for the kharif crops in the rain-fed areas. The high temperature and high relative humidity are, however, oppressive and injurious to health. It is in the season of general rains (July to September) that people suffer from many diseases and epidemics.

BREAKS IN THE MONSOONS

The migration of the monsoon rainfall zone is one of the major sub-seasonal variations of the summer (or south-westerly) monsoon. Thus, the monsoon is not a continual deluge of a number of months, duration, but has inter-seasonal variability; being made of a series of discrete events, both pluvial and dry. Viewed locally, these are the active and break monsoons respectively which exist on a time scale ranging from a few days to few weeks. Thus, while the monsoon appears to have a well-defined annual cycle, closer examination shows that the monsoon has substantial variability which becomes evident as the intensity of monsoon rains wax and wane through the wet season. Periods during which there is a rapid succession of weather disturbances or storms lasting a few days are referred to as *active periods* of the monsoon. Periods during which there is no rainfall for few days are the *break periods* of the monsoon. During an active phase, the Tropical Easterly Jet Stream (TEJ) remains very strong in the upper troposphere indicating strong convection and latent heating. But, when the maximum cloudiness remains locked up in the foothills of the Himalayas and the monsoon rainfall zone moves in this direction, subsidence occurs to produce a weak easterly flow in the upper troposphere. This creates the condition of break in monsoons.

In break monsoon condition, there is a general rise of pressure (as well as temperature) over the country and the isobars show marked refraction along the west coast. Cloudiness decreases and the south-easterlies at the surface levels over northern India are replaced by hot westerly air which blows over the plains, since the broad-scale surface pressure (the monsoon trough) shifts to the Himalayas and the rainfall practically ceases over the country outside the Himalayan regions and the southern slopes of the Himalayas, leading to high floods in the plains of these Himalayan rivers. Thus, though there is no rain over the plains, all the major northern and eastern Indian rivers rise and floods ensue.

Under weak monsoon conditions and in the years when the eastern end of the axis of the monsoon trough is oriented southward in Orissa, Jharkhand, Chhattisgarh and Madhya Pradesh, a low valley trough develops over the Assam Plain aligned along river Brahmaputra between the eastern Himalayas and the Shillong Plateau. The vertical extent of this low valley trough is 2 to 3 kilometres with the south west Monsoon lying to the south of the trough, remaining independent of the main monsoon trough. But, when the latter moves northwards and extends to the Himalayas, it joins the trough over the Assam Plain to cause heavy rainfall there.

The break in monsoon conditions generally occurs in the peak months of July and August, and lasts for at least 3 to 5 days over 500 to 1000 kilometres length in these months. The breaks occur

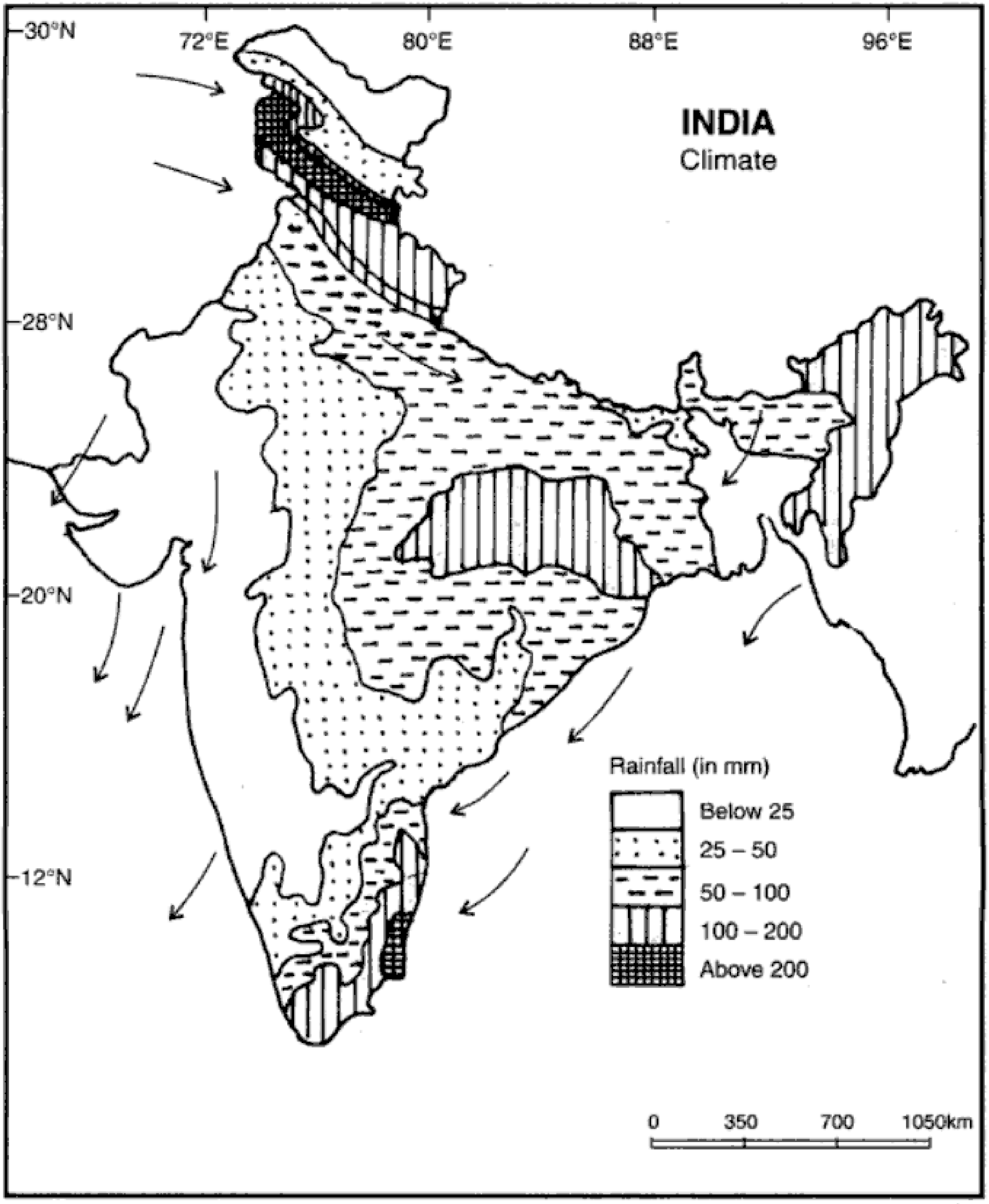

Fig. 4.13 Rainfall and Winds in January

and Haryana. Temperature exceeding 54°C was recorded at Sri Ganganagar in 1967. At some places, particularly in north-western India, day temperature may be as high as 45°C or 47°C. The mean minimum daily temperature in May also remains quite high being about 26°C at Delhi and Jaipur. The temperature in the eastern states of India and in the hilly regions in the month of May is generally cool and invigorating **(Fig. 4.14)**.

In the month of April the 30°C isotherm of average temperature encloses a vast area of the country between 10°N and 26°N latitudes (except the west coast and the hilly states of north -east India). The diurnal range of temperature ranges between 5°C and 6°C in coastal areas, but reaches 20°C in the interior parts of the country and in the north-west Satluj Ganga Plains.

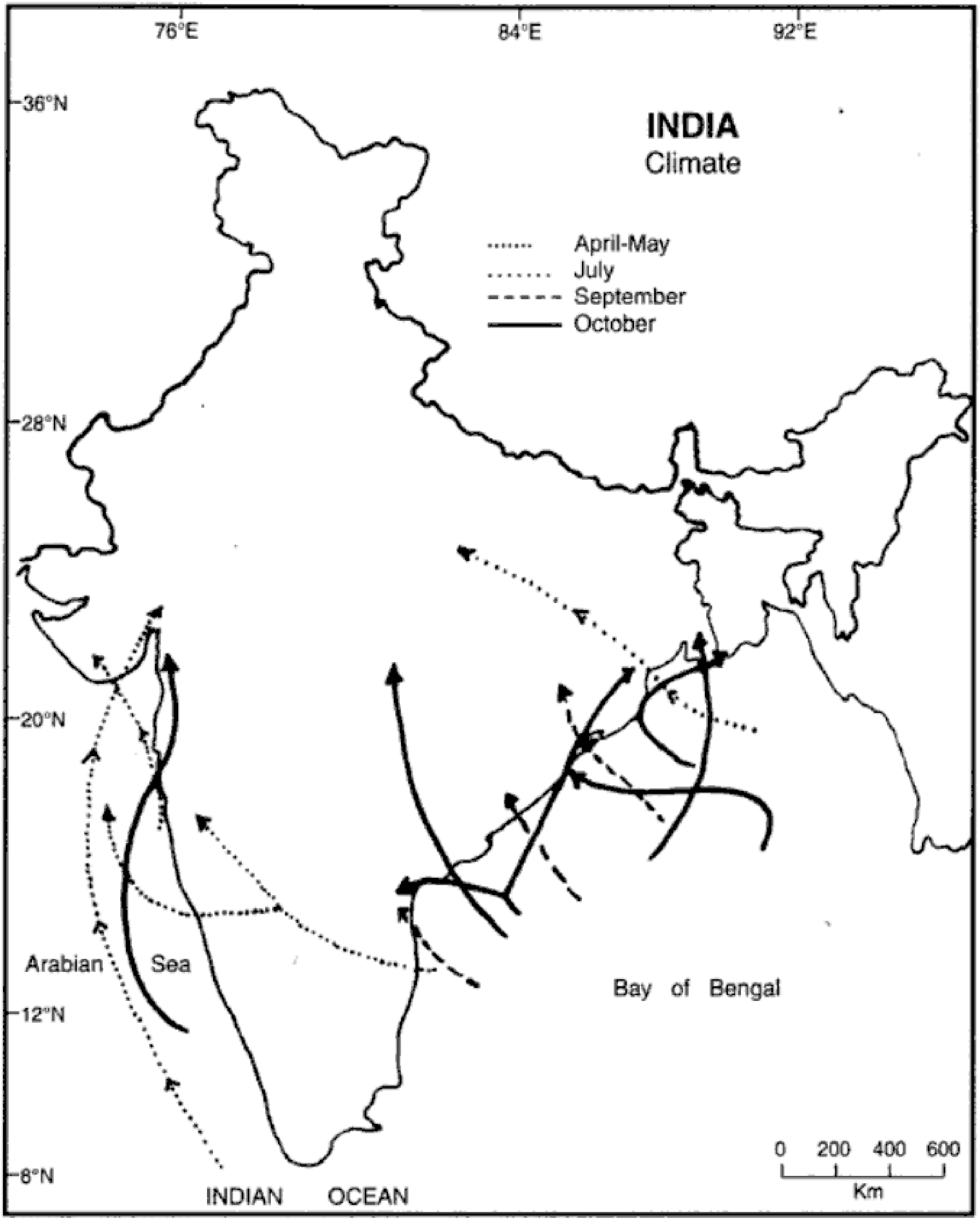

Fig. 4.17 Cyclones

The distribution of rainfall during the rainy season has been plotted in **Fig. 4.16.** It may be seen from this figure that the western coast, Sahyadris, Meghalaya, Arunachal Pradesh, Mizoram, Nagaland, Sikkim, and Darjeeling hills get more than 200 cm of rainfall. The remaining parts of north-eastern India, West Bengal, Orissa, Jharkhand, Bihar, Chhattisgarh, the Tarai region and hills of Uttarakhand receive rainfall between 100 to 200 cm. Similarly, the southern and western Uttar Pradesh, northern and western Madhya Pradesh, eastern Maharashtra and Gujarat, and northern Andhra Pradesh experience rainfall between 50 and 100 cm. Rajasthan, western Gujarat, southern Andhra Pradesh, Karnataka plateau, Tamil Nadu, plains of Haryana, Punjab, and Jammu and Kashmir receive less than 60 cm of rainfall. The lowest rainfall is recorded in the Thar desert along the border of Pakistan, and the Ladakh region of Jammu and Kashmir state (**Fig. 4.18**).

It may be noted from **Fig. 4.20** that the highest variability is found in the areas where the average annual rainfall is the lowest. For example, the desert areas of Barmer, Ganganagar, Jaisalmer, Jodhpur, etc. have less than 20 cm of average annual rainfall. In these areas the variability of rainfall is around 60 per cent. Contrary to this, in the areas where the average annual rainfall is over 200 cm (Mawsynram and Cherrapunji, Meghalaya Plateau), the annual variability of rainfall is less than 10 per cent. The Western slopes of Western Ghats, the Lesser Himalayas, the Shiwaliks and the Tarai belt also record between 100–200 cm of average annual rainfall. The variability of rainfall in these regions is around 10 to 20 per cent. Thus, there is an inverse relationship between the average annual rainfall and variability in rainfall.

The variability of rainfall has a significant role in the agricultural operations and other economic activities of the country. The areas showing high variability of rainfall have chronic deficiency of water. Such regions are highly prone to droughts, floods and famines, while the areas with high average annual rainfall are less affected by droughts; though flood is a regular feature in flood prone areas.

CLIMATIC REGIONS OF INDIA

India is often referred to as a country with tropical monsoon type of climate. The large size of India, its latitudinal extent, the presence of the Himalayas in the north, and the Indian Ocean, Arabian Sea and Bay of Bengal in the south have resulted in great variations in the distribution of temperature and precipitation in the subcontinent of India.

A number of attempts have been made by climatologists, geographers and experts of agriculture to divide India into climatic regions. While some of these classifications have been suggested for world climates, others are exclusively applied to Indian conditions. Some of the important climatic divisions of India were made by the following experts:

1. H.E. Blandford, 1889
2. W. Koppen, 1918, 1931, 1936
3. C.W. Thornthwaite 1931,1933, 1948
4. L.D. Stamp and W.G. Kendrew, 1953
5. S.P. Chatterji, 1953
6. G.T. Trewartha, 1954
7. V.P. Subramanyam, 1956
8. B.L.C. Johnson, 1969
9. K.L Rao, et.al., 1971
10. R.L. Singh, 1971

A systematic study of the climatic divisions of India was attempted for the first time by H.E. Blandford—the first Director General of the Indian Meteorological Department—in 1889, who discovered that all types of climates found in the world are present within the subcontinent of India. This classification based on temperature and rainfall of a few selected stations of India was almost an overgeneralisation. A brief description of some of the important classifications of Indian climate has been given in the following:

5. *The Transitional Zone*

This climate is found in Eastern Uttar Pradesh, western and north-western Bihar, and north-western Jharkhand. The average annual rainfall in this zone varies between 100 to 150 cm. Over 90 per cent of the total annual rainfall is recorded during the season of general rains from the Bay of Bengal stream of the South-West Monsoon. The mean January temperature reads about 15°C while the mean maximum in the month of July reads over 40°C.

B. Tropical India

1. *Region of Very Heavy Rainfall*

This climatic divison stretches over Assam, Meghalaya, Nagaland, Manipur, Tripura and Mizoram. The average annual rainfall in these areas is over 200 cm. The heaviest rainfall in the world is recorded in this region at the stations of Mawsynram and Cherrapunji. Over 90 per cent of the average annual rainfall is recorded during the season of the South-West Monsoon. There are significant variations in the mean monthly temperature of January and July owing to undulating and mountainous topography.

2. *Region of Heavy Rainfall*

This region covers West-Bengal, Orissa, Jharkhand and eastern parts of Andhra Pradesh. The average annual rainfall in this region varies between 100–200 cm. There is a general decrease in the amount of rainfall from east to west. The mean January temperature is over 18°C, while about 30°C is recorded during the months of June and July.

3. *Region of Moderate Rainfall*

This region lies to the east of the Western Ghats and includs Gujarat, south-western Madhya Pradesh, Maharashtra, Karnataka and greater parts of Andhra Pradesh. Being in the rain-shadow area of the Western Ghats, this region receives relatively less rainfall of about 75 cm. The average temperature in the months of January and July is about 18°C and 32°C respectively.

4. *The Konkan Coast*

It stretches from the mouth of Tapi river to Goa. The average annual rainfall is more than 200 cm, of which over 90 per cent is recorded from the Arabian stream of the South-West Monsoon. The mean January temperature remains around 24°C while the mean July temperature reads about 27°C. The average annual range of temperature varies between 3°C to 6°C depending on the distance from the coast and the equator. In general, the annual range of temperature increases from south to north.

5. *The Malabar Coast*

This climatic division lies between Goa and Cape Camorin (Kanniyakumari). The Malabar coast records over 250 cm of rainfall. The average annual temperature reads around 27°C with 3°C being the annual range of temperature. Kochi is a typical example of this region.

6. *The Tamil Nadu Coast*

This region includes the greater parts of the state of Tamil Nadu and the Coromandal Coast. The average annual rainfall varies between 100–150 cm. Most of the rainfall is recorded during the season of retreating monsoon (October to December). The average temperature for the month of January is 24°C, while the July temperature reads around 30°C.

CLIMATIC DIVISIONS OF INDIA BY R.L. SINGH (1971)

Professor R.L. Singh modified the climatic divisions of Stamp and Kendrew in 1971. Prof. Singh has divided India into 10 major climatic divisions. His classification is quantitative as well as qualitative, largely based on the amount of rainfall and temperature. In fact, the modifications have been done on the basis of variations in temperature **(Fig. 4.24)**. A brief account of Singh's classification has been presented in the following section:

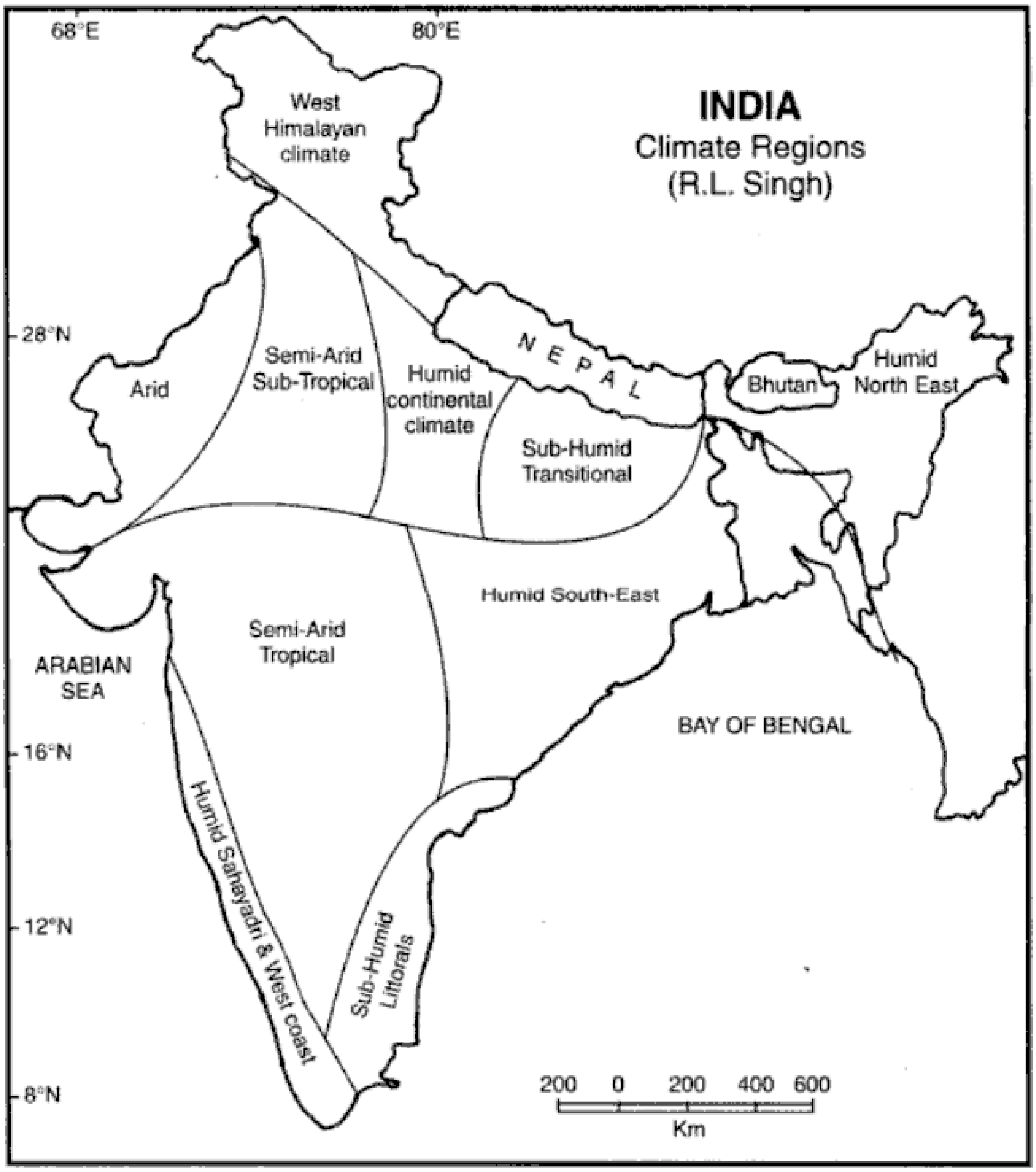

Fig. 4.24 R.L. Singh's Climatic Divisions

I. The Humid North-East

This climatic division includes the whole of north-east India (except Tripura), Sikkim and north-western West Bengal. The average annual rainfall in this climatic division is more than 200 cm. The mean July temperature varies between 25°C and 33°C, while mean January temperature reads between 10°C and 25°C.

(i) to make judicious and scientific utilisation of agricultural land, water and livestock resources,
(ii) to enhance and stabilise the income of the people of drought prone areas, particularly of the weaker section of society, and
(iii) restoration of ecological balance.

Some of the important elements of the programme include:

(a) Integrated watershed management and management of water resources.
(b) Soil and moisture conservation measures.
(c) Afforestation with special emphasis on social and agro-forestry.
(d) Development of pasture lands and forest range management in conjunction with development of sheep husbandry.
(e) Livestock development and dairy development.
(f) Restructuring of cropping patterns and changes in agronomic practices.
(g) Adoption of scientific rotation of crops with an emphasis on the leguminous (pulses) crops.
(h) Development of subsidiary occupations.
(i) Water harvesting.
(j) Development of minor irrigation projects.
(k) Construction of underground canals and lined canals.
(l) Desalination of sea-water for irrigation and domestic use.
(m) Diversification of agriculture.
(n) Development of cottage and household industries.
(o) Development of alternate sources of energy (solar, wind and biogas) for domestic and industrial purposes.
(p) More research is required to increase agricultural productivity in the dry farming regions.

These steps, if taken together, can go a long way in minimising the miseries of people living in the drought prone areas of the county.

Some of the important achievements of the Drought Prone Area Programme include the Indira Gandhi Canal Project, Sardar Sarovar Project (Narmada), and the Central Arid Research Institute, Jodhpur to promote drought resistant plants, trees and crops.

FLOODS

Floods occur when peak discharge exceeds channel capacity, and this may be brought about naturally by intense precipitation, snow and ice-melt, storm surges in coastal regions, and the rifting of barriers, such as ice-dams, or by the failure of man-made structures, by deforestation, urbanisations, (which reduce infiltration and interception), and by engineering works such as land drainage or the straightening of embankments of rivers.

Flood has also been defined as a state of high water level along a river channel or coast that leads to inundation of land which is normally submerged. Flood is an important component of hydrological cycle of a drainage basin. In fact, droughts and floods are the two extremes of the hydrological cycle. While droughts occur due to the failure of rainfall; floods generally occur in the event of excessive rainfall. Thus, flood is a natural hazard which occurs in response to heavy rains and it becomes a disaster when it inflicts heavy loss to life and property.

Causes of Floods

The main factors responsible for the occurrence of floods are: (i) Meteorological, (ii) Geomorphic, and (iii) Anthropogenic.

Construction of buildings, factories, etc. in the zone adjacent to the river channels should be prohibited. The areas occasionally flooded after a few years should be under green-belts in which social forestry is a priority.

7. Other Measures

The following additional measures are suggested by the Flood Control Commission: (i) restriction on indiscriminate felling of trees in hilly regions, (ii) protecting one kilometre tract along the major rivers for massive afforestation, where agriculture and house construction prohibited, (iii) Regular dredging of river beds, (iv) formation of National Water Grid through which flood waters could be diverted to dry areas through diversion channels or could be stored in reservoirs, (v) to develop suitable drainage channels in water-logged areas, and (vi) engineering effective methods to protect the coastal areas from tides and sea-surges.

Flood Control Programme and Strategies

The National Flood Control Programme was launched in India after the devastating flood of 1954. The programme consists of three phases which have been briefly described in the following section:

1. **The Immediate Phase:** This phase extends over two years and includes the collection of basic hydrological data and execution of immediate flood protection measures like construction of embankments, improvement of river channels and raising the vulnerable villages above the flood level.
2. **The Short-Term Phase:** This phase lasts for the next five years. In this phase there is emphasis on improvement of surface drainage, establishment of effective flood warning system, shifting or raising of villages above flood level, construction of diversion channels, construction of embankments and raised platforms to be used during the period of floods.
3. **The Long-Term Phase:** The long-term phase includes construction of dams and storage reservoirs, digging large diversion channels, taking suitable steps for land-use improvement, and soil conservation in the catchment area of the main river and its tributaries.

In order to overcome the problem of floods in the country, the Government of India has set up a National Flood Commission ***(Rashtriya Barh Ayog)***. This Commission has taken a holistic view of the flood problem. Many multi-purpose projects and large dams have been constructed to overcome this problem. Recently, the Brahmaputra River Board has been constituted to control floods in the Brahmaputra Valley.

REFERENCES

Blandford, W.T., 1876, 'Physical Geography of Indian Desert', ***Journal of Asiatic Society of Bengal.***

Chang, C.P., and Krishnamurti, T.N. 1987, ***Monsoon Meteorology,*** Oxford University Press, Oxford.

Chatterji, A.K., (1992), ***Monsoons, Cyclones and Floods in India,*** Birla Economic Research Foundation, New Delhi, Radiant Publishers.

Das, P.K., (1968), ***The Monsoon,*** National Book Trust, New Delhi.

Deshpande, C.D., 1987, ***India: A Regional Interpretation,*** Indian Council of Social Science Research and Northern Book Centre, New Delhi.