Gulmarg or Pahalgam in Kashmir at the same time.

2. On a December night, the temperature may dip to –40°C at Dras or Kargil in J&K while it may be as high as 20°C-22°C at Thiruvananthapuram or Chennai at the same time.
3. Mawsynram in Meghalaya receives as high as 1,221 cm of annual rainfall while at Jaisalmer (Rajasthan) the annual rainfall rarely exceeds 12 cm. Tura, in the Garo Hills, may sometimes receive as much rainfall in a single day as is received by Jaisalmer in 10 years.
4. The Ganga delta and the coastal plains of Odisha are hit by strong rain storms almost every third or fifth day in July and August, while the Coromandel Coast, a thousand kilometres to the south, goes dry during these months.
5. The people of Mumbai and the Konkan Coast do not have to suffer the extremes of climate but these extremes affect the life of people of interior parts of the country such as Delhi and Agra.
6. Places like Goa, Hyderabad, Bhubaneshwar and Patna get rains by the first quarter of June while the rains are awaited till the end of June or early July at places like Agra, Delhi and Chandigarh.

Rem broad points

FACTORS INFLUENCING THE CLIMATE OF INDIA

The climate of India is a complex phenomenon and is influenced by a large number of geographical factors. Some of the important factors are briefly discussed as under :

1. Location and Latitudinal Extent. The mainland of India extends roughly from 8°N to 37°N and the Tropic of Cancer passes through the middle of the country. Areas south of the Tropic of Cancer are closer to the equator and experience high temperature throughout the year. The northern parts on the other hand lie in the warm temperate zone. Hence they experience comparatively lower temperatures. Some places record considerably low temperatures particularly in winter. Water bodies comprising the Arabian sea and the Bay of Bengal surround the peninsular India and make climatic conditions mild along the coastal areas.

2. Distance from the Sea. Areas near the coast have equable or *maritine climate*. On the contrary, interior locations are deprived of the moderating influence of the sea and experience extreme or *continental climate*. For example the annual range of temperature at Kochi does not exceed 3°C whereas it is as high as 20°C at Delhi. Similarly, the amount of annual rainfall at Kolkata is 119 cm which falls to a low of 24 cm at Bikaner.

3. The Northern Mountain Ranges. As mentioned earlier, India is separated from the rest of Asia by the impenetrable wall of the Himalayan mountain ranges. These ranges protect India from the bitterly cold and dry winds of Central Asia during winter. Further, these mountain ranges act as an effective physical barrier for rain bearing south-west monsoon winds to cross the northern frontiers of India. Thus, the Himalayan mountain ranges act as a climatic divide between the Indian Sub-continent and Central Asia.

4. Physiography. Physiography of India has a great bearing on major elements of climate such as temperature, atmospheric pressure, direction of winds and the amount of rainfall. In fact, physical map of India is very closely related to the climatic conditions of the country. Places located at higher altitude have cool climate even though they are located in the peninsular India, *e.g.*, Ooty. Several hill stations and the Himalayan ranges are much cooler than the places located in the Great Plain of North India. The greatest control of physiography in the peninsular India is seen in the distribution of rainfall. The south-west monsoon winds from the Arabian sea strike almost perpendicular at the Western Ghats and cause copious rainfall in the Western Coastal plain and the western slopes of the Western Ghats. On the contrary, vast areas of Maharashtra, Karnataka, Telangana, Andhra Pradesh and Tamil Nadu lie in *rainishadow* or *leewoad* side of the Western Ghats and receive scanty rainfall. The physiographic control of the mighty Himalayas over the climate of the country goes without saying. The monsoon winds from the Bay of Bengal are bifurcated into two branches by the physiographic features. One branch goes to the

Brahmaputra valley through the Meghalaya plateau. Here the funnel shaped Cherrapunji valley forces the moisture laden monsoon winds to rise along the steep slope and make this area the wettest place in the world. The other branch of monsoons from the Bay of Bengal enters the Ganga valley. Its northward-movement is obstructed by the Himalayan ranges and it advances westwards up the Ganga plain. Initially this branch causes heavy rainfall but the amount of rainfall decreases as the monsoons loose much of the moisture content while advancing westwards.

5. Monsoon Winds. The most dominating factor of the Indian climate is the 'monsoon winds' as a result of which it is often called the ***monsoon climate***. The complete reversal of the monsoon winds brings about a sudden change in the seasons—the harsh summer season suddenly giving way to eagerly awaited monsoon or rainy season. The south-west summer monsoons from the Arabian sea and the Bay of Bengal bring rainfall to the entire country. The north-eastern winter monsoon travel from land to sea and do not cause much rainfall except along the Caromandel coast after getting moisture from the Bay of Bengal.

6. Upper Air Circulation. The changes in the upper air circulation over Indian landmass influences the climate of India to a great extent. Jet streams in the upper air system influence the Indian climate in the following ways :

(*i*) ***Westerly Jet Stream.*** Westerly jet stream blows at a very high speed during winter over the sub-tropical zone. This jet stream is bifurcated by the Himalayan ranges. The northern branch of this jet stream blows along the northern edge of this barrier. The southern branch blows eastwards south of the Himalayan ranges along 25° north latitude. Meteorologists believe that this branch of jet stream exercises a significant influence on the winter weather conditions in India. This jet stream is responsible for bringing western disturbances from the Mediterranean region in to the Indian sub-continent. Winter rain and heat storms in north-western plains and occasional heavy snowfall in hilly regions are caused by these disturbances. These are generally followed by cold waves in the whole of northern plains.

(*ii*) ***Easterly Jet Stream.*** Reversal in upper air circulation takes place in summer due to the apparent shift of the sun's vertical rays in the northern hemisphere. The westerly jet stream is replaced by the easterly jet stream which owes its origin to the heating of the Tibet plateau. This leads to the development of an easterly cold jet stream centered around 15°N latitude and blowing over peninsular India. This helps in the sudden onset of the south-west monsoons.

7. Tropical Cyclones and Western Disturbances. Tropical cyclones originate in the Bay of Bengal and Arabian Sea and the influence large parts of the peninsular India. Majority of the cyclones originate in the Bay of Bengal and influence the weather conditions during the south-west monsoon season. Some cyclones are born during the retreating monsoon season, *i.e.*, in October and November and influence the weather conditions along the eastern coast of India.

The western disturbances originate over the Mediterranean sea and travel eastward under the influence of westerly jet stream. They influence the winter weather conditions over most of Northern-plains and Western Himalayan region.

8. El-Nino Effect. El-Nino is a narrow warm current which occasionally appears off the coast of Peru in December (See **Fig. 5.9**). It is a temporary replacement of the cold Peru current which normally flows along the coast. This current is responsible for wide spread floods and droughts in the tropical regions of the world. Sometimes it becomes more intense and increases the surface water temperatures of the sea by 10°C. This warming of tropical Pacific waters affects the global pattern of pressure and wind systems including the monsoon winds in the Indian Ocean. Meteorologists believe that the severe droughts of 1987, 2009 and 2014 in India were caused by El-Nino.

9. La Nina. After an El-Nino, weather conditions return to normal. However, some times trade winds become so strong that they cause abnormal accumulation of cold water in the central and eastern Pacific region. This event is called ***La Nina***, which in effect is the complete reversal of El Nino. A La Nina also marks an active hurricane season. But in India, the presence of La Nina portends exceptionally good news. It is the harbinger of heavy monsoon showers in India.

La Nina usually follows a strong El Nino. How the two weather pattern anomalies compare :

El Nino the little boy	La Nino the little girl
• Trade winds weaken, warm waters move east	• Strong Pacific trade winds blow from surface water westward.
• Pacific jet stream is pulled further south than normal; picks up storms the jet stream could normally miss	• Cold water rises to the surface
• Weakens Indian monsoons	• Strengthens Indian monsoons
• El Nino occurs after 3 to 5 years	• La Nino occurs roughly half as often as El Nino; lasts from 1 to 3 years.

10. Southern Oscillation. There is a strange linkage of meteorological changes often observed between the Indian and the Pacific Oceans. It has been noticed that whenever the surface level pressure is high over the Indian Ocean, there is low pressure over the Pacific Ocean and *vice-versa*. This inter-relation of high and low pressure over the Pacific and the Indian Ocean is called ***Southern Oscillation***. When the winter pressure is high over the Pacific Ocean and low over the Indian ocean, the south-west monsoons in India tend to be stronger. In the reverse case, the monsoons are most likely to be weaker.

THE MONSOON WINDS

The term monsoon has been derived from the Arabic *mausin* or from the Malayan *monsin* meaning '*season*'. Thus the monsoons are seasonal winds which reverse their direction of flow with the change of season. They flow from sea to land during the summer and from land to sea during winter. In other words, the monsoon is a double system of seasonal winds, that is, the sum of summer and winter winds. There seems to be a lack of agreement on a precise definition of the monsoon and different scholars have tried to define the monsoon winds in different ways.

According to **A.A. Rama Sastry**, "*Monsoons are large scale seasonal wind systems flowing over vast*

is the key-note of the monsoonal climate". The reversal of the monsoon wind system is fully emphasised by **Conrad**. According to him, "*a true thermal monsoon demands a complete reversal of winds, that is an angle of about 180° between the dominant winds at extreme seasons*". This is further elaborated by **P.A. Menon**, when he expressed the opinion that "*the main criterion used in demarcating the monsoon areas is the reversal of wind systems between summer and winter*". Thus between July and January there should be a shift of nearly 180° in the prevailing wind direction with seasonal wind showing high degree of steadiness. The reversal of monsoon winds take place in a definite manner keeping rhythm with change of season. Therefore, it is often said that *rhythm is the key-note of the monsoonal climate.* Some scholars tend to treat the monsoon winds as land and sea breezes on a large scale. **Koppen** (1923), **Hann** (1932) and **Angot** (1943) believe that the "*monsoons represent simply a land and sea breezes on a large scale, and that the annual period of the monsoon corresponds to the diurnal period of the breezes*."

While discussing the monsoon winds **C.S. Ramage** (1971) suggested the following four features of monsoon winds :

(*i*) The prevailing wind direction should shift by at least 120° between January and July.

(*ii*) The average frequency of prevailing wind directions in January and July should exceed 40 per cent.

(*iii*) The mean resultant wind velocity in at least one of the months should exceed 3 m/s.

(*iv*) There should be fewer than one cyclone-anticyclone alternation every two years, in either month, over a five degree latitude/longitude grid.

On the basis of above criteria he demarcated the area of the monsoon region as a rectangle roughly extending from 35° N to 25° S latitudes and 30° W to 173° E longitudes.

Mechanism of the Monsoons

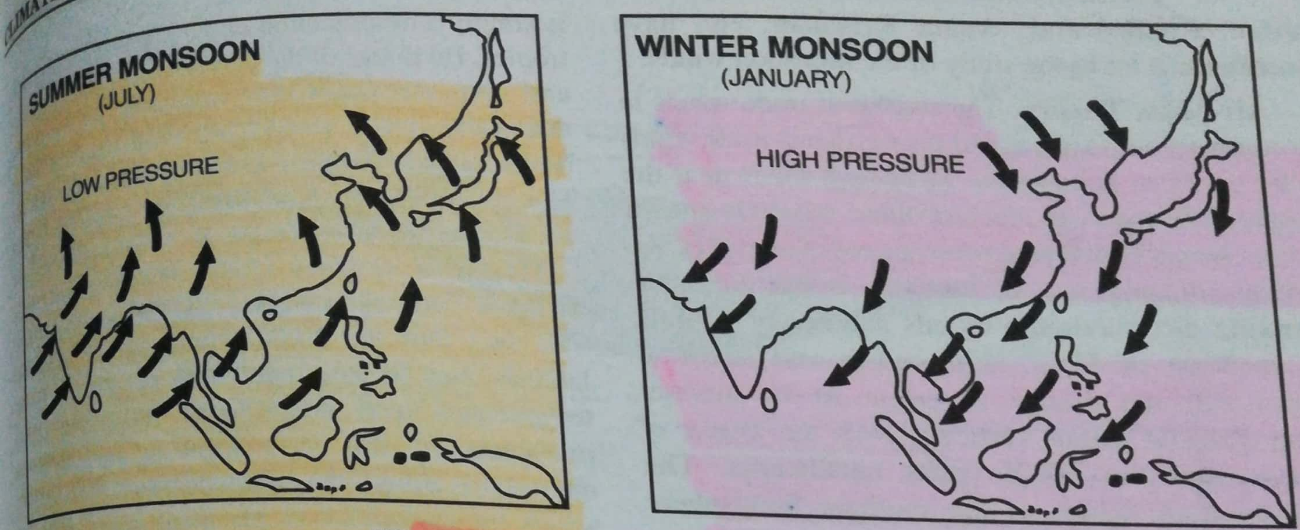


FIG. 5.1. Summer and Winter Monsoon

explanation is available till date. Over the years many mysteries of the monsoons have been unravelled but still much remains to be done. The theories regarding the monsoons are generally divided into following two broad categories :

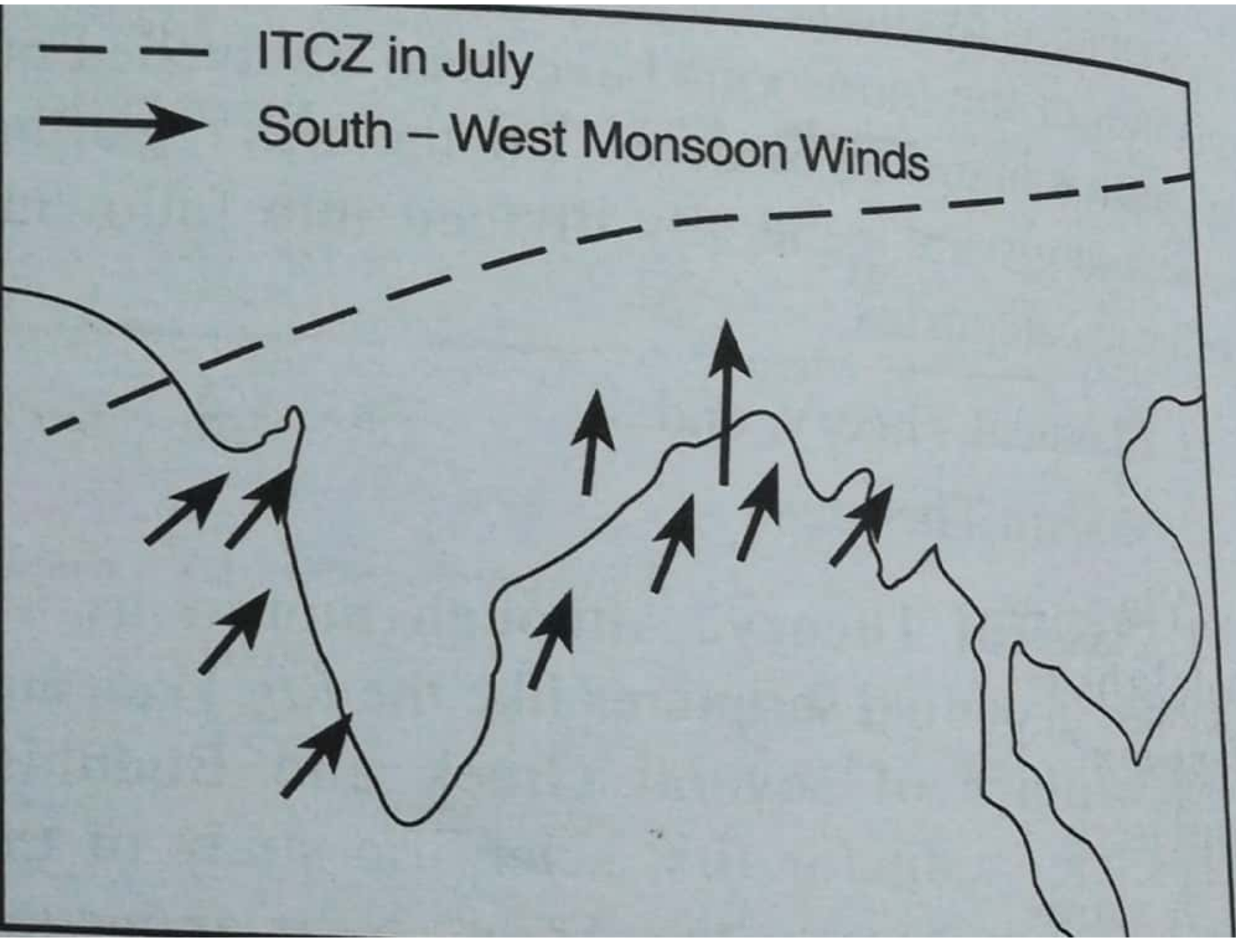
1. Classical Theory, and
2. Modern Theories.

1. Classical Theory. Although monsoons are mentioned in our old scriptures like the *Rig Veda* and in the writings of several Greek and Buddhist scholars, the credit for first scientific study of the monsoon winds goes to the Arabs. Near about the tenth century, Al Masudi, an Arab explorer from Baghdad, gave an account of the reversal of ocean currents and the monsoon winds over the north Indian Ocean. Date of commencement of

(*b*) ***Winter Monsoon.*** In winter the sun shines vertically over the Tropic of Capricorn. The north western part of India grows colder than Arabian Sea and Bay of Bengal and the flow of the monsoon is reversed (**Fig. 5.1**).

Halley's ideas are basically the same as those involved in land and sea breeze except that in the case of the monsoon day and night are replaced by summer and winter, and the narrow coastal strip and adjacent sea are replaced by large portions of continents and oceans.

2. Modern Theories. Halley's classical theory based on differential heating of land and water as the main driving force of the monsoon winds dominated the scene for about three centuries. However, th



Ped
Mo
the
5.4

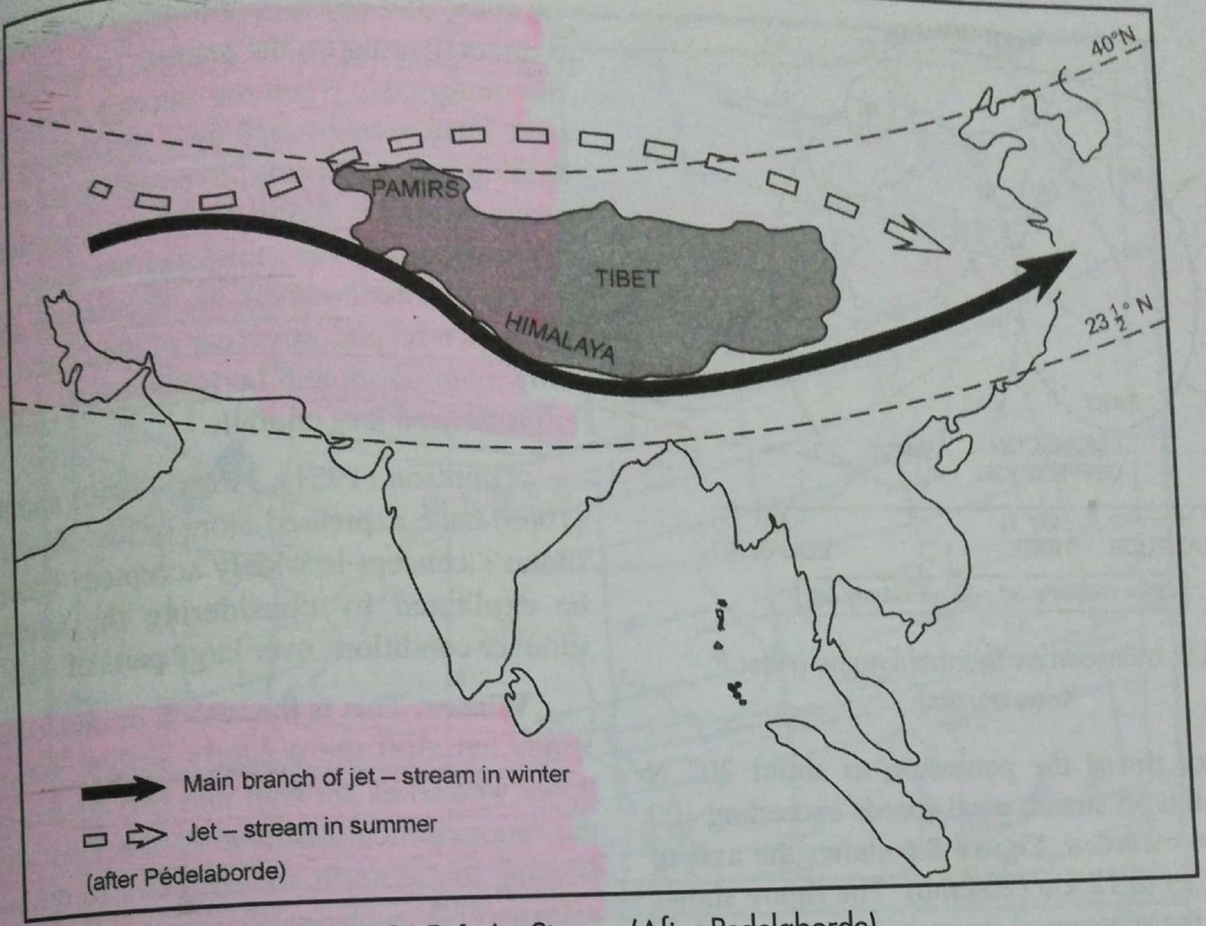


FIG. 5.4. Jet Stream (After Pedelaborde)

Yin's ideas are well recognised by **Pierre Pedelaborde** (1963), in his book entitled ***'The Monsoon'***. The map, showing the seasonal shift of the westerly jet stream, has been reproduced in **figure** 5.4. It shows that in winter the western jet stream flows along the southern slopes of the Himalayas but in summer it shifts northwards, rather dramatically, and flows along the northern edge of the Tibet Plateau. The periodic movements of the Jet stream are often indicators of the onset and subsequent withdrawal of the monsoon.

P. Koteswaram (1952), put forward his ideas about the monsoon winds based on his studies of upper air circulation. He has tried to establish a relationship between the monsoons and the atmospheric conditions prevailing over Tibet Plateau. Tibet is an ellipsoidal plateau at an altitude of about 4,000 m above sea level with an area of about 4.5 million sq km This plateau is surrounded by mountain ranges which rise 6,000-8,000 m above sea level. It gets heated in summer and is 2°C to 3°C warmer than the air over the adjoining regions. Koteswaram, supported by Flohn, feels that because the Tibet Plateau is a source of heat for the atmosphere, it generates an area of rising air. During its ascent the air spreads outwards and gradually sinks over the equatorial part of the Indian Ocean. At this stage, the ascending air is deflected to the right by the earth's rotation and moves in an anti-clockwise direction leading to anticyclonic conditions in the upper troposphere over Tibet around 300-200 mb (9 to 12 km). It finally approaches the west coast of India as a return current from a south-westerly direction and is termed as equatorial westerlies (**Fig. 5.5**). It picks up moisture from the Indian Ocean and causes copious rainfall in India and adjoining countries.

The south-west monsoon in southern Asia is overlain by strong upper easterlies with a pronounced jet at 100 to 200 mb. These easterly winds, which often record speeds exceeding 100 knot are known as the ***Easterly Jet Stream of the tropics***. The Easterly Jet Stream was first inferred by P. Koteswaram and P.R. Krishna in 1952 and aroused considerable interest among tropical meteorologists. A careful study of the jets would suggest that the core of the easterly jet is at 13 km (150 mb) while that of the westerly jet is at 9 km. Over India, the axis of the strongest winds in the easterly jet may extend from

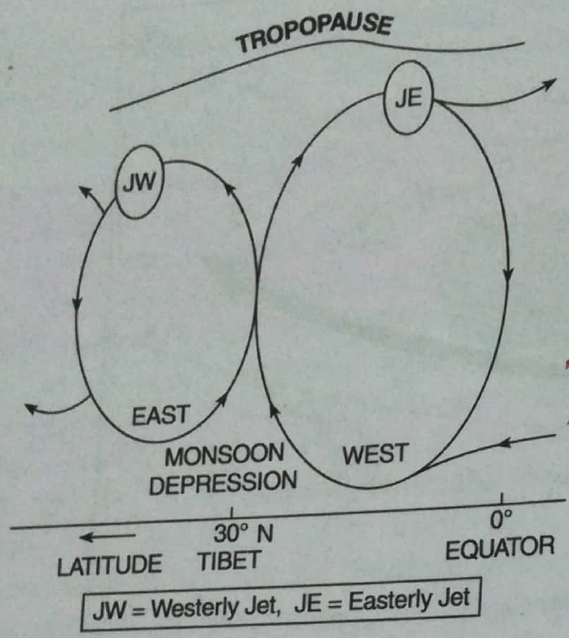


FIG. 5.5. Monsoon as Thermal Engine (After P. Koteswaram)

the southern tip of the peninsula to about 20° N latitude. In this jet stream wind speeds exceeding 100 knot may be recorded. **Figure 5.6** shows the axis of the easterly jet at 12 km (200 mb). The figure shows that there is the subtropical westerly jet to the north of the Himalayas besides the easterly jet over the peninsular India. It has already been made clear in **Fig. 5.4** that the westerly jet stream is located along the southern slopes of the Himalayas in winter but it suddenly shifts to the north with the onset of the monsoon. The periodic movements of the sub-tropical jet stream provide a useful indication of the onset and subsequent withdrawal of the monsoon. In fact, northward movement of the subtropical jet is the first indication of the onset of the monsoon over India.

Recent observations have revealed that the intensity and duration of heating of Tibet Plateau has a direct bearing on the amount of rainfall in India by the monsoons. When the summer temperature of air over Tibet remains high for a sufficiently long time, it helps in strengthening the easterly jet and results in heavy rainfall in India. The easterly jet does not come into existence if the snow over the Tibet Plateau does not melt. This hampers the occurrence of rainfall in India. Therefore, any year of thick and widespread snow over Tibet will be followed by a year of weak monsoon and less rainfall.

Thomson (1951), Flohn, (1960) and Stephenson (1965) have expressed more or less similar views but Flohn's concept is widely accepted. These ideas can be explained by considering the winter and the summer conditions over large parts of Asia.

Winter. This is the season of outblowing surface winds but aloft the westerly airflow dominates. The upper westerlies are split into two distinct currents by the topographical obstacle of the Tibet Plateau, one flowing to the north and the other to the south of the plateau. The two branches reunite off the east coast of China (**Fig. 5.7**). The southern branch over northern India corresponds with a strong latitudinal thermal gradient which, along with other factors, is responsible for the development of southerly jet. The southern branch is stronger, with an average speed of about 240 km p.h. at 200 mb compared with 70 to 90 km p.h. of the northern branch. Air subsiding beneath this upper westerly current gives dry outblowing northerly winds from the subtropical anticyclone over northwestern India and Pakistan. The surface winds blow from northwest over most parts of northern India.

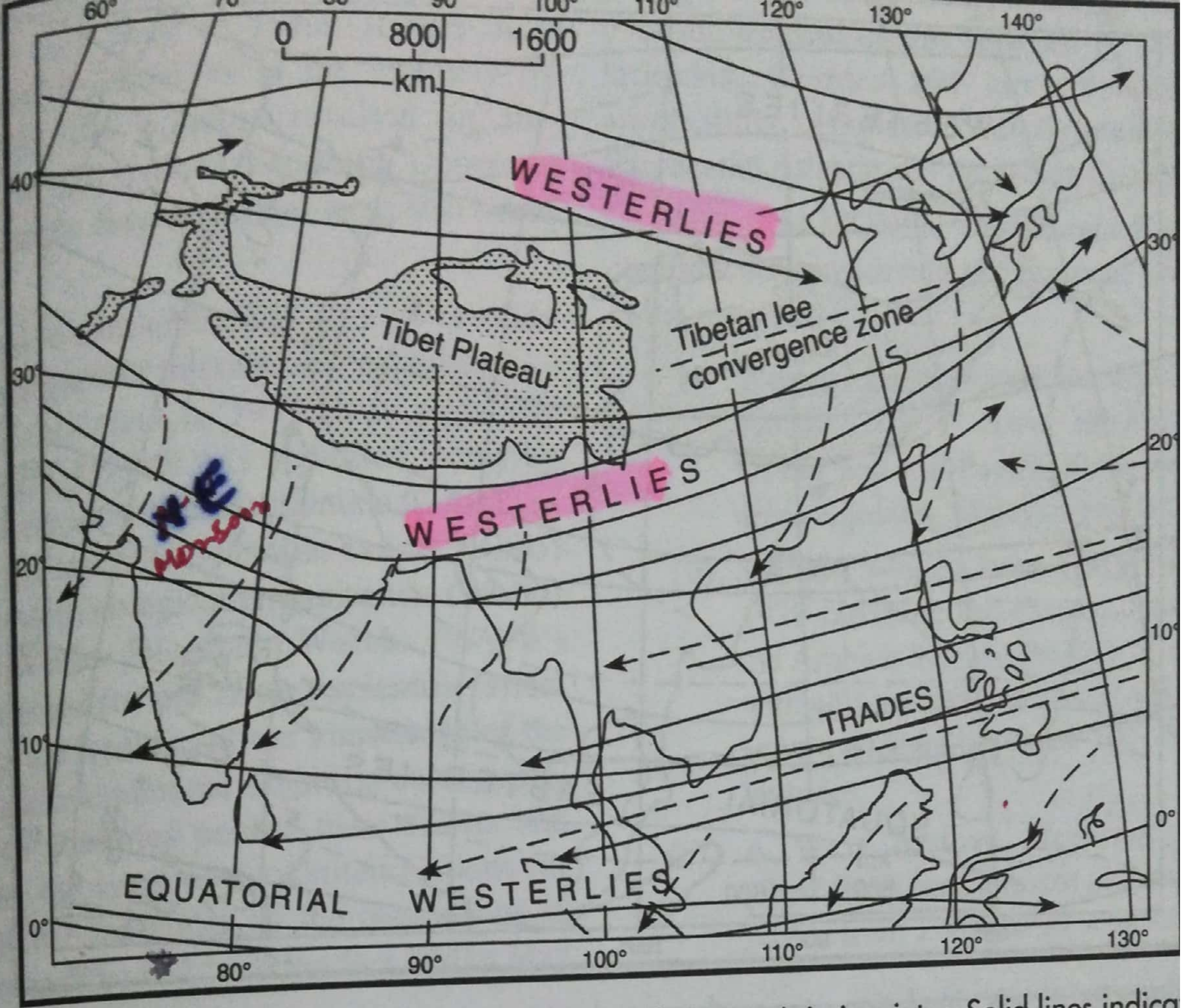


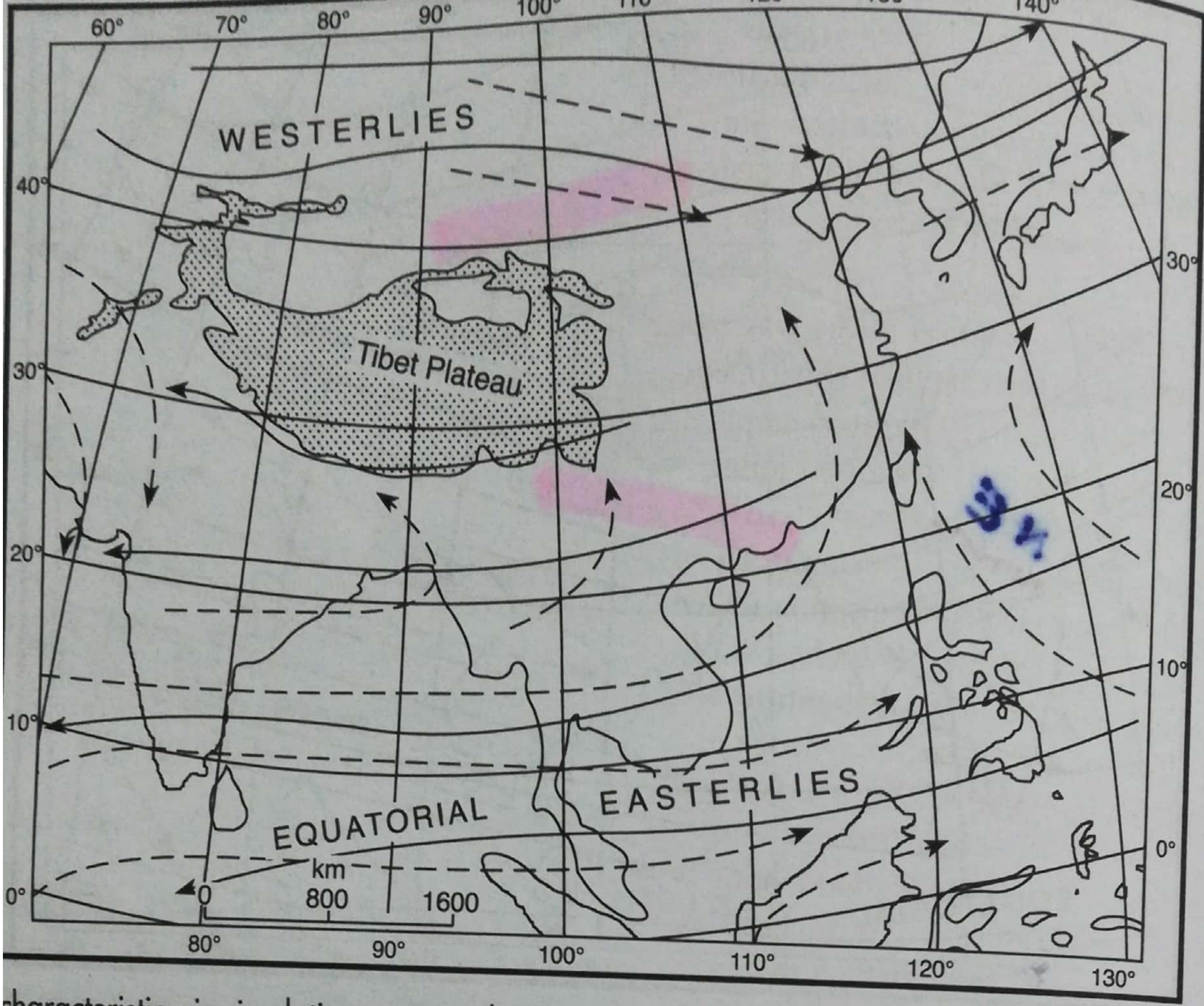
FIG. 5.7. The characteristic air circulation over southern and eastern Asia in winter. Solid lines indica[te] ... about 3000 m and dashed lines that at about 600 m. The names refer to the wind systems a[t] ...

The upper jet is responsible for steering of the western depressions from the Mediterranean Sea. Some of the depressions continue eastwards, redeveloping in the zone of jet stream confluence about 30° N, 105° E beyond the area of subsidence in the immediate lee of Tibet.

Summer. With the beginning of summer in the month of March, the upper westerlies start their northward march, but whereas the northerly jet strengthens and begins to extend across central China and into Japan, the southerly branch remains positioned south of Tibet, although weakening in intensity. The weather over northern India becomes hot, dry and squally due to larger incoming solar radiation. By the end of May the southern jet begins to break and later it is diverted to the north of Tibet Plateau. Over India, the Equatorial Trough pushes northwards with the weakening of the upper westerlies south of Tibet, but the burst of the monsoon does not take place until the upper-air circulation has switched to its summer pattern (Fig. 5.8). The low level changes are related to the

high level easterly jet stream over s... about 15° N latitude.

T.N. Krishnamurti used data ... atmosphere to calculate the patterns of c... convergence at 200 mb for the period o... 1967. He observed an area of strong ... 200 mb over northern India and ... coincides with the upper-level diverge... with the easterly jet. Similarly he fou... component to the flow from this ... represents the upper branch of the *Had*... happenings are closely related to the In... **S. Rama Rattan** opined that the d... monsoon winds is deeply connecte... stream in addition to the differential ... and sea. The upper air circulation i... anticyclonic pattern between 40° ... whereas cyclonic conditions prevail ... Western and eastern jets flow to the r... of the Himalayas respectively. Th... becomes powerful and is stationed at ... This results in more active south-wes...



characteristic air circulation over southern and eastern Asia in summer. Solid lines indicate air flow at ıt 6,000 m and dashed lines that at about 600 m. Note that the low-level flow is very uniform between ıt 600 and 3,000 m.

l is caused. **Raman** and **Ramanathan** ssing the tropical easterly jet stream at the easterly winds become very active troposphere after the beginning of the . The latent heat produced due to cloud s into *inversion of temperature* and causes **anth Krishnan** is of the opinion that the monsoons are deeply influenced by the cyclones in the upper troposphere ° and 25° N latitudes. These winds start in the beginning of the summer season o 30° N about 5-6 weeks later. Besides eat between 20° and 40° N latitudes gives ength to the south-west monsoons. **S. thy** in his essay on '*Trying to solve the Riddle*' expressed the view that the are influenced by the north-east trade weak north-east trade wind results in weak and leads to drought conditions.

ndian monsoons, particularly the south-west , have generated a lot of interest among the gists all over the world. Concerted efforts on data collection and of intensive studies of monsoon regimes by various meteorological services and organisations from different nations have been made during the last six decades. Much has been done but much more is yet to be done. The first attempt was made during International India Ocean Expedition (IIOE) from 1962 to 1965. It was organised jointly by the International Council of Scientific Unions. (ICSU), Scientific Committee on Ocean Research (SCOR) and UNESCO with World Meteorological Organisation (WMO) joining the meteorology programme. Special oceonographic and atmospheric studies were carried out with the aid of research vessels, instrumented aircrafts, rockets as well as special upsonde and dropsonde soundings. Two more experiments were conducted, jointly, by India and the former USSR in 1973 and 1977, with limited participation from other countries. These experiments are known as the ***Indo-Soviet Monsoon Experiment (ISMEX)*** and Monsoon-77 respectively. It was observed from these experiments that there is a specific zone off the coast of Kenya where the

Monsoons from the southern hemisphere crossed the equator on their way to India. It was also observed that the fluctuations in the intensity of low-level across the equator resulted in the fluctuations of rainfall over Maharashtra. Upper air observations over the Bay of Bengal were also made in 1977.

More intensive data collection effort was made under the aegis of another international experiment— the Monsoon Experiment in 1979. It is popularly known as ***MONEX-1979***. It was organised jointly by Global Atmospheric Research Programme (GARP) of the International Council of Scientific Unions (ICSU) and the World Meteorological Organisation (WMO) under their World Weather Watch (WWW) programme. It is so far the largest scientific effort made to extend the frontiers of our knowledge of the monsoons by the international scientific community. As many as 45 countries pooled their talents and resources under the aegis of the United Nations for this great venture. Some idea of the dimensions of this experiment may be had from the fact that in May 1979 as many as 52 research ships were deployed over the tropical oceans between 10° N and 10° S latitudes. Besides 104 aircraft missions were successfully completed over different parts of the Pacific, the Atlantic and the Indian Ocean.

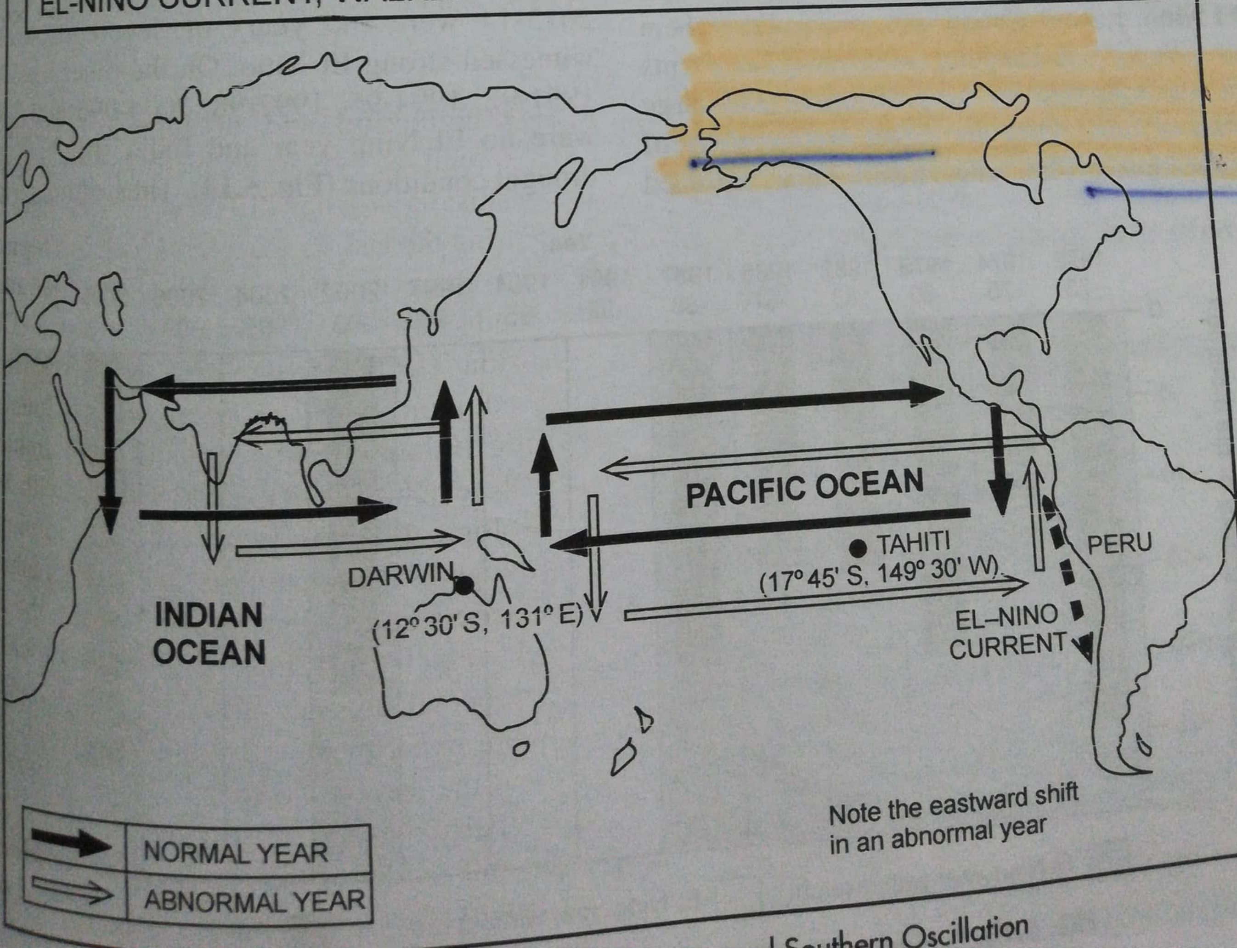
The great MONEX was designed to have three components considering the seasonal characteristics of the monsoon :

(*i*) Winter Monex from 1 December 1978 to 5 March 1979 to cover the eastern Indian Ocean and the Pacific along with the land areas adjoining Malaysia and Indonesia.

(*ii*) Summer Monex from 1 May to 31 August 1979 covering the eastern coast of Africa, the Arabian Sea and the Bay of Bengal along with adjacent landmasses. It also covered the Indian Ocean between 10° N to 10° S latitudes.

(*iii*) A West African Monsoon Experiment (WAMEX) over western and central parts of Africa from 1 May to 31 August 1979.

EL-NINO CURRENT, WALKER CIRCULATION AND SOUTHERN OSCILLATION



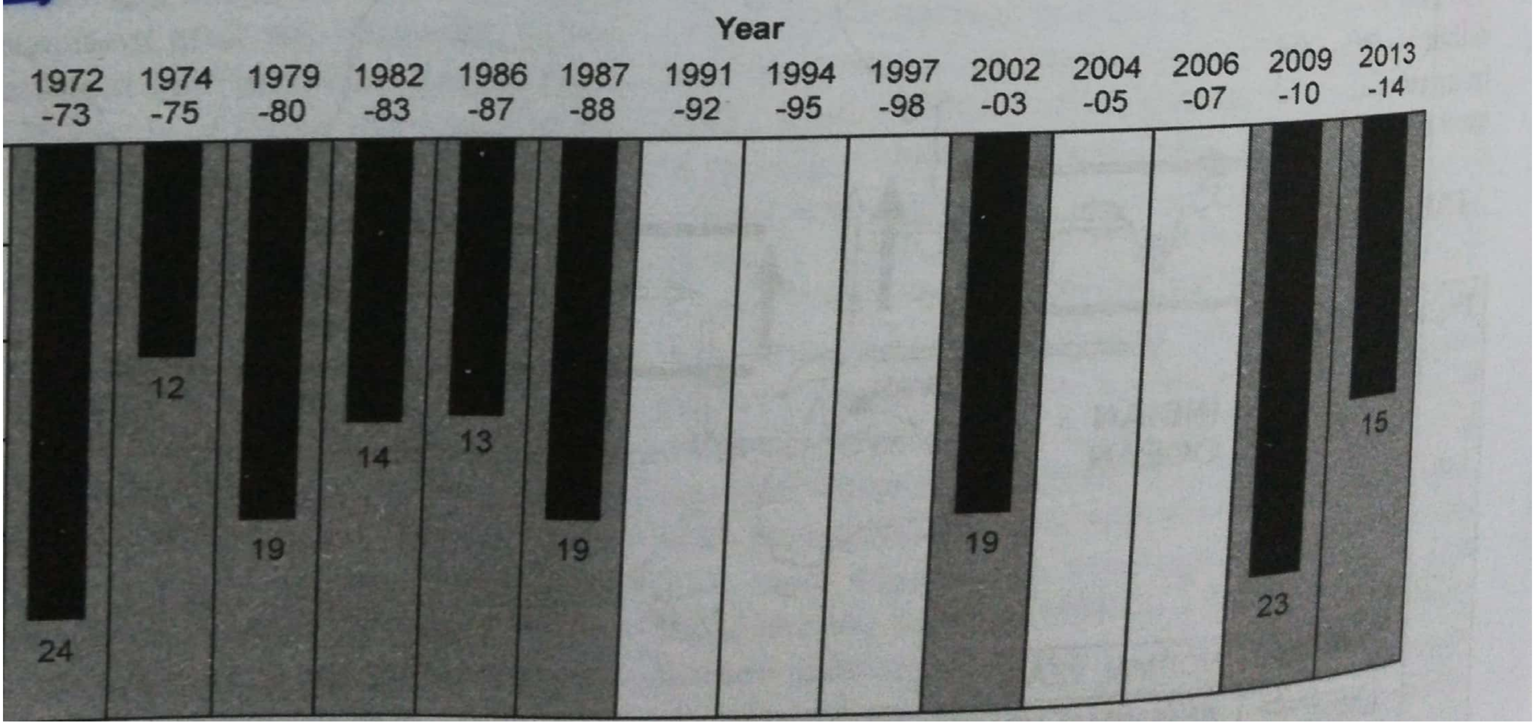
Southern Oscillation

rnational MONEX Management Centres were set up in Kuala Lumpur and New Delhi ise the winter and summer components of iment.

IEX-1979 suffered some setback due to behaviour of the monsoons in that year. he cold surges was intense in China Sea winter MONEX. A strong anticyclone in the Arabian Sea in summer of 1979. The monsoon was deflected southwards before e Kerala coast under the influence of this and started blowing parallel to the coast. ly the onset of southwest monsoon over delayed by 12 days. Moreover, July was d by several weak or break-monsoon and there was only one monsoon depres- re, 1979 was not a normal monsoon year failed to study the normal behaviour of s. But the vagaries of the monsoon are nd in a scientific and analytical of the monsoons, a study of anomalies re important. It is in this context that assumes unparalled significance.

ctions, the Southern Oscillation and ecent studies have revealed that there link between meteorological events arated by long distances and large ne. They are called ***meteorological*** s. The one which has aroused considerable interest among the meteorologists is the difference between an El Nino and the Southern Oscillation. ***El Nino*** (EN) is a narrow warm current which appears off the coast of Peru in December. In Spanish, it means *The Child Christ* because it appears around Christmas. In some years this warm current is more intense than usual.

The El Nino phenomenon, which influences the Indian monsoon, reveals that when the surface temperature goes up in the southern Pacific Ocean, India receives deficient rainfall. However, there had been some years during which the El Nino phenomenon did not occur, but India still got deficient rainfall, and conversely, India received sufficient rainfall during an El Nino year. A study of the one hundred years from 1870 to 1970 of the Indian monsoons shows that out of 43 deficient monsoon years, 19 were associated with an El Nino. On the other hand, there were 6 El Nino years which were also years of good monsoon rain. Analysis of meteorological data for three decades from 1972-73 to 2013-14 shows that out of 14 draught years 9 had been El Nino years and 5 were non El Nino years. Years 1972-73, 1979-80, 1987-88, 2009-10 and 2013-14 were the years of severe drought and witnessed strong El Nino. On the other hand, years 1991-92, 1994-95, 1997-98, 2004-095 and 2006-07 were no El Nino year and India still had to face drought conditions (**Fig. 5.10**). Thus, although there is



a tendency for poor monsoons to be associated with an El Nino, there is no one-to-one correspondence.

Southern Oscillation (S.O.) is the name ascribed to the curious phenomenon of *sea-saw pattern* of meteorological changes observed between the Pacific and Indian oceans. This great discovery was made by Sir Gilbert Walker in 1920. While working as the head of the Indian Meteorological service, he noticed that when the pressure was high over equatorial south Pacific, it was low over the equatorial south Indian Ocean and vice versa. The pattern of low and high pressures over the Indian and Pacific Oceans (S.O.) gives rise to vertical circulation along the equator with its rising limb over low pressure area and descending limb over high pressure area. This is known as ***Walker Circulation***. The location of low pressure and hence the rising limb over Indian Ocean is considered to be conductive to good monsoon rainfall in India. In other words when there is low pressure over the Indian Ocean in winter months, the chances are that the coming monsoon will be good and will bring sufficient rainfall. Its shifting eastward from its normal position, such as in El Nino years, reduces monsoon rainfall in India. Due to the close association between an El Nino (E.N.) and the Southern Oscillation (S.O.), the two are jointly referred to as an ENSO event. Some of the predictors used by Sir Gilbert Walker are still used in long-range forecasting of the monsoon rainfall.

The main difficulty with the Southern Oscillation is that its priodicity is not fixed and its period varies from two to five years. Different indices have been used to measure the intensity of the Southern Oscillation, but the most frequently used is the Southern Oscillation Index (SOI). This is the difference in pressure between Tahiti (17°45′S, 149°30′W) in French Polynesia, representing the Pacific Ocean and Port Darwin (12°30′S, 131°E), in northern Australia representing the Indian Ocean. The positive and negative values of the SOI *i.e.* Tahiti minus the Port Darwin pressure are pointers towards good or bad rainfall in India (see the following table)

TABLE 5.1. Southern Oscillation Index (SOI) and associated weather phenomena

Positive SOI :	Negative SOI :
(*i*) Tahiti pressure greater than that of Port Darwin (*ii*) Pressure high over east Pacific and low	(*i*) Port Darwin pressure exceeds that of Tahiti. (*ii*) Pressure high over Indian Ocean and low

Scientists of India Meteorological Department (IMD) joined an international study programme called the Tropical Oceans and Global Atmosphere (TOGA) in 1985. This is an interesting and ambitious programme which investigates both teleconnections effects and the internal variability. As a follow up to TOGA, the climate variability (CLIVAR) was set up in January 1995, to develop an internationally operational climate forecasting system.

Another major programme is the Indian Middle Atmospheric Programme (IMAP) initiated by the Department of Space. This programme has been launched to augment the existing weather prediction scheme.

After the severe drought of 1987, parametric and power regression models have been developed to forecast monsoon rainfall by utilising signals from 15 parameters. Some of the parameters are global while others are regional. These parameters are divided into four broad categories, *viz*. (*a*) temperature, (*b*) pressure (*c*) wind pattern and (*d*) snow cover and are listed below :

(*a*) *Temperature related parameters*

1. El Nino in current year
2. El Nino in previous year
3. Northern India (March)
4. East coast of India (March)
5. Central India (May)
6. Northern hemisphere (Jan. and Feb.)