Lecture Notes

on

Climatology

For

Integrated Meteorological Training Course

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CHAPTER 1
CLIMATOLOGY AND ITS APPLICATIONS

1. Climatology: An Atmospheric Science

Atmospheric scientists often subdivide study of complexity of gaseous envelope that surrounds the earth into specific areas of interest. One such division identifies the fields of meteorology and climatology. **Meteorology** is a science that deals with motion and the phenomena of the atmosphere with a view to both forecasting weather and explaining the processes involved. It deals largely with status of atmosphere over a short period of time and utilizes physical principles to attain its goal. **Climatology** is the study of atmospheric conditions over a longer period of time. It includes the study of different kinds of weather that occur at a place. Dynamic change in the atmosphere brings about variation and occasionally great extremes that must be treated on the long term as well as the short term basis. As a result, climatology may be defined as the aggregate of weather at a place over a given time period.

There is diversity of approaches available in climate studies. Figure 1. Illustrates the major subgroups of climatology, the approaches that can be used in their implementation, and the scales at which the work can be completed.

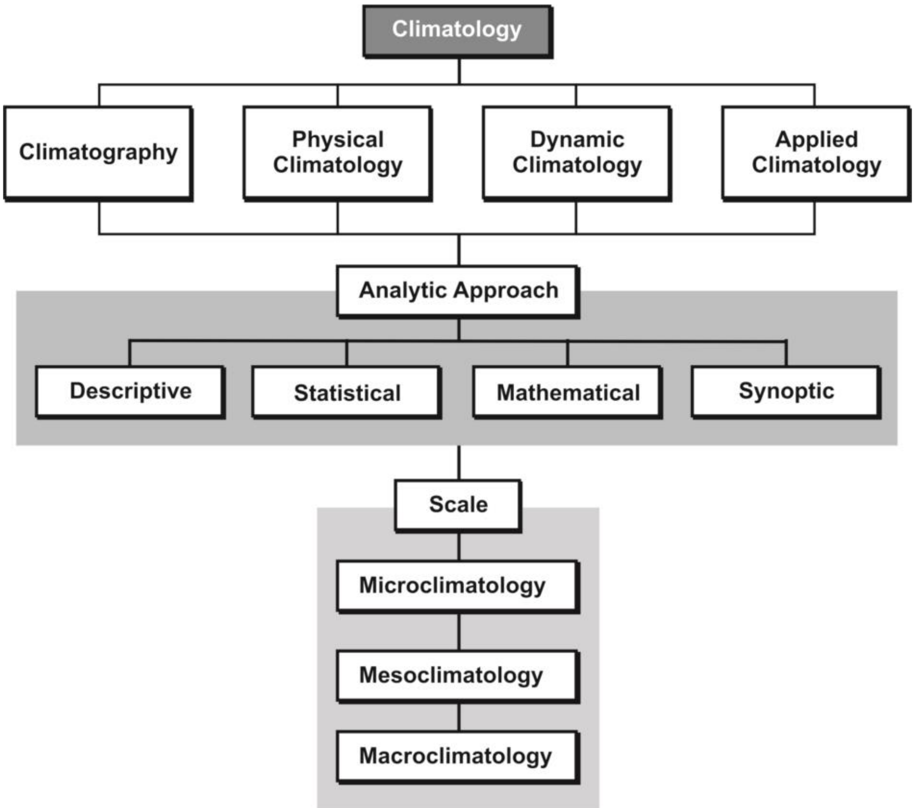


Figure 1. Subgroups, Analytical methods and scales of climatic study.
(From J. E. Olive 1981, P4 used by permission of V. H. Winston and Sons.)

Climatography consists of the basic presentation of data and its verbal or cartographic description.

Physical Climatology deals largely with the energy exchanges and physical components.

Dynamic Climatology is more concerned with atmospheric motion and exchanges that lead to and result from that motion.

Applied Climatology is the scientific application of climatic data to specific problems within such areas of forestry, agriculture, and industry. It can involve the application of climatic data and theory of other disciplines, such as geomorphology and soil science.

The analytical approaches suggested in the above figure 1. are self-explanatory, with the possible exception of the synoptic approach, an analytic method that combines each of the others. The object of synoptic climatology is to relate local or regional climates to atmospheric circulation.

2. Temperature structure of the atmosphere

In general terms, the atmosphere can be considered as a series of concentric layers or shells surrounding the earth. The most commonly used method to describe atmospheric layering uses temperature as the variable. This is illustrated in Figure 2. , which shows temperature changes with height.

The **troposphere** is the lowest level, where “weather” occurs. In this layer, there is generally uniform decrease of temperature with height. The lowest part of the troposphere, up to 1.5 km or 2 km is called friction layer. The upper limit of the troposphere is the **tropopause**. It is zone where generally decrease of temperature ceases and temperature remains fairly constant with height (isothermal-equal temperature). The tropopause also represents the upper limit of large scale turbulence and mixing of the layer.

The **stratosphere** extends from the 10 km to 45 km above the surface. In this lower section, temperatures are fairly constant, but at an elevation of 30 km they increase toward the upper limit of this zone, the **stratospause**. Air circulation in the stratosphere is characteristically persistent, with winds blowing at high velocities.

The **mesosphere**, above the stratopause, is identified by a marked temperature decrease with altitude. Beginning at an elevation of about 80 km, the decline continues until the **mesopause** is reached.

The **thermosphere** lying above the mesopause has no defined upper limit. It is so named because a very high thermodynamic temperature attained.

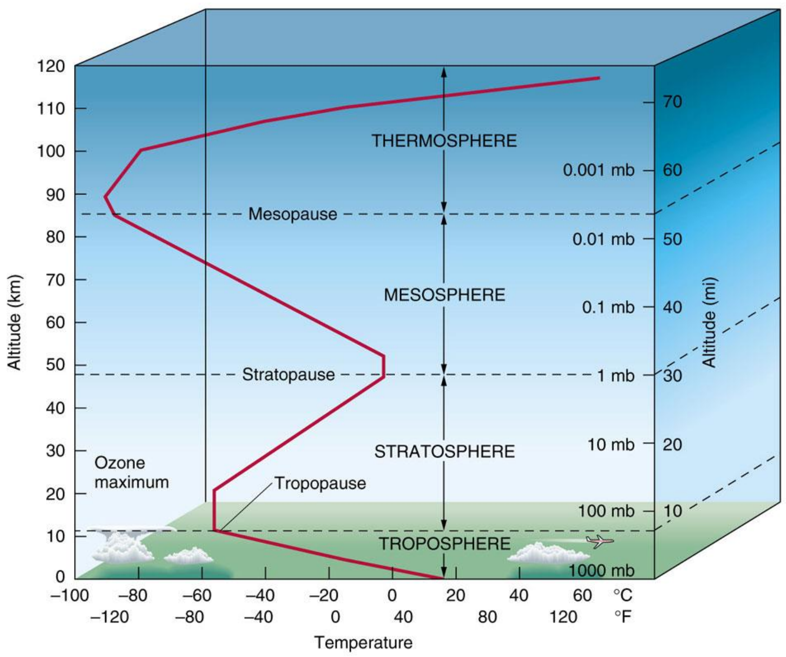


Figure 2. Thermal Structure of Atmosphere

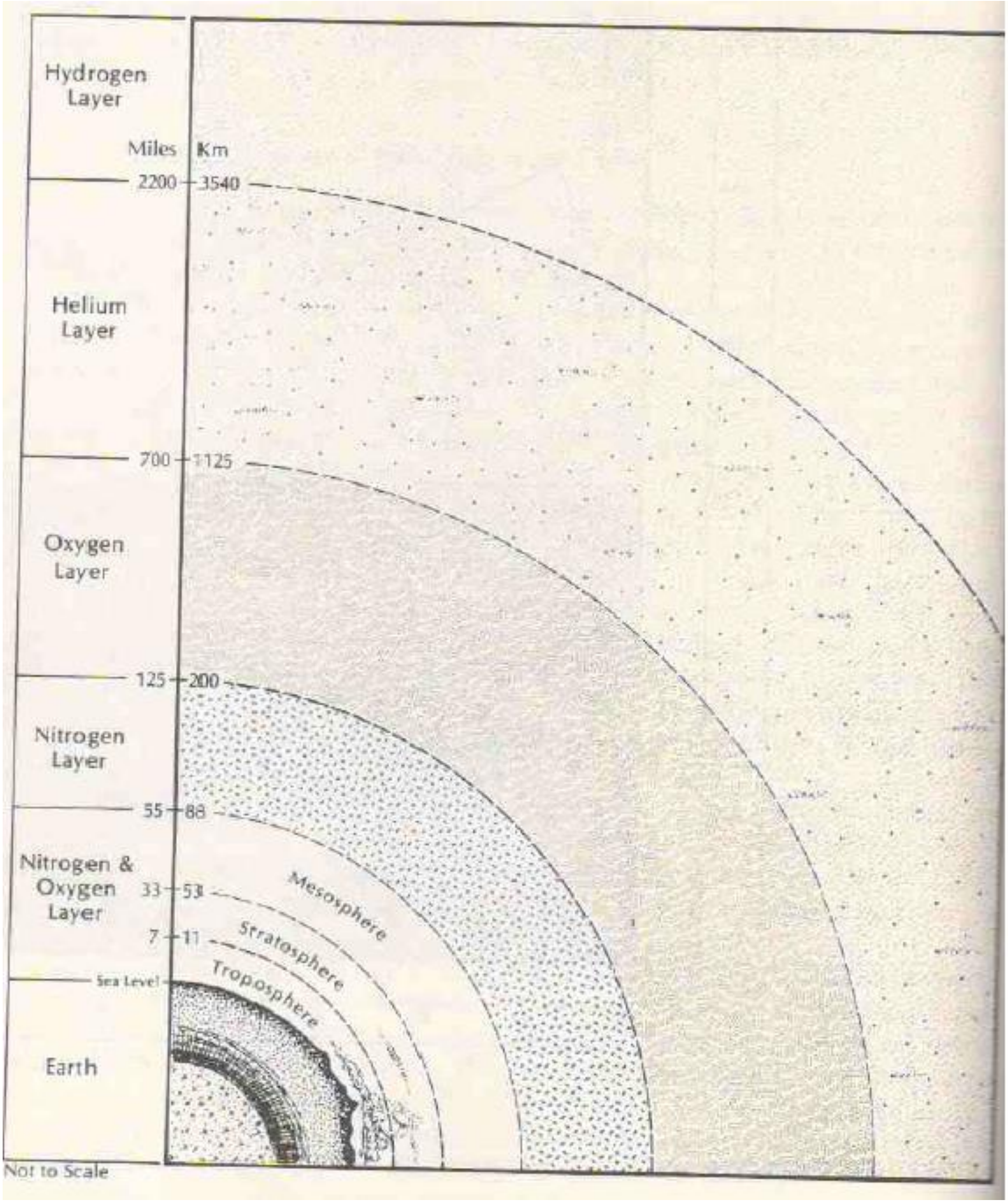


Figure 3. Schematic cross section of Earth's Atmosphere showing broad chemical dividions

3. Applications of Climatology

Climatology is a fascinating area of study. It relates directly in which the environment functions and the everyday lives of people in addition to workings and nature of the atmosphere. Applied Climatology is used to –

a) Improve efficiency of various economic activities that are influenced by climate,
b) Aid in the needs of societal activities,
c) Reduce the losses incurred from climatic hazards.

Consider the following examples:

Energy: Climate plays a part in the use and development of both fossil fuels and the renewable energy sources. The use of fossil fuels to generate energy is so climate related that the concept of heating and cooling degree days is used by engineers to estimate energy demands. The potential an area has for the development of renewable sources is directly related to the atmospheric conditions. To evaluate the potential for the direct use of solar energy and wind power requires detailed knowledge of the climatic conditions that prevail.

Food: The success of agriculture is determined by how well farmers adapt their crops and activities to climate.

Water: Many human problems are related to excesses or deficits of water. The applied climatologist supplies important information on everything from the chances of flood occurring to the relative severity of the flood as well as his concern with drought includes the environmental degradation that can result when a location experiences slowing increasing aridity.

Health: Studies of the relationships between health, disease, mortality, and climate show some remarkable results. Climate influences the relative merits of a location as a health resort or as a tourist center. The effect of climates at high altitudes provides an apt example of the hazard.

Industry and Trade: Applied climatologists have a significant input into the industrial and trade sectors of an economy. For example,

a) Building and construction: site conditions, design in relation to climate, energy costs, construction conditions.
b) Commerce: Storage of materials, accidents, plant operation, sales planning
c) Communication: Construction, maintenance of systems, appropriate design
d) Services: Insurance, environmental law, disaster control
e) Forestry: Productivity, hazards, regeneration, biological hazards.

At first glance, it may be difficult to accurately assess the relationship of climatology to many of these activities. However, a little thought will clearly indicate the significance of applied climatology.

CHAPTER 2

CLIMATIC ELEMENTS

2.1 Weather elements

The weather elements that are used to describe climate are also the elements that determine the type of climate for a region. The most important elements of weather which in different combinations make up the climate of a particular place or area are: solar radiation, air temperature, air pressure, wind velocity and wind direction, humidity and precipitation, and amount of cloudiness. The climatic elements of temperature, precipitation, and wind are the most significant elements used to express the climate of a region.

Temperature:

The temperature of an area is dependent upon

a) latitude or the distribution of the incoming and outgoing radiation,
b) the nature of the surface (land or water),
c) the altitude and the
d) prevailing winds.

The air temperature normally used in climatology is that recorded at the surface. Moisture or lack of moisture modifies the temperature. The more moisture in a region, the smaller the temperature range, and the drier the region, the greater the temperature range. Moisture is also influenced by temperature. Warmer air can hold more moisture than a cooler air, resulting in increased evaporation and a higher probability of clouds and precipitation. Moisture, when coupled with condensation and evaporation, is an extremely important climatic element. It ultimately determines the type of climate for a specific region.

Precipitation:

Precipitation is the second most important climatic element. In most studies, precipitation is defined as water reaching Earth's surface by falling either in a liquid or a solid state. The most significant forms are rain and snow. Precipitation has a wide range of variability over the earth's surface. Because of its variability, a longer series of observations is generally required to establish mean or an average. It often becomes necessary to include such factors as average number of days with precipitation and average amount per day. Precipitation is expressed in millimeters. Since precipitation amounts are directly associated with amounts and type of clouds, cloud cover must also be considered with precipitation. Cloud climatology also includes phenomena such as fog and thunderstorms.

Wind:

Wind is the climatic element that transports heat and moisture into a region. Climatologists are mostly interested in wind with regards to its direction, speed, and gustiness. Wind is therefore usually discussed in terms of prevailing direction, average speeds, and maximum gusts. Some climatological studies use resultant wind, which is the vectorial average of all wind directions and speeds for a given level, at a specific place, and for a given period.

2.2 Expression of climatic elements

Climatic elements are observed over long periods of time; therefore, specific terms must be used to express these elements so they have a definite meaning.

Mean (Average):

The mean is the most commonly used climatological parameter. The term mean normally refers to a mathematical averaging obtained by adding the values of all factors or cases and then dividing by the number of items. For example, the average daily temperature would be the sum of the hourly temperatures divided by 24.

The mean temperature of 1 day has been devised by simply adding the maximum and minimum temperature values for that day and dividing by 2. In analyzing weather data, the terms average and mean are often used interchangeably.

Normal:

In climatology, the term normal is applied to the average value over aperiod of time, which serves as a standard with which values (occurring on a date or during a specified time) may be compared. These periods of time may be a particular month or other portion of the year. They may refer to a season or to a year as a whole. The normal is usually determined over a 20- or 30-year period.

Absolute:

In climatology, the term absolute is usually applied to the extreme highest and lowest values for any given meteorological element recorded at the place of observation and are most frequently applied to temperature.

Extreme:

The term extreme is applied to the highest and lowest value for a particular meteorological element occurring over a period of time. This period of time is usually a matter of months, seasons or years. The term may be used for a calendar day only, for which it is particularly applicable to temperature. At time the term is applied to the average of the highest and lowest temperatures as mean monthly or mean annual extremes.

Range:

Range is the difference between the highest and lowest values and reflects the extreme variations of these values. Since it has a high variability, this statistic is not recommended for precise work. Range is related to extreme values of record and can be useful in determining the extreme range for the records available.

Frequency:

Frequency is defined as the number of times a certain value occurs within a specified period of time. A frequency distribution may be used to present a condensed presentation of large data.

Mode:

Mode is defined as the value occurring with the greatest frequency or the value about which the most cases occur.

Median:

The median is the value at the midpoint in an array. It is determined by arranging all values in order of size. Rough estimates of the median may be obtained by taking the middle value of an ordered series; if there are two middle values they may be averaged to obtain the median. The median is not widely used in climatological computations. A longer period of record might be required to formulate an accurate median.

Degree-Day:

A degree-day is the number of degrees the mean daily temperature is above or below a standard temperature base. Degree days are accumulated over a season. At any point in the season, the total can be used as an index of past temperature effect upon some quantity, such as plant growth, fuel consumption, power output, etc. Degree-days are frequently applied to fuel and power consumption in the form of heating degree-days and cooling degree-days.

Average and standard deviations

In the analysis of climatological data, it may be desirable to compute the deviation of all items from a central point. This can be obtained from a computation of either the mean (or average) deviation or the standard deviation. These are termed measures of dispersion and are used to determine whether the average is truly representative or to determine the extent to which data vary from the average.

Average deviation :

Average deviation is obtained by computing the arithmetic average of the deviations from an average of the data.

Average deviation = $\sum d / n$

where d (the deviations) and n is the number of items.

Standard deviation:

Standard deviation is the measure of the scatter or spread of all values in a series of observations.

Standard deviation = SQRT($\sum d^2 / n$)

where d^2 is the sum of the squared deviations from the arithmetic average, and n is the number of items in the group of data.

CHAPTER 3

CLIMATIC ZONES AND CLIMATIC CONTROLS

3.1 Climatic zones

The basic grouping of areas into climatic zones consists of classifying climates into five broad belts based on astronomical or mathematical factors. Actually they are zones of sunshine or solar climate and include the torrid or tropical zone, the two temperate zones, and the two polar zones.

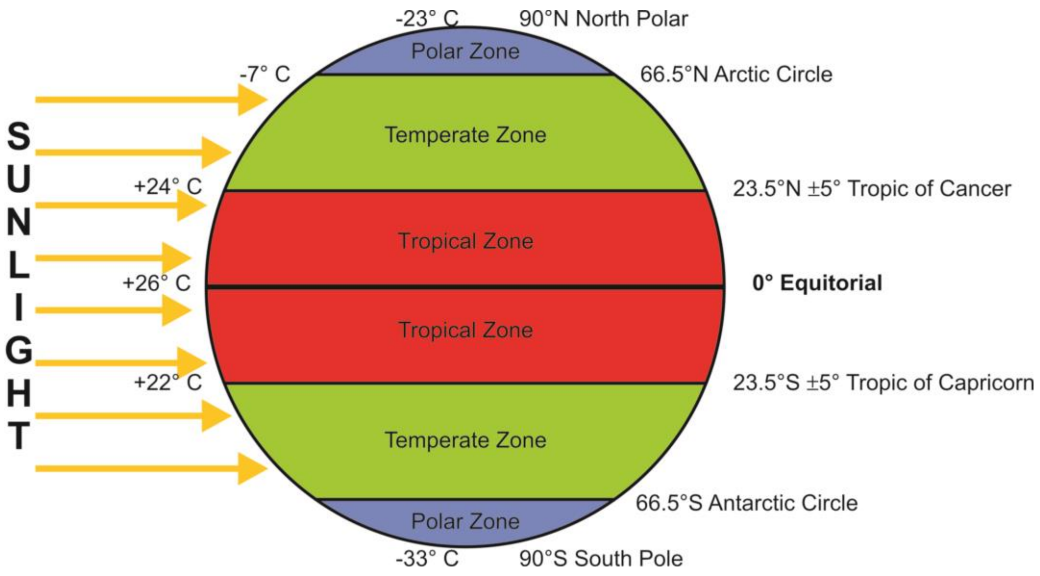
The tropical zone is limited on the Tropic of Cancer and on the south by the Tropic of Cancer which are located at 23 1/2º north and south latitude, respectively.

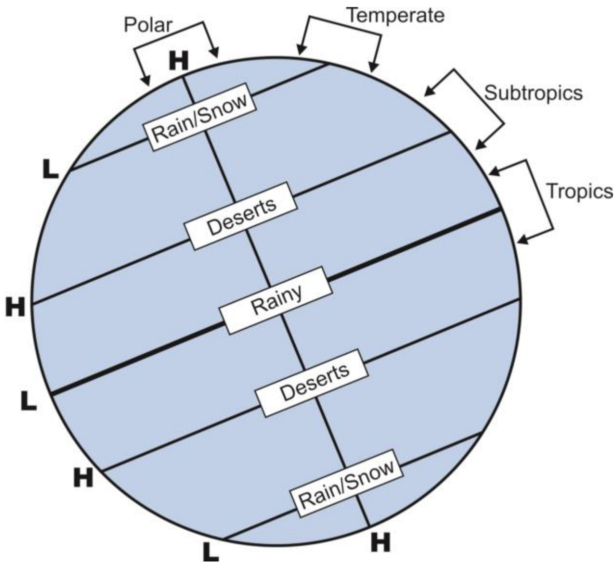
The temperate zone of the Northern Hemisphere is limited on the south by the Tropic of Cancer and on the north by the Arctic Circle located at 66 1/2º north latitude. The temperate zone of the Southern Hemisphere is bounded on the north by the Tropic of Capricorn and on the south by the Antarctic Circle located at 66 1/2º south latitude.

The two polar zones are the areas in the Polar Regions which have the Arctic and Antarctic Circles as their boundaries.

Technically, Climatic zones are limited by isotherms rather than by parallels of latitude. A glance at any chart depicting the isotherms over the surface of the earth shows the isotherms do not coincide with latitude lines. The astronomical or latitude zones therefore differ from the zones of heat.

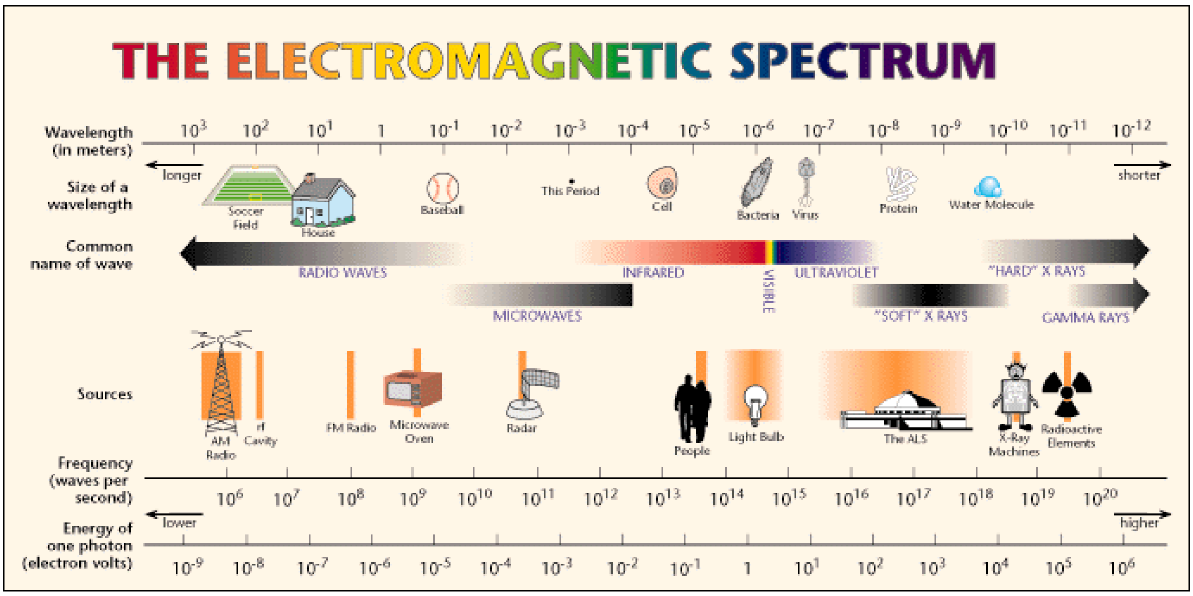
The Climatic zones are shown below:





Electromagnetic energy travels in waves and spans a broad spectrum from very long radio waves to very short gamma rays. The human eye can only detect only a small portion of this spectrum called visible light. Our Sun is a source of energy across the full spectrum, and its electromagnetic radiation bombards our atmosphere constantly. However, the Earth's atmosphere protects us from exposure to a range of higher energy waves that can be harmful to life. Examples are Gamma rays, x-rays, and some ultraviolet waves. Electromagnetic radiation is reflected or absorbed mainly by several gases in the Earth's atmosphere, among the most important being water vapor, carbon dioxide, and ozone. Some radiation, such as visible light, largely passes (is transmitted) through the atmosphere. These regions of the spectrum with wavelengths that can pass through the atmosphere are referred to as "atmospheric windows." Some microwaves can even pass through clouds, which make them the best wavelength for transmitting satellite communication signals.

The Electromagnetic spectrum is shown below:



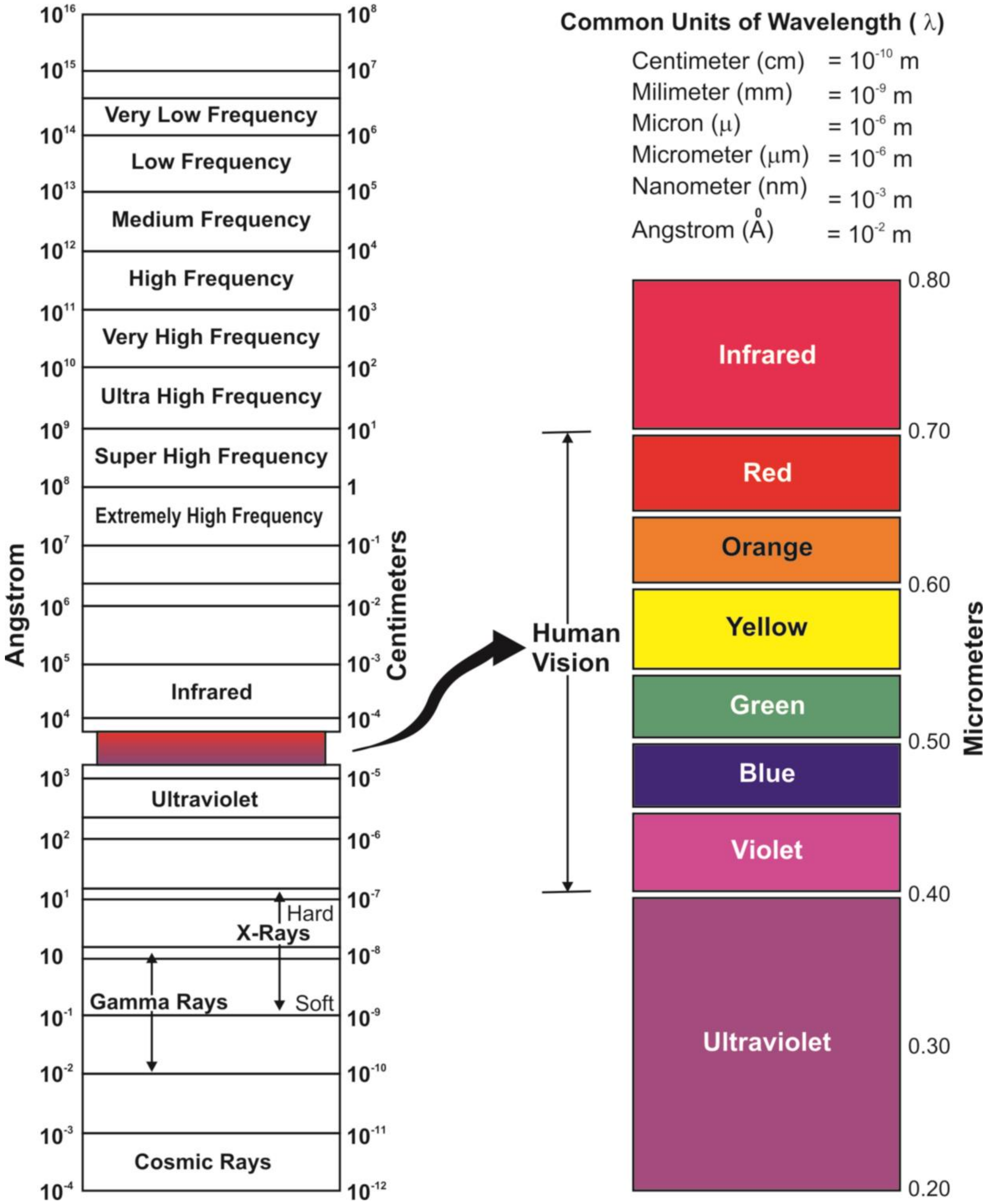


Figure 4. Eectromagnetic Spectrum

The cause of seasons is due to orbit of the earth round the sun. This is shown below.

Winter -December to February.
Spring-March to May.
Summer-June to August.
Fall(autumn)-September to November

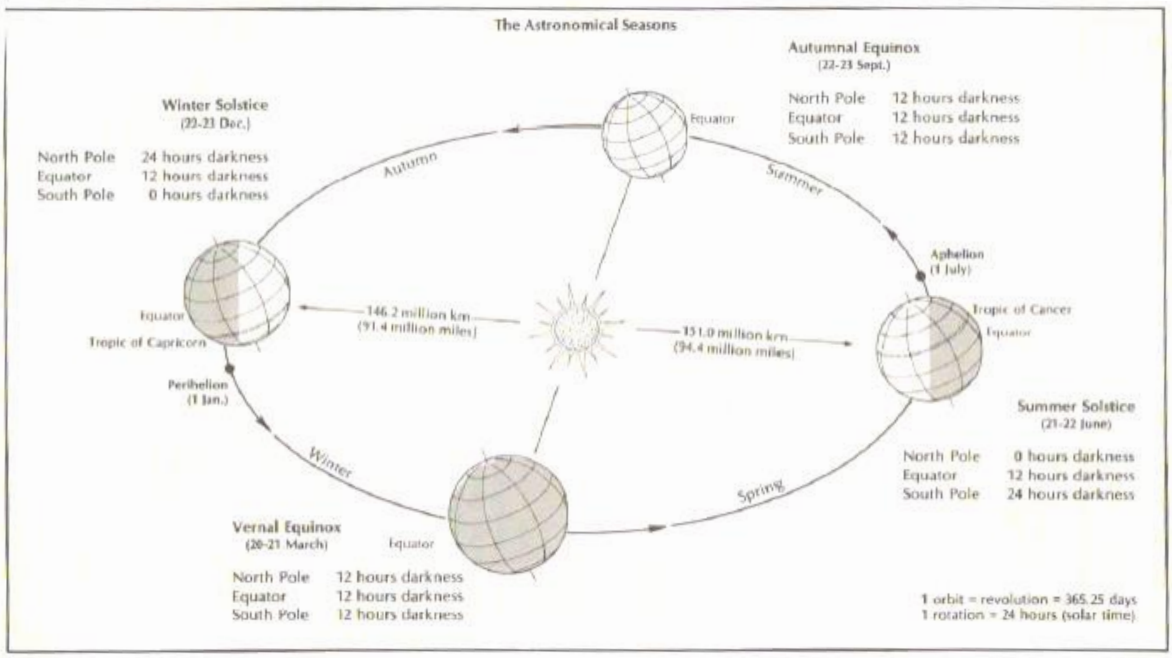


Figure 5. Orbit of the Earth round the Sun

However, On the basis of climate, the period of year has been divided into four seasons in India. They are:-

1) Cold weather season (winter season) – January and February
2) Pre-monsoon or Hot weather season – March to May
3) SW or Summer Monsoon season – June to September
4) Post monsoon season – October to December

3.2 Climatic Controls

The variation of climatic elements from place to place and from season to season is due to several factors called climatic controls. Four climatic controls largely determine the climate of every ocean and continental region. These controls are latitude, land and water distribution, topography, and ocean currents. Another factor, which is now significant in determining a region's climate, is man. Man's influence on climate through pollution, deforestation, and irrigation, is now considered as climatic factor.

Latitude:

Latitude (or the position of earth relative to the Sun) has a marked effect on climatic elements. The angle at which rays of sunlight reach Earth and the number of Sun hours each day depends upon the distance of the Sun, from the equator. Therefore, the latitude directly influences the sources and direction of air masses and the weather they bring with them into a region.

Land and Water Distribution

Location of continents and oceans greatly influences Earth's pattern of air temperature as well as the sources of movement of air masses.

(a) Influence of Air Temperature

Coastal areas assume the temperature characteristics of the land or water that is on their windward side. In latitude of prevailing westerly winds, for example, west coasts of continents have oceanic temperatures and east coasts have continental temperatures which are determined by wind flow. Mixing process in the upper layer of the ocean sharply reduces air temperature contrasts between day and night and between winter and summer over oceanic areas. Strong seasonal and diurnal contrasts exist in the interior continents due to lack of redistribution of heat by turbulence and negligible effect of conduction. In the Southern Hemisphere, the temperature gradient does not have as great a seasonal change as it does in the Northern Hemisphere due to more water surface in Southern Hemisphere and tapering of continents of Southern Hemisphere towards the poles.

The distribution of water vapor and clouds is another important factor influencing air temperature. In areas with high percentage of clouds the solar energy is easily trapped in the lower layers due to the greenhouse effect. Thus, areas of high moisture content have relatively high temperature.

(b) Influence on Air Circulation

The higher mean temperature of Northern Hemisphere is an effect of higher percentage of land and warmer oceans in Northern Hemisphere due to the movement of warm equatorial waters from the Southern Hemisphere in to the Northern Hemisphere caused by the southeast trades crossing the equator. Another factor is the partial protection of oceans of Northern Hemisphere from cold polar waters and arctic ice by land barriers. There is no such barrier between the Antarctic region and the southern oceans.

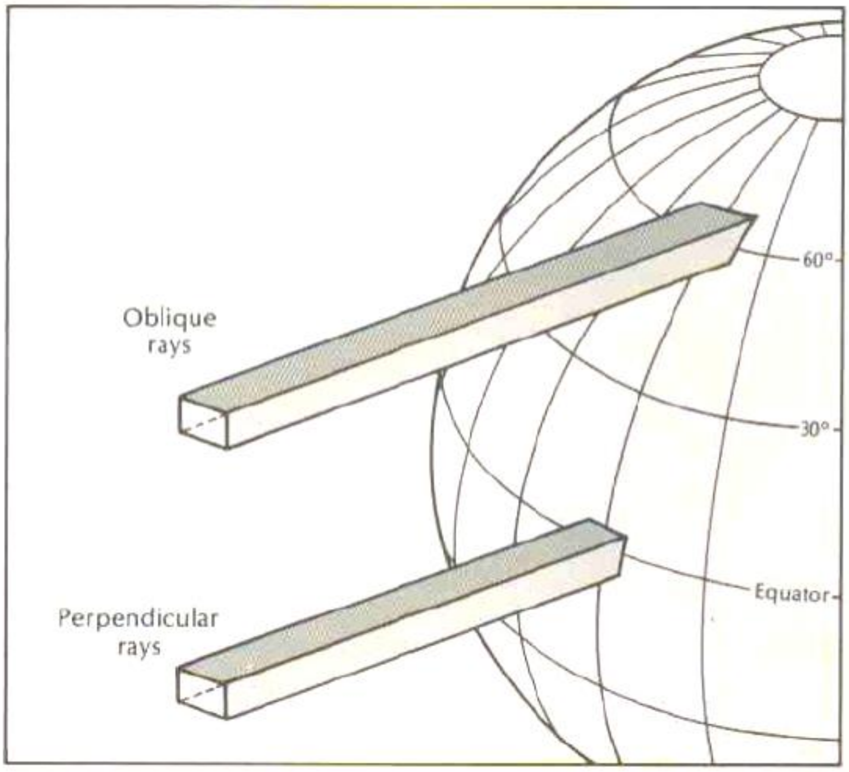


Figure 6. How Sun Angle decreases the intensity of radiation

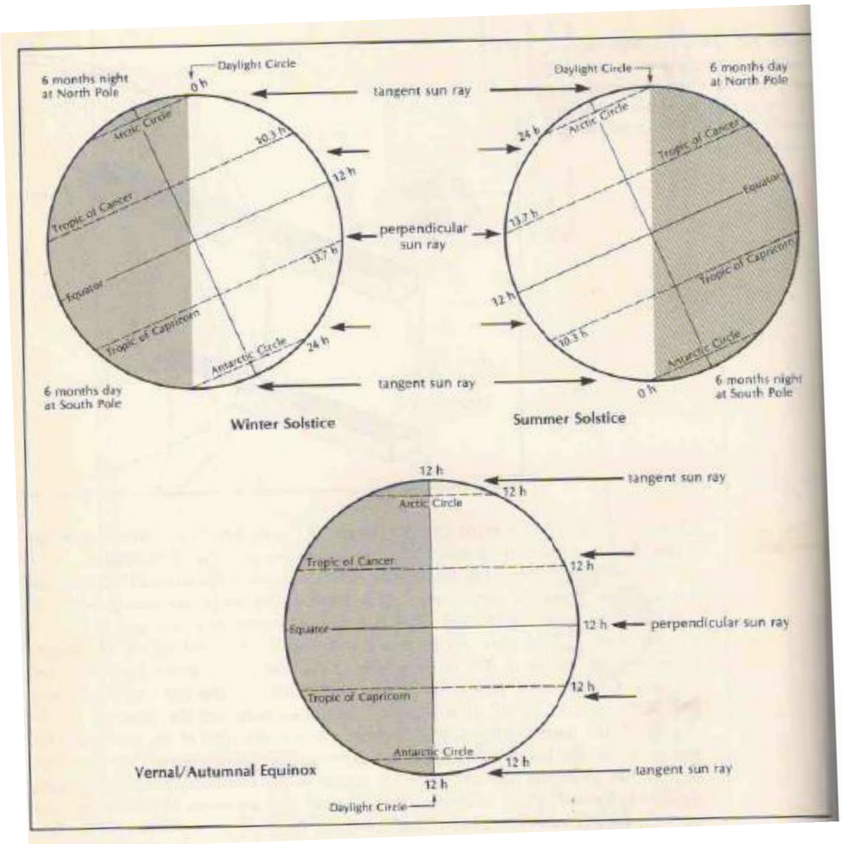


Figure 7. The tilted axis of the earth results in variations of the angle of overhead sun and length of daylight. Diagram shows conditions at the equinoxes and solstices

Topography:

Topography plays an extremely important role in determining the climate of a region. The height of an area above sea level exerts a considerable influence on its climate. All climatic values are affected by surface elevation. An important influence on climate is mountainous terrain, especially, the long, high chains of mountains that act as climatic divides. The orientation of the mountain range may block certain air masses and prevent them from reaching the lee side of the mountains. For example, the Himalayas which are east-west orientations prevent polar air masses from advancing southward. Therefore the climates of India are warmer in winter than are other locations of the same latitude. The most noted influence of mountains is the distribution of precipitation (higher values of precipitation on windward side than on the leeward side). Another important topographical feature is the presence of lakes. The lake effect can be notable for large, unfrozen bodies of water. The lee sides of lakes show considerable diurnal and annual modification in the form of more moderate temperatures; increased moisture, cloud and precipitation; and increased winds (due to less friction) and land and sea breeze effects.

Ocean currents:

Ocean currents play a significant role in controlling the climate of certain regions. Ocean currents transport heat moving cold polar water equator ward into warmer waters and moving the warm equatorial water pole ward into cooler waters. Currents are driven by the major wind systems; therefore, cold southward moving currents flow along the west coasts of continents, and the warm northward moving currents flow along the east coasts of the continents. This is true in both hemispheres. Basically, this results in cooler climates along the west coasts and the warmer climates along the east coasts.

CHAPTER 4

GENERAL CIRCULATION OF THE ATMOSPHERE OVER THE GLOBE

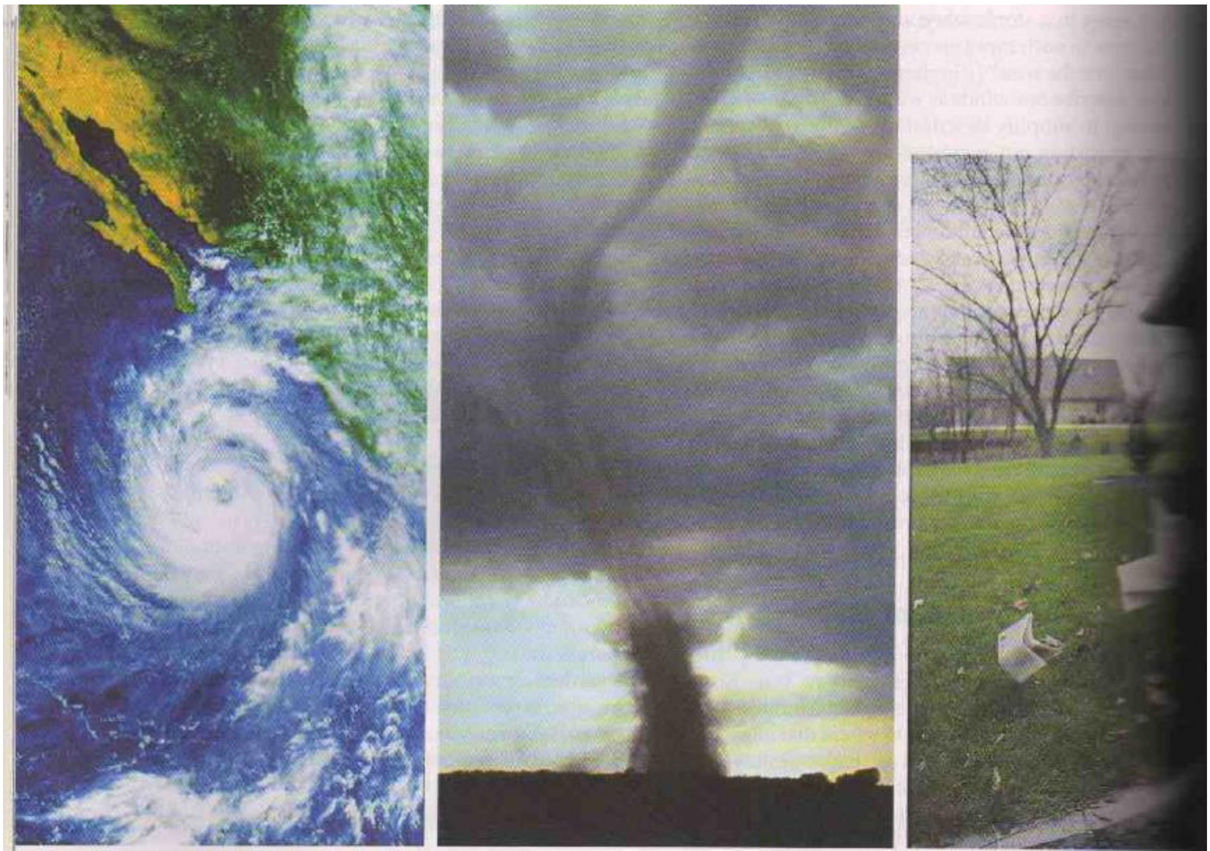
4.1 Scales of Atmospheric motion

The time and size scales for atmospheric motions are given in Table below:

Scale	Time Scale	Distance Scale	Examples
Macro scale			
Planetary	Weeks to longer	1000-40,000 km	Westerlies and trade winds
Synoptic	Days to weeks	100-5000 km	Mid-latitude cyclones, anticyclones and hurricanes, Tropical cyclones
Meso scale	Minutes to hours	1-100 km	Thunderstorms, tornadoes, and land-sea breeze
Micro scale	Second to minutes	< 1 km	Turbulence, dust devils, and gusts

4.2 Large and small scale circulation

The wind systems shown in figure below illustrate the three major categories of atmospheric circulation: macroscale, mesoscale, and microscale. Macroscale circulation includes large planetary-scale flow, such as trade winds that blow consistently for weeks to longer as well as smaller features like Tropical cyclones. Mesoscale circulation is associated with tornadoes, thunderstorms, and numerous local winds that generally last from minutes to hours. Finally, microscale events have life span of from a few seconds to minutes and include dust devils, gusts, and general atmospheric turbulence.



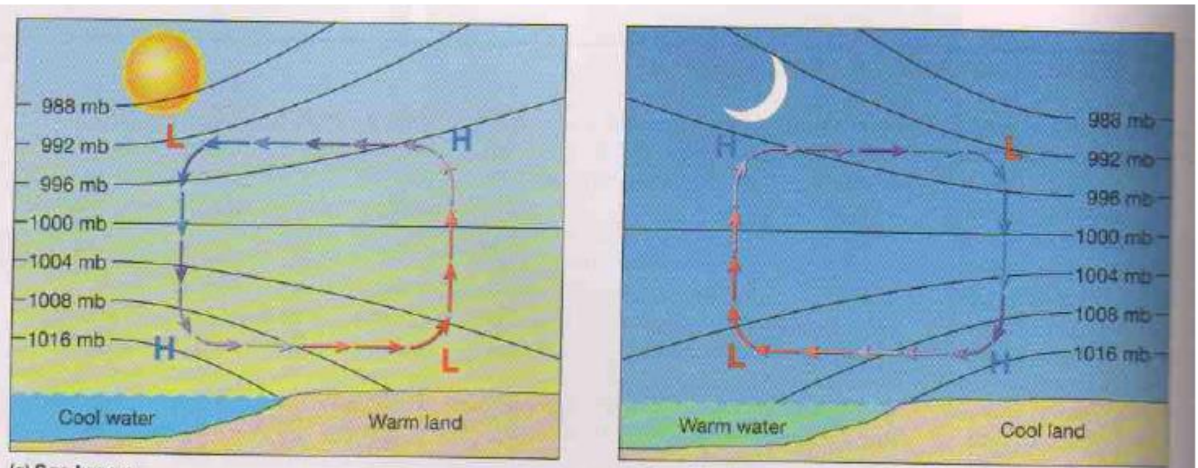
(a) (b) (c)

FIGURE 7–2 Three scales of atmospheric motion. (a) Satellite image of Hurricane Nora, an example of macroscale circulation. (b) Tornadoes exemplify mesoscale wind systems. (c) Gusts

Before examining the large macroscale circulation for Earth, let us turn to some mesoscale winds:

Land and Sea Breezes

Land is heated more intensely during day light hours than is an adjacent body of water. As a result, the air above the land surface heats and expands, creating an area of low pressure. A sea breeze then develops, as cooler air over the water moves onto the land. At night, the reverse may take place; the land cools more rapidly than the sea and a land breeze develops.

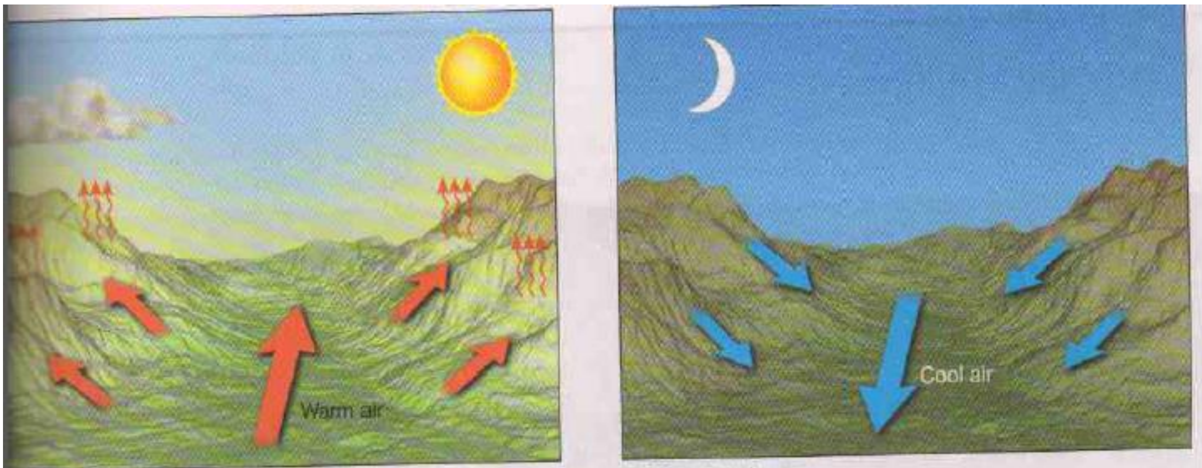


(a) **Sea breeze** (b) **Land breeze**

FIGURE 7–3 Illustration of a sea breeze and a land breeze. (a) During the daylight hours the air above the land heats and expands, creating an area of lower pressure. Cooler and denser air over the water moves onto the land, generating a sea breeze. (b) At night the land cools more rapidly than the sea, generating an offshore flow called a *land breeze*.

Mountain and Valley Breezes

During the day, air along the mountain slopes is heated more intensely than air at the same elevation over the valley floor. This warmer air glides up along the mountain slope and generates a valley breeze. These can often be identified by the isolated cumulus clouds that develop over the adjacent mountain peaks. During night time, rapid radiation heat loss along the mountain slopes cools the air, which drains into the valley below and causes a mountain breeze.



Valley breeze (b) **Mountain breeze**

GURE 7–4 Valley and mountain breezes. (a) Heating during the daylight hours warms the air ong the mountain slopes. This warm air rises, generating a valley breeze. (b) After sunset, cooling the air near the mountain can result in cool air drainage into the valley, producing the mountain eeze.

Chinook (Foehn) winds

These are often created when a strong pressure gradient develops in a mountainous region. As the air descends the leeward slopes of the mountains, it is heated adiabatically and becomes drier. These winds often bring drastic change and melting snow cover over the ground in short order. The Native American word Chinook means "snow eater".

Katabatic (Fall) winds

These winds originate when cold air, situated over a highland area such as the ice sheets of Greenland or Antarctica, is set in motion. Under the influence of gravity, the cold air cascades over the rim of a highland like a water fall. although the air is heated adiabatically, the initial temperatures are so low that the wind arrives in the lowlands still colder and more dense than the air it displaces. Examples are mistral which blows from the French Alps towards the Mediterranean Sea, bora, which originates in the mountains of Yugoslavia and blows to the Adriatic Sea.

4.3 Three Cell Circulation Model

This was proposed for each hemisphere in the 1920's and has been modified to fit upper –air observations, it remains a useful way to examine global circulation. Hadley in 1735 was well aware that solar energy drives the winds and proposed that the large temperature contrast between the poles and the equator creates one large convection cell in each hemisphere (northern and southern).

In the zones between the equator and roughly 30º latitude north and south, the circulation closely resembles the model used by Hadley for the whole earth. Near the equator, the warm rising air that releases latent heat during the formation of cumulus towers is believed to provide the energy to drive the Hadley cells. As the flow aloft in the Hadley cells moves poleward, it begins to subside in a zone between 20º and 35º latitude due the two reasons, viz. (1) as upper level flow moves away from the stormy equatorial region, where the release of latent heat condensation keeps the air warm and buoyant, radiation cooling increases the density of air. (2) because of Coriolis force becoming stronger with increase of distance from the equator, the poleward moving upper air is deflected into a nearly west to east flow by the time it reaches 25º latitude. A convergence is formed aloft due to the Coriolis force and results in subsidence. Consequently, this zone of subsidence is the site of the world's subtropical deserts (Sahara desert of North Africa, the great Australian desert). Due to general weak winds in this zone, the region is popularly known as the horse latitudes. From the center of the horse latitudes, the surface flow splits in to two branches: Equatorward flow deflected by Coriolis force to form reliable trade winds. In the northern hemisphere the trades are from the northeast, where as in the southern hemisphere the trades are from the southeast. The trade winds from both the hemispheres meet at the equator in a region that has a weak pressure gradient which is known as doldrums.

The circulation between 30º and 60º latitude (north and south) is more complicated. The net surface flow is poleward, and because of the Coriolis force, the winds have strong westerly component. Relatively little is known about the circulation in high (polar) latitudes. It is understood that subsidence at the poles produces a surface flow that moves equatorward and is deflected into the polar easterlies of both hemispheres. The meeting of cold polar winds moving equatorward with the warmer westerly flow of the mid latitudes is named as polar front.

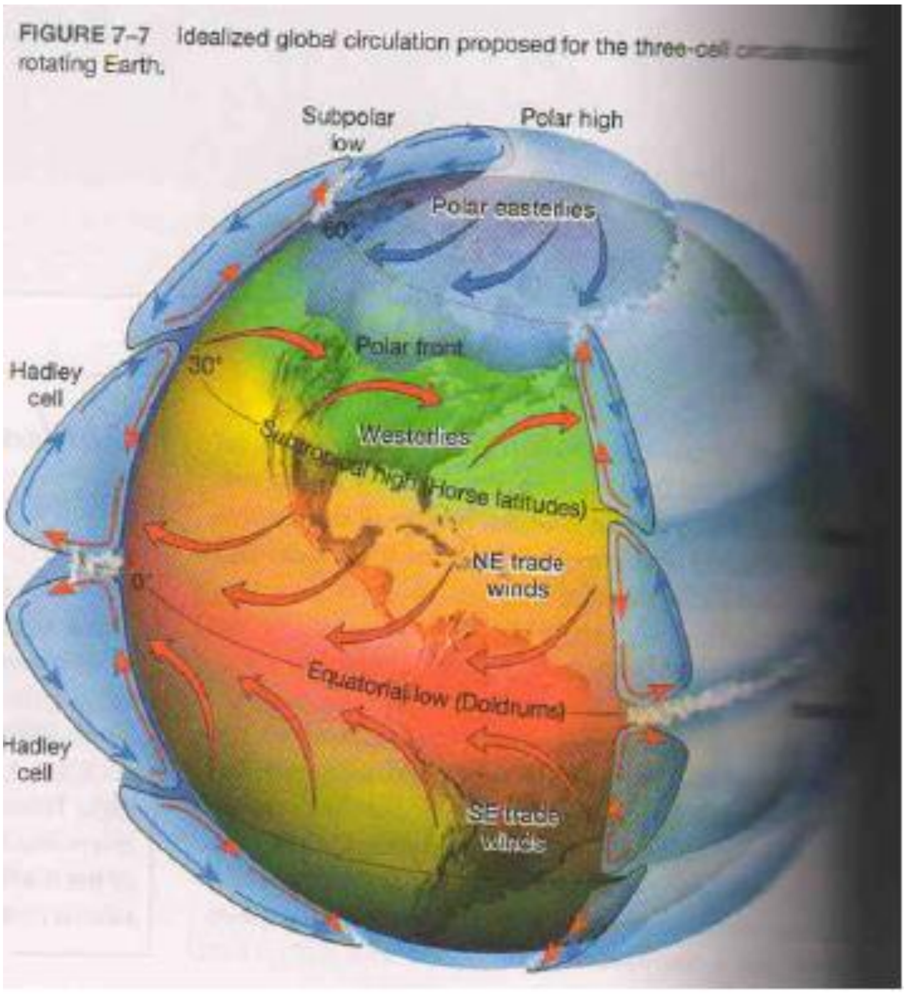


FIGURE 7–7 Idealized global circulation proposed for the three-cell circ... rotating Earth.

4.4 Observed distribution of Pressure and winds

If earth had a uniform surface, two latitudinally oriented belts of high and two of low pressure would exist as shown in figure below. Near the equator, the warm rising branch of the Hadley cells is associated with the pressure zone, known as the **equatorial low** which is marked by abundant precipitation. Because it is a region where both the trade winds converge, it is referred to **inter tropical convergence zone**.

FIGURE 7-8 (a) An imaginary uniform Earth with idealized zonal (continuous) pressure belts. (b) The real Earth with disruptions of the zonal pattern caused by large landmasses. These disruptions break up pressure zones into semipermanent high- and low-pressure cells.

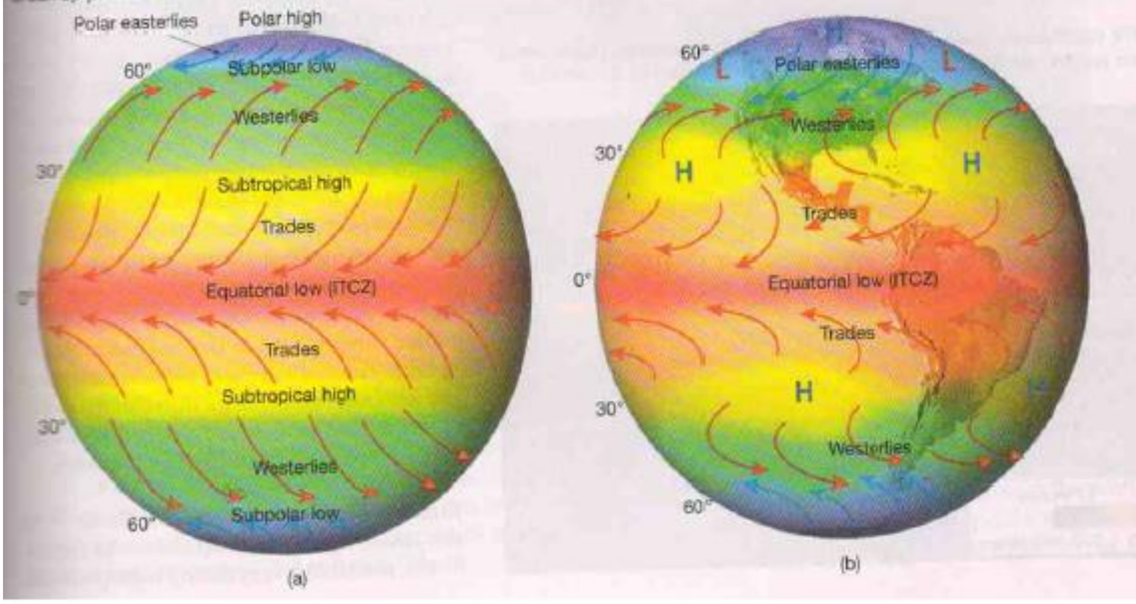
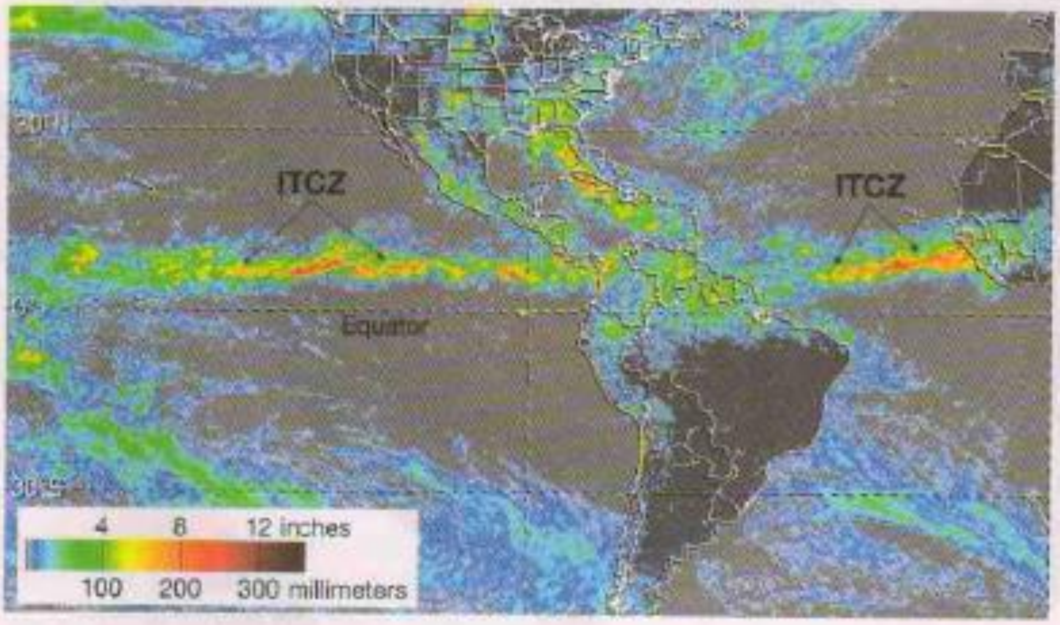


FIGURE 7-9 The intertropical convergence zone (ITCZ) is seen as the band of heavy rainfall shown in reds and yellows, which extends east–west just north of the equator. (Courtesy of NOAA)



Up to this point, we have only considered the global pressure systems as it they were continuous belts around Earth. However, because the Earth's surface is not uniform, the only true zonal distribution of pressure exists along the sub polar low in the Southern Hemisphere. To a lesser extent, the equatorial low is also continuous. At other latitudes, particularly in the northern hemisphere, the zonal pattern is replaced by semi permanent cells of high and low pressure.

January Pressure and Wind patterns

Figure 4 (a) shows a very strong high pressure center, called the Siberian High, over the frozen landscape of northern Asia. The polar highs are prominent features of the winter circulation over the northern continents. Two intense semi permanent low pressure centers (the Aleutian low and the Icelandic low) are situated over the North Pacific and North Atlantic respectively. These regions are always experiencing low pressure and hence the term semi permanent. The areas affected by these lows experience cloudy conditions and abundant winter precipitation.

July Pressure and Wind patterns

During the summer months, the sub tropical highs in the Northern Hemisphere migrate westward and become more intense than during the winter months. These strong high pressure centers dominate the summer circulation over the oceans and pump warm moist air on to the continents that lie to the west of these highs. This results in an increase in precipitation over parts of eastern North America and Southeast Asia. During the peak of the summer monsoon, the subtropical high is found in the North Atlantic is positioned near the island of Bermuda, hence the name Bermuda high.

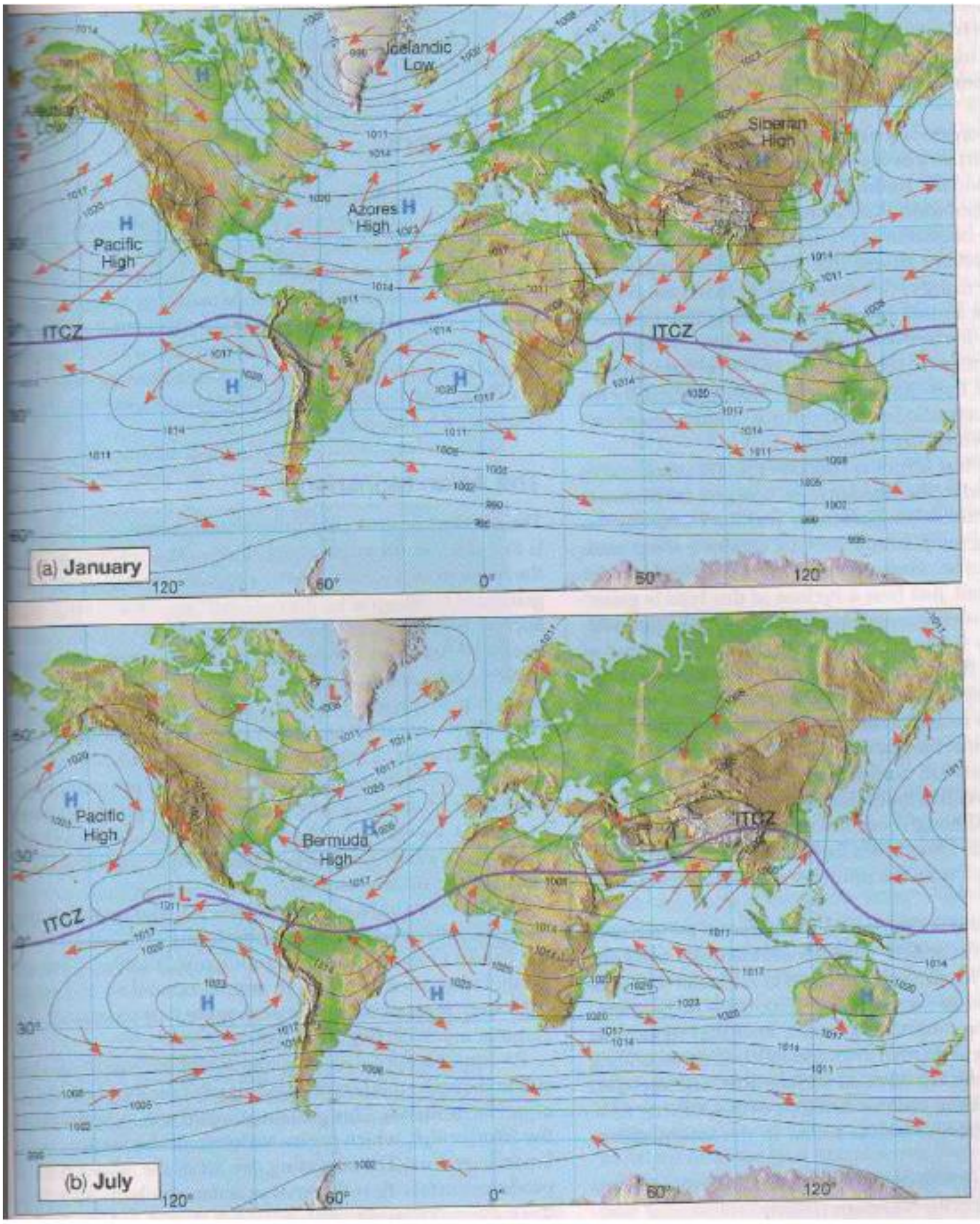


Figure 4 Average surface pressure and associated global circulation
a) January b) July

CONTENTS

(Ref. used for these notes: Indian Climatology by N C Biswas)

CHAPTER 1
WINTER SEASON

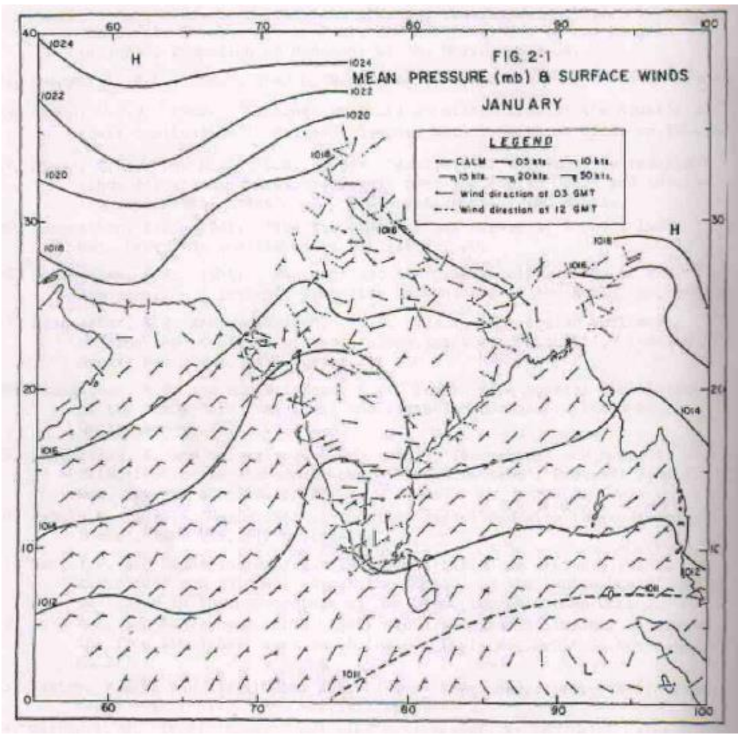
1.1 Climatic Pattern

January is taken as the representative month for the winter season. Winter conditions commence over North India from December itself.

1.1.1 Mean Sea Level Pressure

Siberian High (45ºN / 105ºE) in the northern hemispheric winter is the most intense high pressure cell over the globe. India is at the southern periphery of this high. Pressure gradient is stronger to the north of Himalayas and weaker over India. A weak ridge runs from West Rajasthan to central parts of Bihar and a prominent ridge runs along the east coast.

A trough extends from Kerala to Gujarat and another from Tennasserim coast to Assam.



1.1.2 Surface winds

Surface winds are mainly from northeast to the south of 25ºN both over land and sea. North of 25ºN and west of 88ºE, the winds are mainly north-westerly. However, easterlies prevail over Assam. Mean wind speed is light over the land and about 10 kts over the sea areas.

1.1.3 Upper Level winds

The subtropical high pressure belt, which is almost a permanent feature over the globe throughout the year, is marked throughout the troposphere and defines the wind flow. The winds are westerlies to the north of the sub tropical edge and easterlies to its south

At 850 hPa level, the subtropical ridge runs over India and neighbourhood between 18ºN and 20ºN. It tilts southward with height. It runs roughly along 12ºN and 500 hPa and along 8ºN at 200 hPa levels.

The westerly winds strengthen with height over north India between 25ºN and 30ºN. The wind speed in this belt is about 40 kts at 500 hPa. About 75 kts at 300 hPa and 85 kts at 200 hPa levels. Beyond 200 hPa the wind speed gradually decreases.

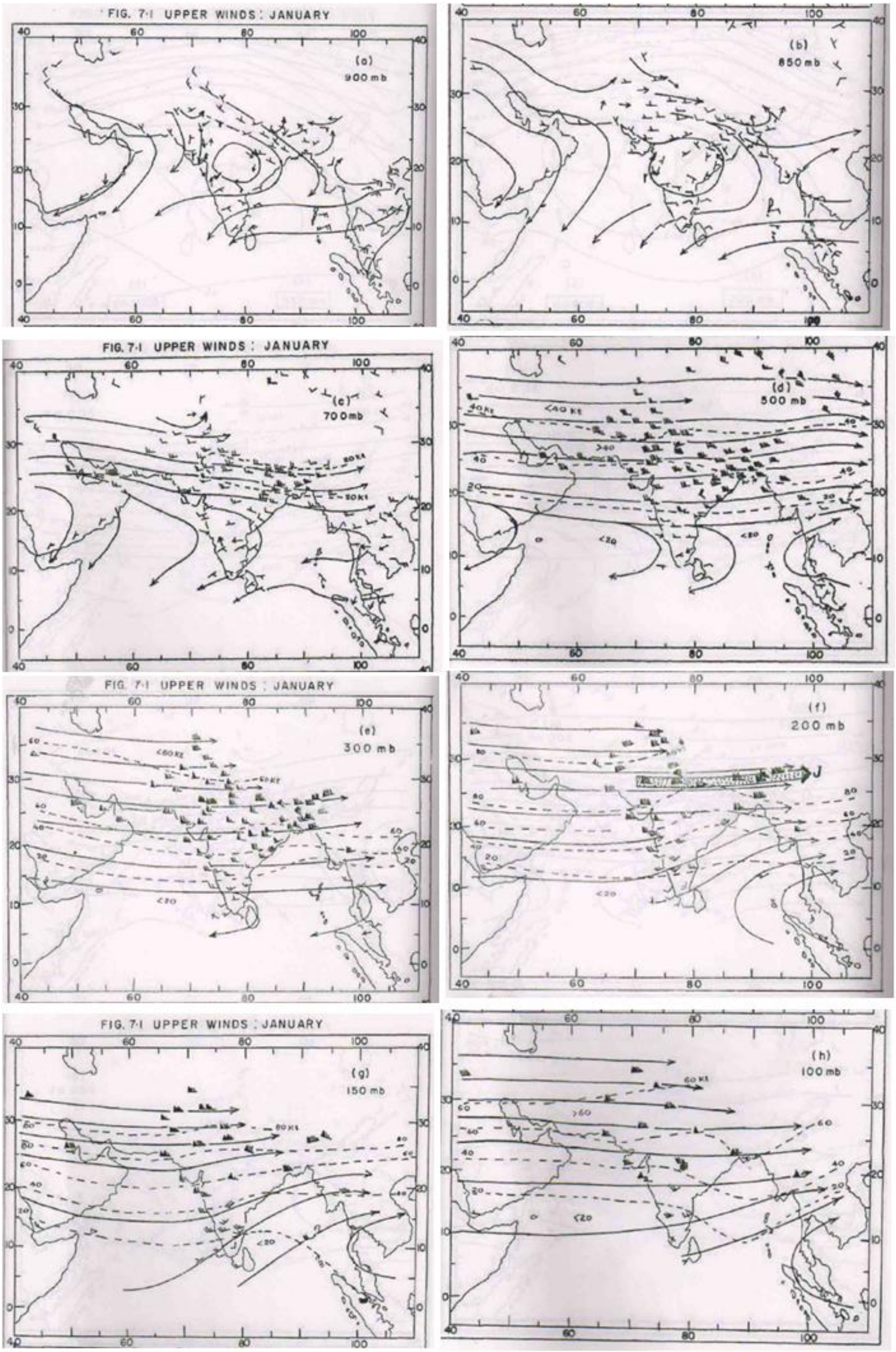


FIG. 7·1 UPPER WINDS : JANUARY

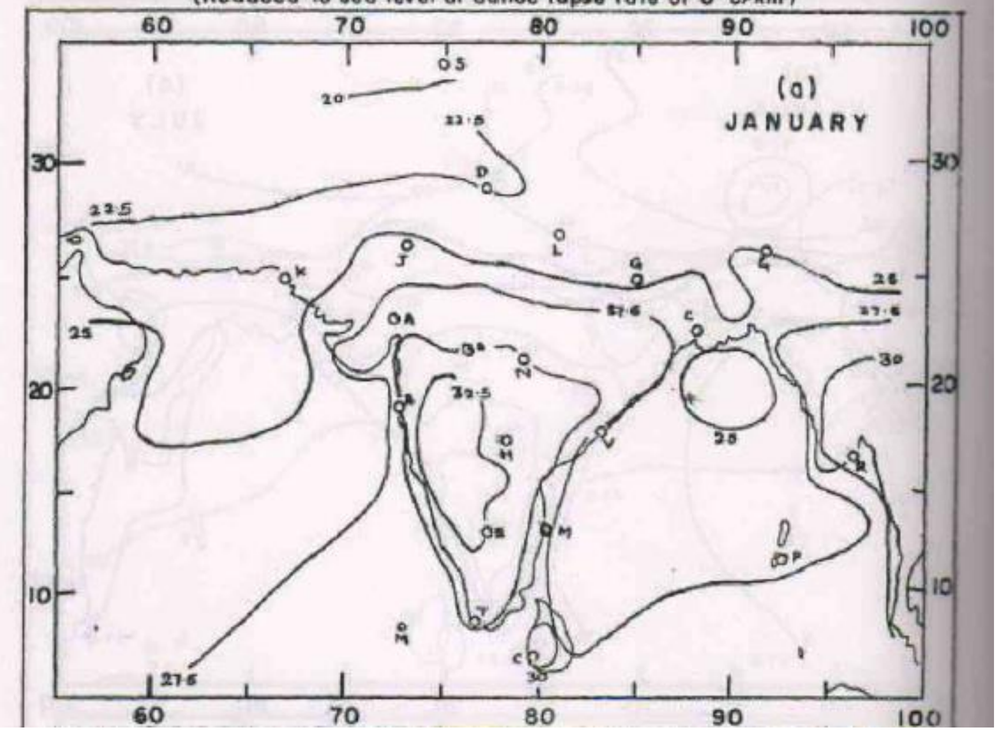
1.1.4 Temperature

1.1.4.1 Mean Maximum Temperature (January)

Peninsular India, south of 20º N is comparatively warmer than to the north. Mean maximum temperature to the south of 20º N is 30º C or more. It decreases northward and becomes 5º C or below over Kashmir. Thermal gradient over India to the south of 30º N is somewhat flat but increases rapidly to the north of it. The isotherms are more or less parallel to the latitudes over north India.

FIG.4·2 MEAN MAXIMUM TEMPERATURE IN °C

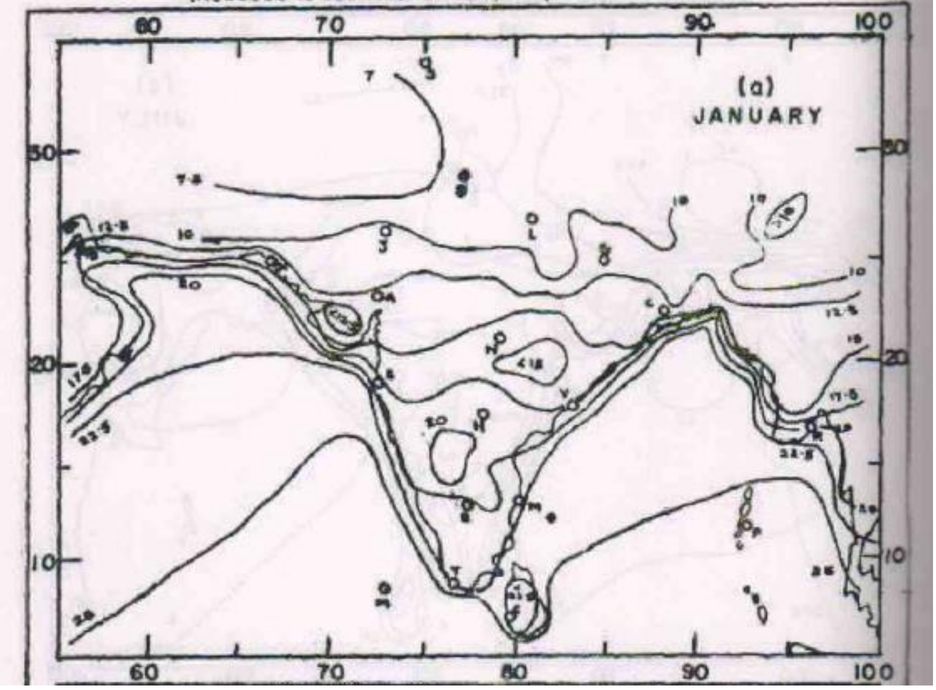
(Reduced to sea level at adhoc lapse rate of 6°c/km)



1.1.4.2 Mean Minimum Temperature (January)

Night minimum temperatures over extreme south Peninsula are more than 20º C. They decrease northwards and become below 0º C over Ladak and neighbourhood. They are below 10º C to the north of 23º N. The isotherms run more or less parallel to the latitudes except in coastal areas.

FIG. 4-3 MEAN MINIMUM TEMPERATURE IN °C
(Reduced to sea level at adhoc lapse rate of 6°c/km)

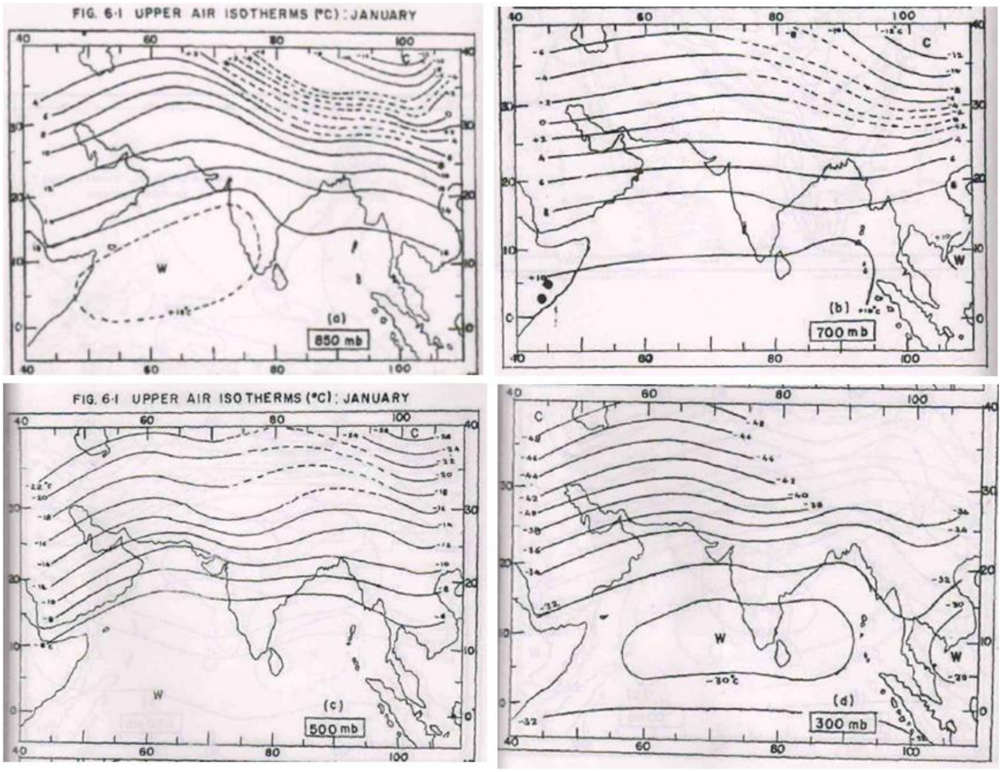


1.1.4.3 Diurnal Range of Temperature (January)

Diurnal range of temperature is more than 10º C over the entire Indian subcontinent except in the coastal areas of Andhra Pradesh, Tamil Nadu, Kerala and Karnataka and Kashmir where it is less than 10º C It is greater than 15º C over NW India, Saurashtra and Kutch, West Madhya Pradesh. North Maharashtra and Telangana and is between 10º C and 15º C elsewhere

1.1.4.4 Upper Air Temperature (January)

Temperature decreases with height upto 200 hPa level during the season. Also temperature decreases northwards from 15º N at all levels between 850 hPa and 300 hPa levels. Thermal high in the upper air lies to the south of 15º N at 200 hPa level. Temperature over India is somewhat flat and lies within 2º C of 51º C. Above 200 hPa level, the temperature gradient is reversed.



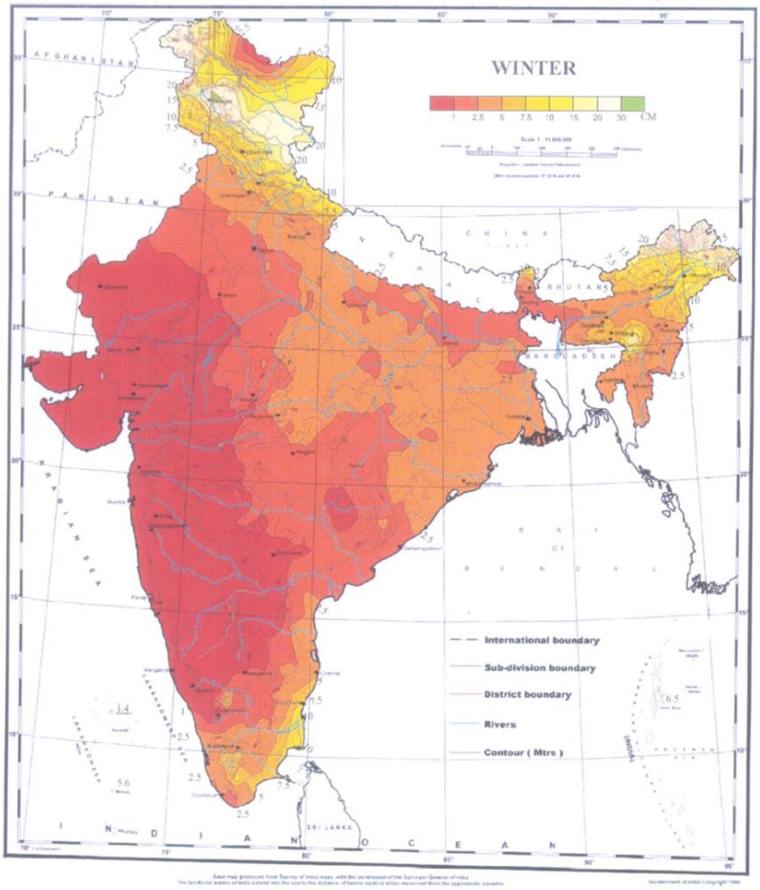
1.1.5 Rainfall (January and February)

The winter rainfall over India is a small percentage of the annual rainfall except in Kashmir and neighbourhood. It is more than 20 cm over Kashmir, Punjab, Haryana, Himachal Pradesh, NW Uttar Pradesh, Northeastern states Bihar Plateau and adjoining Madhya Pradesh, Orissa, coastal and southern parts of interior Tamil Nadu and South Kerala receive more than 5 cm of rainfall during the season. It is less than 1 cm over Western parts of India extending from west Rajasthan in the north to south Karnataka in the south and between 1 and 5 cm in the remaining parts of India.

Rainfall over northern India occurs in association with the passage of western disturbances and induced systems and in the south peninsula due to the movement of easterly waves.

RAINFALL (cm)

Map No.37



1.1.6 Normal Weather during Winter Season in India

Normally the weather is dry over India during the winter season, clear sky, low humidity; low mean temperature with large diurnal range of temperatures is the normal weather pattern over India during the season. However, the dry spell is broken at intervals with the passage of western disturbances across North India and Easterly waves across extreme south Peninsula

1.2 Synoptic Feature

The common synoptic features during the season are (1) Western disturbances and induces systems

(ii) Trough in middle and upper tropospheric westerlies.
(iii) Sub-tropical Westerly jet.

The above disturbances affect the weather over northern and adjoining central India. The extreme south peninsula of India is affected by

(iv) Easterly Waves.

1.2.1 Western Disturbances (W.D) and Induced Systems.

A western Disturbance is a synoptic system in mid latitude westerly winds which moves from west to east across north India. It can be seen as a low pressure area over north Pakistan and neighbourhood which is extended atleast up 0.9 km. a.s.l. as a cyclonic circulation (CYCIR) or trough or as a CYCIR/trough in the lower troposphere. Normally the disturbances affect Indian subcontinent to the north of Lat. 30º N. The WDs are often associated with a trough in the middle and upper troposphere, which tilts westward with height.

When two or more closed isobars at an interval of 2 hPa can be drawn on sea level chart over north Pakistan and adjoining Punjab then the W.D is referred to as Western Depression. The WDs develop over Mediterranean Sea, Black Sea and Caspian Sea. On some occasions its origin can be traced to Atlantic Ocean.

Occasionally under the influence of WDs, lows or CYCIRs develop in the lower troposphere over Rajasthan and west Madhya Pradesh (south of Lat. 30N). These disturbances are referred to as Induced Systems. Movement of induced systems is about 5 per day or less. However, faster movement occurs under the influence of mid or upper tropospheric trough.

Life period of a sequence of WDs per month including the Induced lows move across India during winter season. They are less frequent in post – monsoon and pre monsoon season. Their frequency is 2 to 4 in Nov & Dec., about 5 in March and April and 2 to 3 in May.

Weather associated with the western disturbances are (i) Precipitation (ii) Cold wave condition and (iii) Fog.

(i) Precipitation

Precipitation in association with a W.D first commences over Jammu and Kashmir, Himachal Pradesh, Punjab and Haryana and the next day over East Rajasthan and West Uttar Pradesh. Many times rainfall may cease at this stage. In some cases, rainfall belt extends southwards to Madhya Pradesh and during the following 2 days (though not always) it spreads to east Uttar Pradesh Bihar, Orissa, West Bengal and Sikkim and Assam. Even the disturbance which does not affect NW India south of 30 N sometimes causes precipitation over Assam & Arunachal Pradesh 2 to 3 days after the weather over western Himalayas.

Precipitation normally occurs in the forward sector of a WD as a thundershower. Hails also occur over north India in association with the WDs. The higher reaches of western Himalayas, Sikkim and Arunachal Pradesh often get snowfall.

Cold wave

Cold wave conditions are generally experienced during November to March. It is a relative term with respect to night minimum temperatures.

Criteria for cold wave

As per decisions of AMR 2002, it has been decided that the following revised criteria for declaring of cold wave may be introduced w.e.f 1st March 2002.

Wind chill factor plays an important role and brings down the actual minimum temperature depending upon the wind speed. The actual minimum temperature of a station should be reduced to wind chill effective minimum temperature (WCTn) based on wind chill factor using the enclosed table enclosure I WMO No 331/Tech note No. 123 on "The assessment of human bio climate. A limited review of physical parameters 1972)

For declaring cold wave and Cold day WCTn should only be used.

If WCTn is 10 C or less, then only the conditions for cold wave should be considered.

When normal minimum temperature is equal to 10º C or more

Cold wave	**Departure from normal is – 5º C to 6º C**
Severe cold wave	**Departure from normal is – 7º C or less**

When normal minimum temperature is less than 10º C

Cold wave	**Departure from normal is – 4º C to – 5º C**
Severe cold wave	**Departure from normal is -6º C or less**

When WCTn is 0º C or less, cold wave should be declared irrespective of normal minimum temperature of the station. However, this criteria is not applicable for those stations whose normal minimum temperature is below 0 C

Cold day

In the plains of north India, foggy conditions prevail during winter for several days or weeks. The minimum temperature on these days remain above normal, while maximum temperature remain much below normal. This creates cold conditions for prolonged period. To cover such situations the concept of cold day is introduced.

When maximum temperature is less than or equal to 16º C in plains it be declared "Cold Day"

Cold wave conditions for coastal stations.

For coastal stations the threshold value of minimum temperature of 10 C is rarely reached. However, the local people feel discomfort due to wind chill factor which reduces the minimum temperature by few degrees depending upon the wind speed. The cold day concept may be used following the criteria below:-

Criteria for describing "cold day" for coastal stations

i) Actual minimum temperature of a station be reduced to WCTn
ii) This WCTn should be used to declare cold wave or cold day
iii) When minimum temperature departure is – 5º C or less over a station cold day may be described irrespective of threshold value of 10º C
iv) However, when a threshold of 10º C is reached "cold wave" be declared
v) When a station satisfies both the cold wave and cold day criteria when cold wave has a higher priority and has to be declared.

Heat wave/ cold wave and hot day cold day are area specific phenomena. Therefore, they may be described for Met sub division or a part thereof, when at least two stations satisfy the criteria.

Cold waves occur in the rear sector of western disturbances. The lowest temperatures in cold wave are generally reached on the second night of the cold spell, when the minimum temperatures have dropped as much as 10º C to 12º C below normal.

Cold waves may enter NW India from Pakistan or develop over NW India. They usually spread eastwards upto West Bengal and southwards to Telangana. On some occasions a cold wave may intensify over Bihar or East Uttar Pradesh.

Severe cold waves occur over NW India, West Uttar Pradesh, Gujarat, Madhya Pradesh and Vidarbha between December and April. Occasionally they extend eastwards to east Uttar Pradesh or Bihar. A spell of cold wave usually lasts for about 4 to 5 days and on rare cases 7 to 10. However, over a region it is normally observed for not more than a couple of days. Severe cold wave conditions are generally observed from November to March. Jammu and Kashmir is most affected by severe cold wave approx 4 spells per year.

(iii) Fog

Fog is localized phenomenon. It is suspension of very small water droplets in the air reducing the horizontal visibility to less than 1 km. with relative humidity 75 percent or more.

Fog can be classified into 4 types based on the process which causes its formation

a) Radiation Fog Forms mainly due to radiation cooling of surface at night.

b) Advection Fog forms when moist air is transported over colder surface

c) Steaming Fog Caused by the evaporation form warm water into colder air.

d) Frontal Fog is formed by continuous rain ahead of a warm front.

Radiation and Advection fog occur mostly over north India in winter. Conditions favourable for Radiation fog are

a) High Relative Humidity (b) cloud free sky (c) Light wind and
(d) A stable layer with inversion above ground.

In association with western disturbance conditions become favourable for the occurrence of fog over large areas mainly in its rear sector and sometimes ahead of it. The low level moisture content, stability and wind field conditions become favourable for its formation. In the rear sector of the western disturbance radiation fog occurs one or two days after the cessation of rainfall. Normally the radiation occurs in the early morning and may prevail till late forenoon. Along the coastal areas of Orissa, West Bengal. Bangladesh fog generally occurs ahead of a WD which is located further to the west as moist air current is drawn over these areas under the influence of the WD. Occasionally such conditions also occur over Bihar and east Uttar Pradesh when a easterly stream in the lower levels extends over these areas under the influence of WD.

In the Brahmaputra valley of Assam for formation is frequent more than 20 days a month in winter season. The river and abundant vegetation in the valley provide plenty of moisture in the lower level. The overlaying dry and cold westerly flow provides ideal condition for the formation of fog in the area almost daily

In association with an active WD extensive fog occurs over plains of north India during December to March.

1.2.2 Middle and upper tropospheric westerly trough and sub tropical westerly jet (STWJ)

The predominant winds in the mid latitude regions are westerly. However, the streamlines are characterized by wave like motion with alternative troughs and ridges. These waves were extensively studied by Rossby and are known as Rossby waves or planetary waves. These waves generally move from west to east.

The mid latitude westerly troughs sometimes develop large amplitudes (i.e their N – S extent is very large). Such trough extend southward to tropical regions from November to May and indirectly affect the tropical weather. It has also been established that ahead of a trough divergence occurs and helps intensification of systems on the surface/lower tropospheric levels. The waves may be long waves having a wave length of more than 5000 kms. And short waves, having a wave length of 2000 to 3000 km.

Movements of the short wave troughs are faster than the long waves. Long waves are generally of larger amplitude, while the short waves have smaller amplitude. The westerly trough mainly affects weather over the Indian sub continent from October to May. During the monsoon season these troughs are seen rarely in this region.

JET STREAM

According to WMO definition a Jet Stream is a narrow current concentrated along a quasi horizontal axis in the upper troposphere characterized by strong vertical and lateral wind shear featuring one or more velocity maxima. Normally a jet stream is thousands of kilometer in length, hundreds of kilometer in width and a few kilometer in depth. The vertical wind shear is of the order of 5 to 10 m/sec per km and the lateral shear is of the order of 5 m/sec per 100 km.

An arbitrary lower limit of 30 m/sec (60 kt/hour) is assigned to the wind speed along the axis of the jet stream.

Sub Tropical Westerly Jet (STWJ)

Jet stream in the subtropical latitude is a semipermanent feature (Namais and Clapp 1949). It is strongest near the 200 hPa level. During the colder season the subtropical jet stream is a dominating phenomenon in both the hemispheres. The major wind maxima are normally located downstream from the region of strongest confluence.

The STWJ is generally observed over North India from October to May and is strongest during the winter. The main characteristics of the STWJ over India during winter are

(i) The mean position of the jet stream in winter lies near Lat. 26º N (Jodhpur, Allahabad, Guwahati at 200 hPa level (12 km) The mean wind speed at the core is about 100 kts. The axis of the Jet Stream shifts southward as the season advances and towards the end of winter or in early spring it reaches the southernmost position.

(ii) There are two maxima: one over the western India (Jodhpur) and the other over the eastern India (Guwahati)

(iii) The mean wind speed of 95 kts is recorded at 12 km, over Jodhpur and 10.5 km at Guwahati. At 12 km it is 90 kts over Guwahati. The mean wind speed is 80 kts. Over Allahabad both at 10.5 and 12.0 km

(iv) During winter the wind speeds of 60 kts or more are found to the north of Lat. 20º N. At this latitude Jet speed wind is observed in a thin layer of the atmosphere. At Lat. 23º N the Jet wind commences at 9 km and over Assam even at 7 km and extends upto 14 km.

(v) The horizontal wind shear is generally more than 5 km/hr per 100 km to the south of the jet core and the vertical shear is about 20 km hour per km below the core

(vi) The S.T. jet stream lies entirely within the troposphere and about 3 – 4 km below the tropopause and is located near the break in the tropopause between tropical (near 100 hPa) and middle latitude (near 200 – 250 hPa) tropopauses.

(vii) It is strongest in February along Delhi – Allahabad – Guwahati latitudes. It shifts in May to 30 N and disappears from the Indian Latitude during the SW monsoon period. It appears near 30º N in October at 12 km and shifts between 25º N and 30º N in December. Mean wind speed is 70 kts in November and 80 kts in December.

1.2.3 Easterly waves

These are the waves/troughs in the equatorial easterly winds (Trades) having an approximate wave length around 2000 km. These are weak waves and can be detected in the wind field than in the pressure field. The easterly waves are not typical of the whole tropical belt. They are observed in some parts of the tropical belt (namely) north Atlantic and mid Pacific and in the Indian Seas during from November to March and are prominent from the winter season. They can be traced in the Indian Seas from the westward moving isallobaric centre at sea level and wind shift in the upper air. These waves generally attain maximum intensity around 600 hPa. The predominant periodicity of the easterly wave is 7 – 10 days, occasionally 4 -5 days. The wave generally tilts eastward with height. There is lower level convergence and upper level divergence on the east side (rear) of the surface / 0.3 km a.s.l wave. As such, convective shower activity is generally greatest in the rear (east) of a wave although it may occur with much lesser intensity and aerial extent to the west (forward) of it. During winter south Tamil Nadu and south Kerala experience rainfall due to the movement of easterly waves across south Peninsula.

CHAPTER 2
PREMONSOON SEASON

Climatic pattern

It is transition period from winter circulation to summer monsoon circulation. The month of April is taken as the representative month for the season. During this season both days and nights are not, which is occasionally alleviated by local thundershowers. Heat wave conditions over plains of north India and dust/sand storms over northwest India & neighbourhood are the common features of the season.

2.1.1 Sea Level Pressure

It is a transition period from larger pressure gradient from northern latitudes towards south (winter) to large pressure gradient from equatorial region towards north (monsoon). Though the pressure gradient is weak during this season there is dramatic change from the winter pattern. Due to increased heating of lands low pressure area starts developing over the land in March itself. The isobars are tapering shaped over the Peninsular India due to maritime influence. The land heating is more prominent to the north of 20º N. A weak low pressure area develops over Singh and another over Bihar and adjacent U.P. there is an extension of the heat low as a trough of low pressure up to Orissa, over the peninsular India a trough forms with its axis along longitude 78º E Shallow highs develop over the sea areas one over the Central Bay of Bengal and another over the central Arabian Sea. By May the heat low is established over Punjab and adjoining areas with an extension of trough up to Orissa

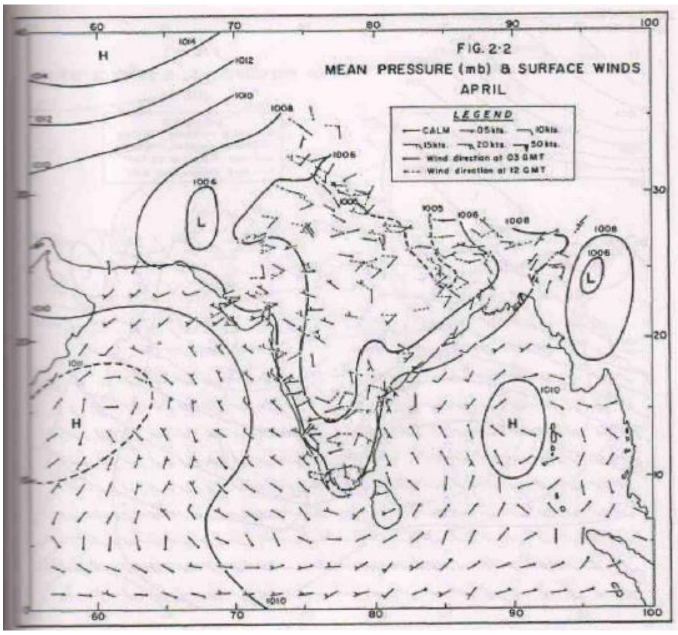


FIG. 2·2
MEAN PRESSURE (mb) & SURFACE WINDS
APRIL

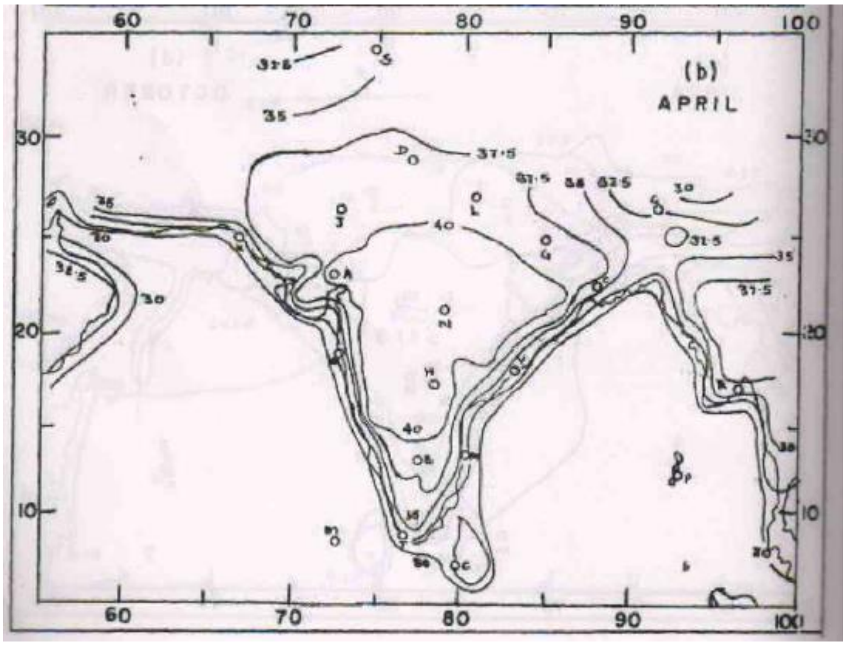
2.1.2 Surface Winds:

The winds are Northwesterly to Northerly to the west of the trough line and southerly to southeasterly to the east of it over the peninsula. In the northern plains of India winds during April are light westerlies whereas over Assam they are light easterlies. Winds over the Arabian Sea and the Bay of Bengal are light and are turning anticyclonically.

2.1.3 Temperature (APRIL)

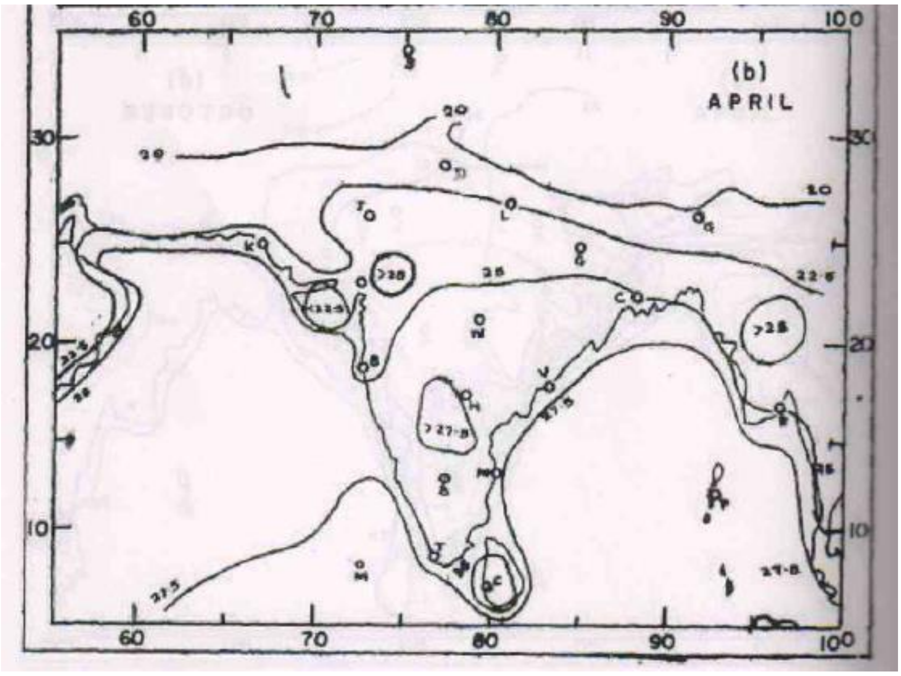
2.1.3.1 Mean Maximum Temperature

A large part of the country between Lats. 14º N and 30º N and Longs. 70º E and 89º E has a very high day temperatures ranging between 37º C and 40º C Day temperatures in Northern Maharashtra and adjoining areas of Gujarat exceed 40º deg. C The mean maximum temperature decrease rapidly northwards over Western Himalayas where it range between 20º C to 30º C. Isotherms over Western Himalayas and in the coastal belt run relatively closer, i.e. Thermal gradient is steeper these areas



2.1.3.2 Mean Minimum Temperature (APRIL)

Over most parts of the country the night temperatures range between 20 ºC and 25 ºC. Along the coastal areas, they are slightly higher than 25º C In northern India the areas closet to Himalayas namely Jammu. Himachal Pradesh, northern parts of Uttar Pradesh, Bihar Plains to the north of 26º N SHWB and SKM and Assam. Arunachal Pradesh and Nagaland, they range between 15 ºC and 20 ºC in Kashmir the night temperatures are less than 10 ºC



2.1.3.3 Diurnal Range (APRIL)

The diurnal range of temperature is rather large over a wide area between Latitudes 15 ºN and 32 ºN and to the west of Longitude 85 ºE excluding the coastal regions and interior Orissa. The diurnal range in these areas is of the order of 15º C to 18º C. Over northeastern states it is around 10 ºC and is less than 10º C along the coastal strips of the peninsular India. As the season advances, the diurnal range slightly increases over most parts of the country.

2.1.4.1 Upper Air (APRIL)

There is not much change in the position of the sub tropical ridge across the country during April from winter season. However, the strength of the westerlies in the middle and upper troposphere (upto 200 hPa) considerably decreases over north Indian plains. With advance of the season the sub tropical ridge shifts northward and the equatorial easterlies gradually penetrate to higher latitudes with increasing strength.

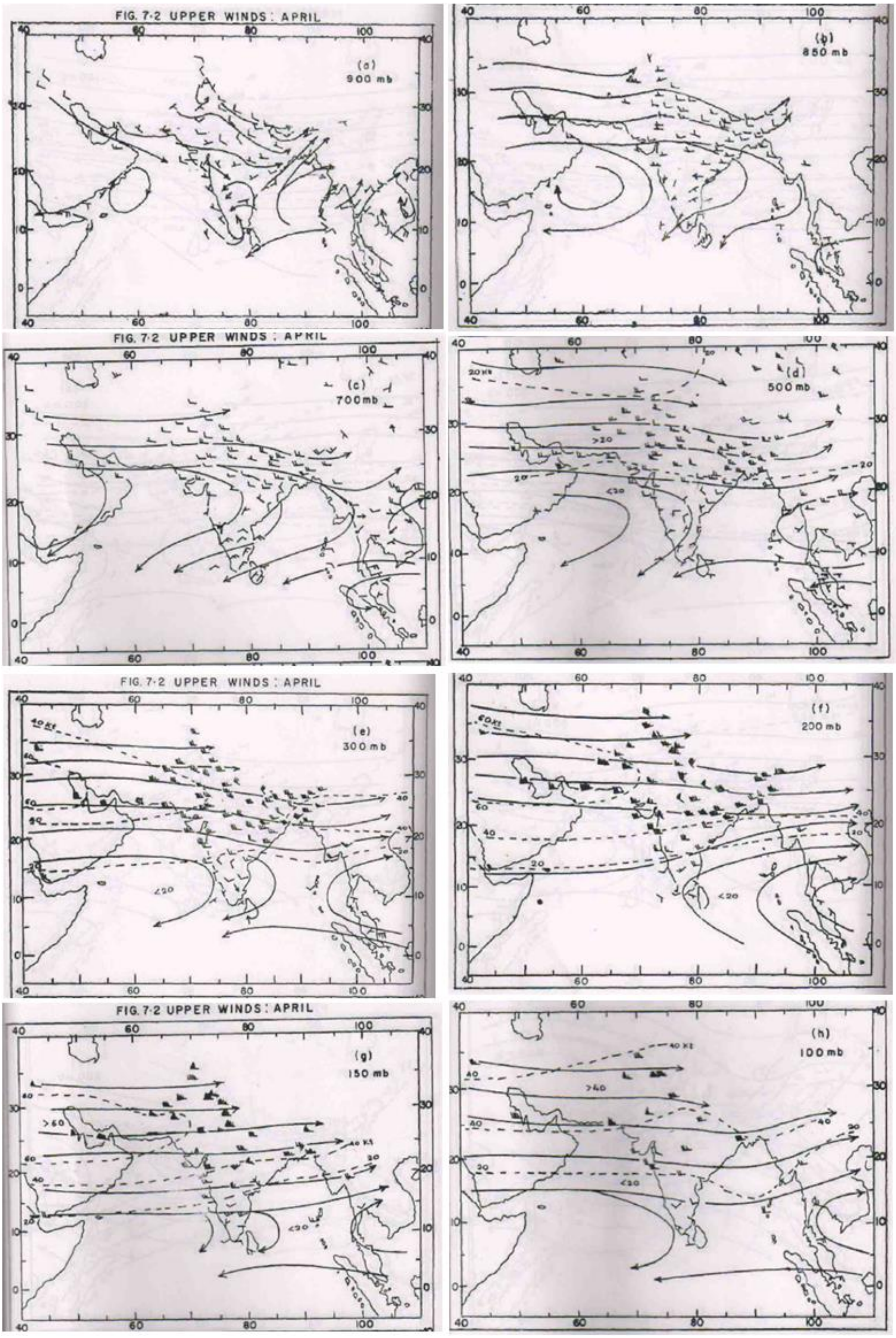


FIG. 7·2 UPPER WINDS: APRIL

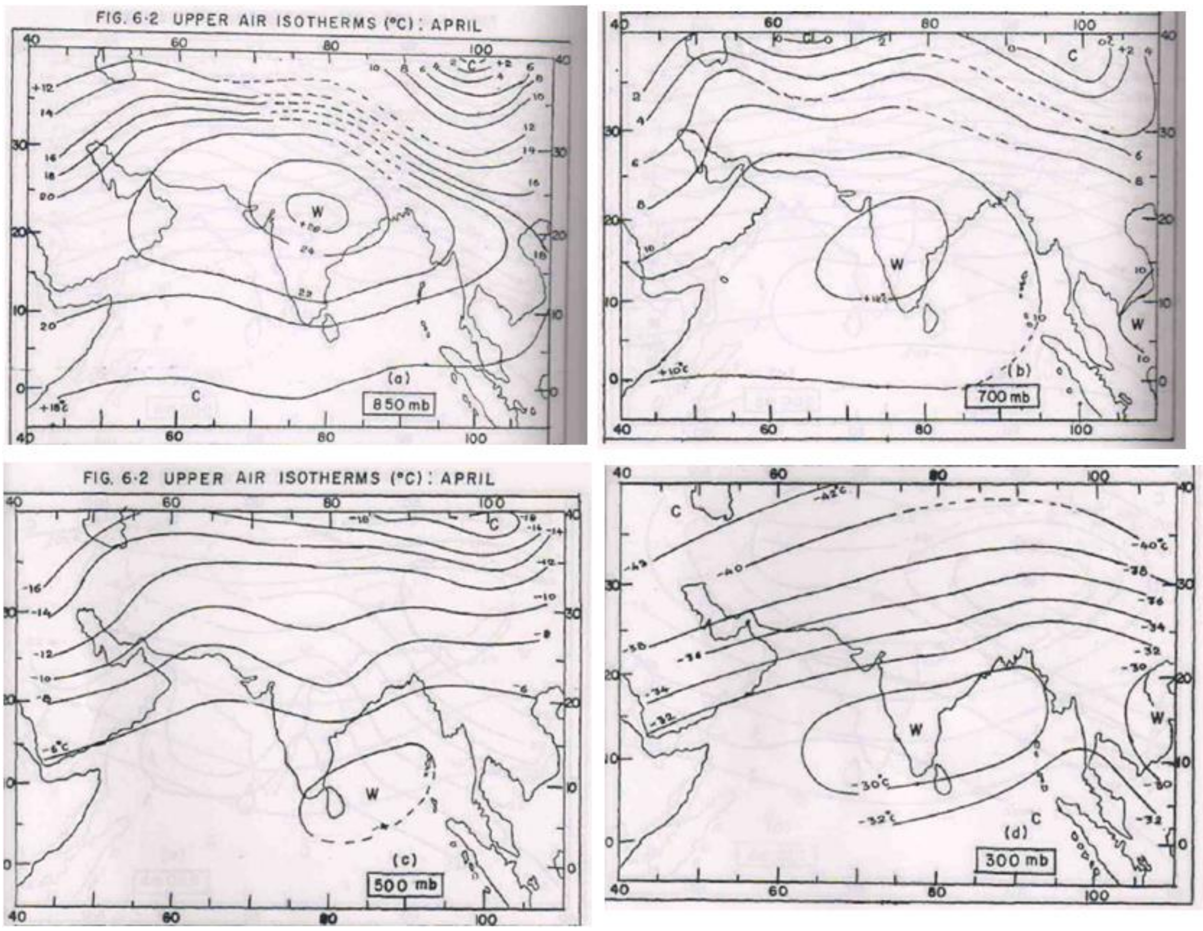
Upper Air Temperature (APRIL)

i) The thermal high shifts northward from winter position and develops over north peninsula and adjoining areas at 850 hPa level. The air temperatures at this level become warmer by 4ºC to 8ºC than the winter period over India.

ii) The thermal high shifts southward with height

iii) The thermal field becomes very flat at 200 hPa level

iv) At 150 hPa and 100 hPa levels there is increase of temperature towards north from the central parts of the peninsula with the advance of the season, the thermal highs is the upper air shift further northward.

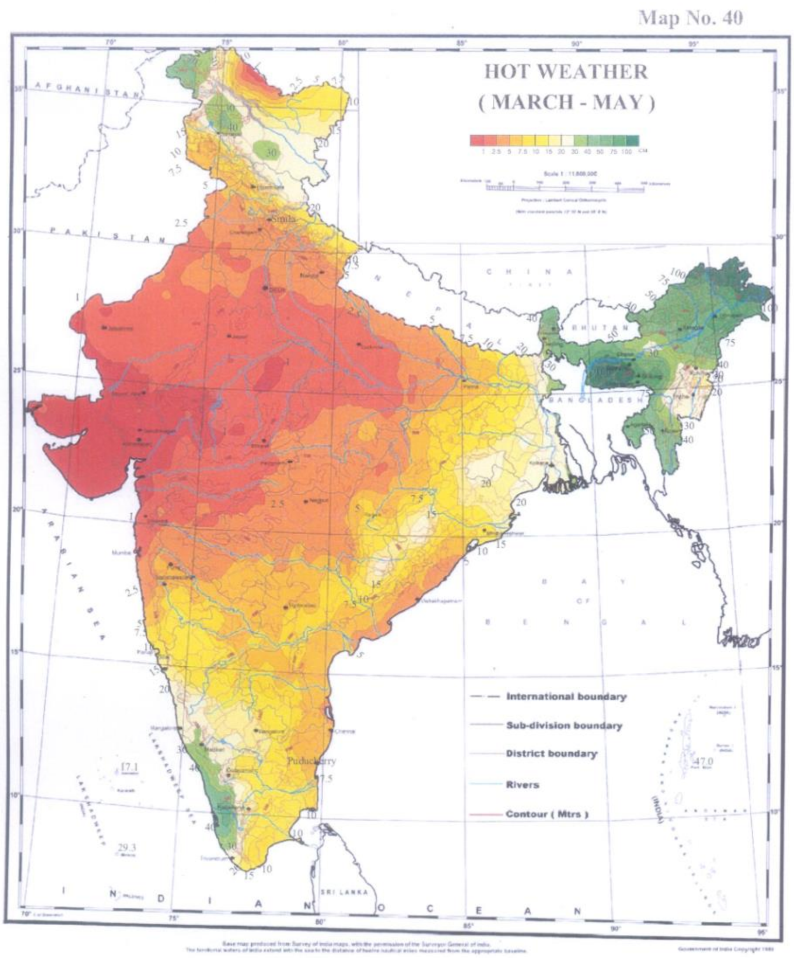


2.1.5 Rainfall (MARCH MAY)

The major rainfall areas during the season are Assam and adjacent states, Kashmir, Himachal Pradesh and south Kerala. In the northeastern states the rainfall amount is higher (100 cm or more) in the southern parts of Meghalaya. It ranges between 30 and 50 cm over the remaining part of the area. It is about 40 – 50 cm over Kashmir Valley and over south Kerala and between 20 – 40 cm over north Kerala of rainfall ranging between 10 to 20 cm occurs during the season over hills of W.UP H.P. rest of NE Indian state. Coastal Andhra and adjoining Telangana and SE A/P and south peninsula. It gradually decreases northwards and westward becoming minimum over west Rajasthan and Saurashtra and Kutch.

The rainfall, over north India occurs due to western disturbance and induced system whereas cause of rainfall over and Peninsular India is due to trough/wind discontinuity and depressions and storms.

RAINFALL (cm)



2.2 Main Synoptic Features and Associated Weather

The main synoptic features during the season are the following:

i) Western disturbances and induced systems, which affect north India
ii) Depressions and cyclonic storms in the Indian seas
iii) Wind discontinuity/trough in the lower troposphere over central and peninsular India E-W trough/wind discontinuity in the lower tropospheric levels extending from Bihar plains to eastern Assam also develops during April end/May.

The pre-monsoon season is known for its intense convective activity over the land areas. Thunderstorms, duststorms, hails storms and their associated features are the chif phenomena of the season which occur in association with the above mentioned synoptic features. Besides convective activities the other important weather phenomenon during the season is the Heat wave condition over the land areas.

The western disturbances and the induced systems and associated weather have been discussed in the winter season features

The wind discontinuity over the peninsular occurs due to the development of anticyclones in the lower troposphere one over the Arabian Sea and the other over the Bay of Bengal. The position of the wind discontinuity/trough meanders over the peninsula according to the strength and position of these two anticyclones.

Thunderstorm activities during the season over almost throughout the length and breadth of India. Sometimes they are accompanied with hails, squalls etc. However, the main regions of high thunderstorm activities in country are

(i) NE India (ii) NW India (iii) East Madhya Pradesh, East Vidarbhha and adjoining Andhra Pradesh (iv) Southwestern parts of the peninsula.

Over these areas, thunderstorms occur on an average 15 – 20 days during the season. In Assam the thunderstorm days are as high as 30 -40 the pre-monsoon period, while it is minimum over West Rajasthan and Gujarat. The activity begins in March and progressively increases with the advance of the season reaching to its peak in May. The areas of high thunderstorm activities are also affected by hailstorms and occasionally by tornadoes.

Though not frequent Tornadoes which are highly devastating micro scale features, occur in Assam and adjacent states, West Bengal, Orissa, Gangetic Plains, Punjab and Haryana.

To discuss the climatology of thunderstorms, India is divided into four divisions, namely

(1) NE India (ii) Northwest India and Uttar Pradesh, (iii) Central parts of the country and (iv) Peninsular India.

2.2.1 Conditions Favourable for Occurrence of Thunderstorms

The size of thunderstorms varies from a few kilometers to tens of kilometers. Their duration may be from a few minutes to a few hours. They are the most violent convective systems in the atmosphere and are associated with cumulonimbus (Cb) clouds. Normally, the entire life span of Cb – cloud is only a few hours. Thunderstorms generate squally winds and squall line and sometimes produce hails known as hailstorms. Following are the favourable conditions for the occurrence of thunderstorms.

i) Conditional and convective instability in the atmosphere
ii) Adequate supply of moisture, particularly in the lower levels.
iii) A dynamical mechanism to realize the instability leading to convection in the atmosphere i.e. uplift over hills and mountains, selective heating from below, convergence etc.

2.2.2 Thunderstorms over NE India

NE India comprises of Assam and adjacent states, West Bengal and Sikkim, Orissa and Bihar. Thunderstorms over NE India are known as ‘Norwesters’ (moving from NW direction) or ‘Kalabaishakhi (Highly destructive local storms in the month of Baishakh). Some of them may reach the violence of tornadoes. They are often accompanied by severe squalls with speeds reaching 150 km per hour. They usually originate in the afternoon over Bihar and neighbourhood and travel eastwards over Gangetic West Bengal. Those affecting Assam and adjacent states have their origin over northern parts of West Bengal during night or early morning and they travel southwards.

Thunderstorm activity over NE India commences in March and reaches to its maximum phase in May. However, in Assam and adjacent states, the activity is fairly high in all the months of the season. In these areas there is considerable increase of thunderstorm activity from March to April and the increase from April to May is only slight. In other sub-divisions of NE India outside Bihar Plains, the activity in May is almost double than that of April. In Bihar plains it mainly occurs during the month of May. Spatial distribution of thunderstorms is more in Assam and less in Bihar. Thunderstorms over NE India occur in association with low level trough or eastward moving western disturbance or induced system.

2.2.3 Thunderstorms/Duststorms over NW India and Uttar Pradesh.

Thunderstorms occur over NW India and West Uttar Pradesh in all the month of the pre-monsoon season. The activity is more in western Himalayas than in the plains and is more during the latter half of the season. The areas of high thunderstorm activity are also the areas of hailstorms and squalls.

Duststorms, which are raised dust in the air occur only in the plain. i.e. in Punjab, Haryana, North Rajasthan and adjoining West Uttar Pradesh, Locally the duststorms are known as ‘ANDHIS’ Duststorm activity starts in April and continues upto June. Their frequency of occurrence is maximum in June. On a few occasions duststorms are followed by thundershowers. Intense surface heating, western disturbances and westerly trough are the causes of duststorms.

Duststorms may be categorized into two types namely

(i) The Pressure Gradient Type and (ii) The convective type.
(i) Pressure gradient type

When the seasonal low pressure area over NW India becomes marked strong gradient builds up to the south of the low causing strong winds (about 30 kts). Which may extent up to 1.5 km. These strong winds raise the dust particles in the air reducing the visibility below 1.0 km such pressure gradient type duststorms occur frequently over Rajasthan in May and June.

The dust raising winds may commence at any time of the day, but become most intense during afternoon/evening. The raised dust particles in air remain suspended for a long time even after there is cessation of the strong winds.

(ii) Convective type

Duration of this type of duststorms varies from a few minutes to a fraction of an hour. It occurs in the later part of the day or night. In this type of duststorms the dust particles are raised by the down draft winds of Cb-clouds in such cases the dust particle may go up to a height of 2 to 3 kms. Convective type duststorms often precede thunderstorms.

2.2.4 Thunderstorms over Central India i.e. Madhya Pradesh and Vidharbha

East Madhya Pradesh and adjoining area experiences high thunderstorm activity during the pre-monsoon season. The activity commences over Madhya Pradesh and Vidarbha by March which increases considerably in April and May. The activity is comparatively less in the western districts of West Madhya Pradesh. The mean monthly thunderstorm days are 10 -12 days over southeast Madhya Pradesh in April – May, while they are only 4 days in the western districts of west Madhya Pradesh. Thunderstorms over this region normally occur during the afternoon evening. The northern part of Madhya Pradesh sometimes gets duststorms. Movement of western disturbance or induced system coupled with orography of the region and the wind discontinuity cause the thunderstorm activities in this region.

2.2.5 Thunderstorm over Peninsular India

The thunderstorms over peninsular India are mainly caused by low level wind discontinuity running close the west coast of India extending from Kerala south Tamil Nadu to western parts of Maharashtra. The seat of thunderstorms shifts with the east west movement of the discontinuity. The location of the wind discontinuity depends upon the positions and intensities of the Bay and the Arabian Sea anticyclones in the lower tropospheric levels. Thunderstorms mostly occur in the afternoon/evening along this line. High thunderstorm activity occurs over Kerala and adjoining Tamil Nadu and Karnataka during this season. However, along the east coast of India, the thunderstorm activity is relatively less. It commences in the month of March and increases to some extent during April and May. Kerala experiences nearly 15 days of thunderstorm activity per month during April and May. Orography coupled with sea breeze is one of the causes of high thunderstorm activity in this region. Thunderstorm activity over south Peninsula increases just prior to the advance of the monsoon.

2.2.6 Heat waves

During the period March to June the normal day temperatures are generally high over the Indian sub continent. Further rise of temperature causes physiological strain, which sometimes may become fatal.

Like 'Cold wave'. In winter season the 'Heat Wave' during the hot season is also a relative term and is defined in terms of the departures of the day's maximum temperatures from the normal.

Conditions, which were in vogue to define heat wave at a place or a region till 2001 in IMD have been modified in 2002. The modified conditions have become effective from the summer of the 2002. The conditions are given below

Criteria for declaring of cold wave

As per decisions of AMR 2002, it has been decided that the following revised criteria for declaring of cold wave may be introduced w.e.f 1st March 2002.

Criteria for Heat wave:

Heat wave need not be considered till maximum temperature of a station reaches at least 40º C for Plains and at least 30º C for Hilly regions.

When normal maximum temperature of a station is less than or equal to 40º C

Heat wave	**Departure from normal is 5º C to 6º C**
Severe Heat wave	**Departure from normal is 7º C or more**

When normal maximum temperature of a station is more than 40º C

Heat wave	**Departure from normal is 4ºC to 5ºC**
Severe Heat wave	**Departure from normal is 6ºC or more**

When actual maximum temperature remains 45ºC or more irrespective of normal maximum temperature, Heat wave should be declared.

Hot day

In the northern plains of the country, dust in suspension occurs in many years for several days, bringing minimum temperature much higher than normal and keeping the maximum temperature around or slightly above normal, sometimes increase in humidity also adds to this discomfort. Nights do not get cooled and become uncomfortable. To cover this situation, hot day concept has been introduced as given below:

Whenever, the maximum temperature remains 40ºC or more and minimum temperature is 5ºC or more above normal it may be defined as HOT DAY provided it I not satisfying the heat wave criteria given above.

Criteria for describing Hot Day for coastal stations

When maximum temperature departure is 5ºC or more from normal Hot Day may be described irrespective of the threshold value or 40ºC. If the threshold value of 40 C is reached Heat Wave may be declared.

When a station satisfies both the Heat Wave and Hot day criteria, then Heat Wave should be given higher priority and be declared.

Hot wind

Hot wind reduces moisture causing dehydration and a prolonged exposure may prove to be fatal. The phenomenon of "Loo" over the plains of northwest India is very well known. It is also described in the weather bulletins and appropriate warnings are being issued at present. The practice present should continue.

The ideal situation for occurrence of heat wave is the transport of dry and warmer air in a region with clear skies for maximum insolation. The favourable conditions for the occurrence of heat wave are given below:

i) Transportation/Prevalence of hot dry air over the region
ii) Absence of moisture in the upper air
iii) Lapse rate should approach dry adiabatic in the air mass to allow warming to a considerable depth.
iv) Large amplitude anticyclonic flow over the area.

Climatological statistics (1911 – 1967) shows that the frequency of severe heat wave conditions are maximum in June and least in April Jammu and Kashmir, Punjab, Uttar Pradesh, Madhya Pradesh, Saurashtra and Kutch, Bihar, West Bengal, Orissa and south Assam have high frequency of heat wave is mainly confined to North India. The interior parts experience heat wave more often than the coastal regions.

Frequency of severe heat waves

MARCH

17 % of the severe heat waves occur in this month. Saurashtra & kutch is the most favourable region of occurrence.

APRIL

The frequency is only 7 %. They occur in the west over the region extending from Jammu and Kashmir to Konkan and in the east over Bihar Plateau, West Bengal and south Assam.

MAY

Frequency is only 10 % and Jammu and Kashmir is the most susceptible region. However, the heat wave conditions are more often observed over eastern parts of India than over the western parts

JUNE

Nearly 54 % of the total incidence is recorded in this month and east Uttar Pradesh is the most favoured region of occurrence.

JULY

Frequency is only 12 % and they occur mainly over west Uttar Pradesh and Punjab.

During heat wave condition maximum temperatures 10 C above normal have often been recorded over east Uttar Pradesh and Bihar Plateau.

Persistence –

Normally a spell of heat wave lasts for about 5 to 6 days and on rare occasions for about 10 days or more. However, severe heat wave does not persist over a sub divisions or a region for more than a day or two outside Bihar Plateau, where it may persists for as much as 4 to 5 days.

Area coverage –

The area coverage at a time varies from spell to spell. With the advance of season. The area coverage becomes larger. Generally the heat wave develops over the north-western part of the country and then spreads in the neighbouring areas. Heat wave gradually shifts eastwards and southwards because of the prevailing winds, which are mainly north-westerly over the country during this period. They never expand/shift to the west for the same reason. Heat wave may also develop over any region in situ under the favourable conditions.

2.3 Storms and Depressions in Pre-monsoon season

Besides intense convective activity, the hot weather season is characterized by the tropical cyclone activity in the Indian seas. Tropical cyclones re bi-model in nature over the India seas having a primary peak in November and a secondary peak in May i.e. one in post monsoon and the other in the pre monsoon season, storms seldom develop during January to March in the Indian seas. Annually 5 – 7 storms develop in the Indian sea which is 7 percent of the global total (about 890). In the pre-monsoon season they develop from April to mid June and in the post monsoon from October to mid December these periods of storm activities in the Indian seas often referred to as the ‘Storm Season’.

Statistics of the cyclonic disturbances during the pre-monsoon season brings out the following features.

i) Bay of Bengal is more prone to depressions and storms than the Arabian Sea in the pre-monsoon season
ii) Peak storm activity normally occurs during the month of May. Also during this month most of the storms attain severe intensity.

Place of origin.

APRIL

Most of the bay storms originate between 8 N and 13 N and to the east of 85 E. In the Arabian Sea their number during this month is very less. A few developed in this month in the SE Arabian sea adjoining to Lakshadweep, Maldives areas.

MAY

Most of them originate between 10° N and 15° N in the bay and between 7° N and 12°N in the Arabian sea.

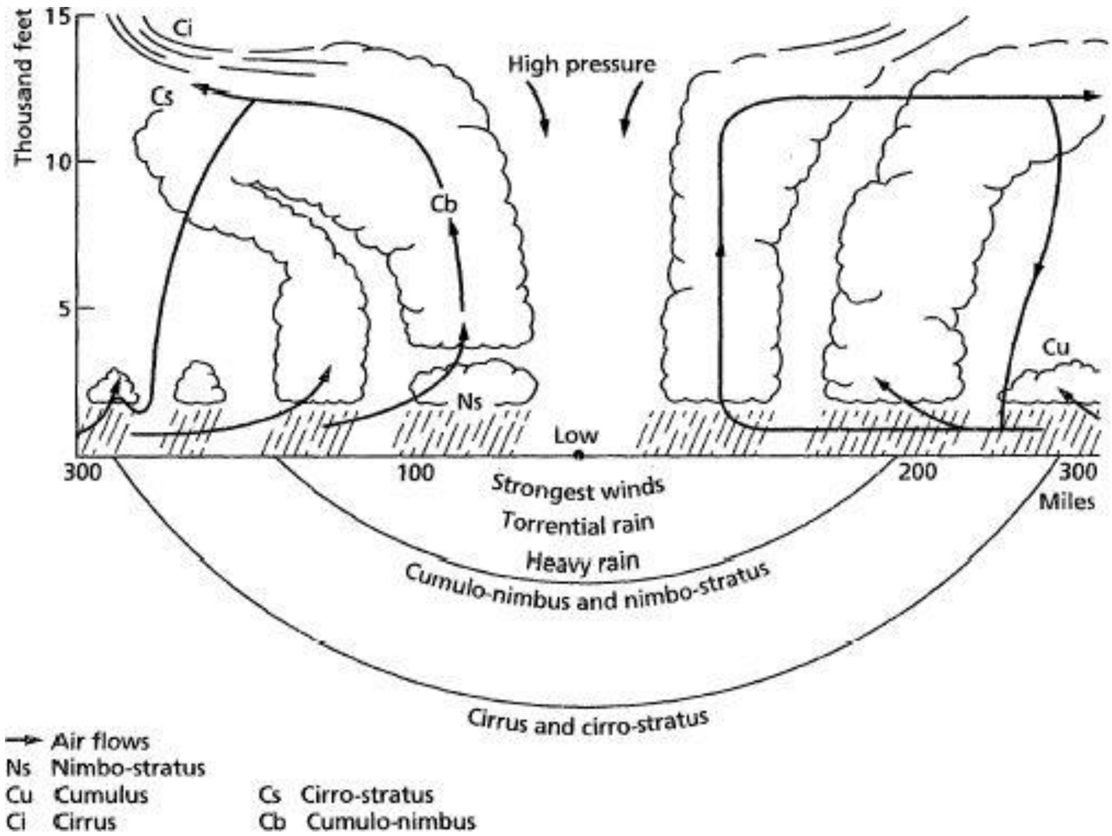
JUNE

Depressions in the Bay of Bengal develop to the north of 15° N and west of 92° E. They generally intensify into storms to the north of 18° N. In the Arabian Sea the formation of storm is between 17° N and 20° N

Formation of storms practically ceases once the SW monsoon is established over the Indian Sea.

Structure

A cyclonic storm is an intense vortex in the atmosphere with a diameter varying between 150 km to 1500 km at the surface; Vertically it extends upto 300 / 200 hPa levels and decreases in size with height. The maximum sustained surface winds associated with a severe storm could be as high as 250 km per hour or more at a distance of 30 – 40 km from its centre. The winds gradually decrease outwards. However, the incidences of such severe storms in the Indian seas are relatively very small compared to other storm basins. A mature tropical cyclone consists of a central region of light winds or calm wind and generally free from clouds known as the eye of the storm. In Indian region the size of the eye has a diameter of about 20 to 30 km and in some cases 50 to 60. Usually large systems can have larger eye region. Maximum sustained winds are normally observed just beyond the eye region. The size of the pre monsoon storms is smaller than the post monsoon storms. The diameter of April and May storms vary between 400 and 600 km. However, the aerial size of the storm is not a measure of its destructive characteristics.



Movement

A large number of storms (about 60 to 70 %) in the Bay of Bengal move towards Bangladesh and Myanmar coasts. Only 30 % of them cross Indian coast.

In April they initially move towards NW or north and later recurve NE wards. In May the movement is widely variable. The whole of the east coast of India and the Bangladesh and Myanmar (Burma) coasts are liable to incidence of storms in May.

In Arabian Sea those forms to the west of 70 E normally move away towards Arabia coast. Those forming close to the Indian coast travel north to northeast and strike west coast of India – mainly Gujarat and Maharashtra coast.

Disastrous weather associated with Cyclonic storms

The destruction caused by a cyclonic storm in the coastal areas is due to the

i) Hurricane winds (> 64 kts)
ii) Torrential Rains
iii) Storm Surge

(i) Hurricane winds

The high winds are packed in a tight ring in the wall cloud region around the 'eye' of a fully developed storm. The hurricane strength wind may extend over an area of 50 – 150 km in diameter. The destruction due to high winds is mostly confined to vulnerable structures.

(ii) Torrential Rains

Very heavy rain occurs in the coastal areas. Normally more intense is the storm, higher is the rainfall amount. Rainfall of the order of 40 cm in 24 hours has occurred in many cases and as high as 50 – 55 cm. has also been reported occasionally. Heavy rainfall causes floods damaging property and perishing lives.

(iii) Storm surge

Storm surge or the tidal waves is a sudden rise in sea level along a narrow coastal belt at the time of storm crossing the coast. In a severe storm the tidal wave as high as 3 to 5 metres strike the coast. It inundates the low lying coastal areas and is responsible for nearly 90 percent of lives lost in a tropical cyclone. It also extensively damages crops and property.

2.4 Tornadoes

A tornado is a vortex of small horizontal extent of severe intensity which extends downward from a thundercloud. It is usually visible as funnel shaped cloud with a broad base in cumulonimbus cloud in association with large Cb clouds or cyclonic storms.

The diameter of a tornado may vary from a few meters to a few hundred meters. The wind speed near the core of a tornado can be as high as 400 – 500 km per hour. The winds are strong also outside the funnel cloud. The winds converge strongly towards the core, resulting in very strong upward motion. The circulation around the tornado is almost always cyclonic in sense. The whole system moves at a speed varying between 100 to 150 km per hour Tornadoes cause tremendous destruction along its path.

The life of tornado varies widely between few minutes and to an hour.

Tornadoes may occur anywhere, except in Polar Regions. However, it has been seen that North America to the east of Rocky Mountains and Australia are prone to severe tornadoes and this suggests that orographic influences are very important for its development.

In India they are not frequent. The most preferred regions of their occurrence in India re Assam and adjoining states, west Bengal, Orissa, Gangetic Plains, Punjab and Haryana, Recent studies revealed that 72 percent of reported tornadoes have occurred in NE India, which al also the regions of maximum thunderstorm activities. Generally strong vertical wind shear in mid tropospheric levels with high humidity in the lower levels favours the formation of tornadoes.

Our knowledge of tornado is very limited and is essentially derived from the destruction they have left behind. However, the post event analysis is useful for a broad understanding of the probable mechanism at work.

Its short life span and extremely small dimension make the tornado detection most difficult with the normal network of observatories. Even after locating a developing tornado it would be extremely difficult to warn the public before they strike.

CHAPTER 3

SW OR SUMMER MONSOON SEASON

Historical background

The word 'Monsoon' has been derived from the Arabic word 'Mausim' which means a season. The word was used by seamen for many centuries to describe a system of alternating winds over the Arabian Sea. The winds, which blow from the north east for six months of the year (Nov April) reverse direction and blow from southwest for the remaining six months.

Reference of monsoon winds in the Red sea could be found in the Navigators guide book written by an unknown Greek sailor around 60 A.D Beautiful description of monsoons appears in Sanskrit classic the Meghdoot which means the messenger of clouds written around 6th century AD by Kalidas.

Ramage (1971) has defined the monsoon areas satisfying the following criteria of wind reversal which is found between Lat 35 N and 25 S and Long 30˚W and 170˚ E

(i) The prevailing wind direction shifts by at least 120 between January and July.
(ii) Average frequency of prevailing wind direction in January and July exceeds 40 percent.
(iii) The mean resultant winds in atleast one of the months exceed 3 mps
(iv) Fewer than one cyclone – anticyclones alternation occurs every two years in either moth in a 5 Lat Long rectangle. It means the sub regions. Where surface cyclones anticyclones alternate infrequently in summer and winter are monsoonal.

3.2 Planetary aspects of monsoon

Planetary monsoons are maintained by Walker and Hadley circulations. These circulations are maintained (i) diabatic heat sources i.e. differential heating of land and ocean and (ii) the deflection of wind due to rotation of the earth. For the Asiatic summer monsoon two parts of heat source and sink are the large scale thermal causes of formation of monsoon circulation one the heat source around north India and Bay of Bengal and heat sink over Malagasy and the second one the heat source over south China sea and the heat sink over Australia. Further the south Indian ocean trade winds after crossing equator turn into monsoonal westerlies in the north Indian ocean and the south china Sea El-Nino southern Oscillation (ENSO) is a phenomenon that affect planetary scale monsoon,.

3.3 Regional aspects of monsoons

The regional aspects of monsoons occur in smaller scale. They are

(i) Summer monsoon or SW monsoon in India and Southeast Asia
(ii) The Australian NW monsoon
(iii) The West African monsoon.
(iv) The winter monsoon over Malaysia and Indonesia

3.4 Climatic pattern over India and neighbourhood during monsoon

3.4.1 Mean sea level pressure distribution

July may be taken as the representative month of the monsoon season. The pressure gradient and wind flow show a complete reversal from the winter In July, which is the summer month for the Northern Hemisphere the Siberian high of the winter season is replaced by a low pressure region covering entire southern parts of Asia and northern parts of Africa with an intense low pressure region (994 hPa) over Pakistan and adjoining Rajasthan, which is known as the 'Seasonal Low' or 'Heat Low' A trough extends from this low over Pakistan to Head Bay with strong pressure gradient to the south. This trough is often referred to as the 'monsoon trough'. The axis of this trough runs in its mean position from Ganganagar to Sagar Islands through Allahabad and Asansol. Weak ridges are present in the Arabian Sea off west coast of India and along coastal Myanmar (Burma)

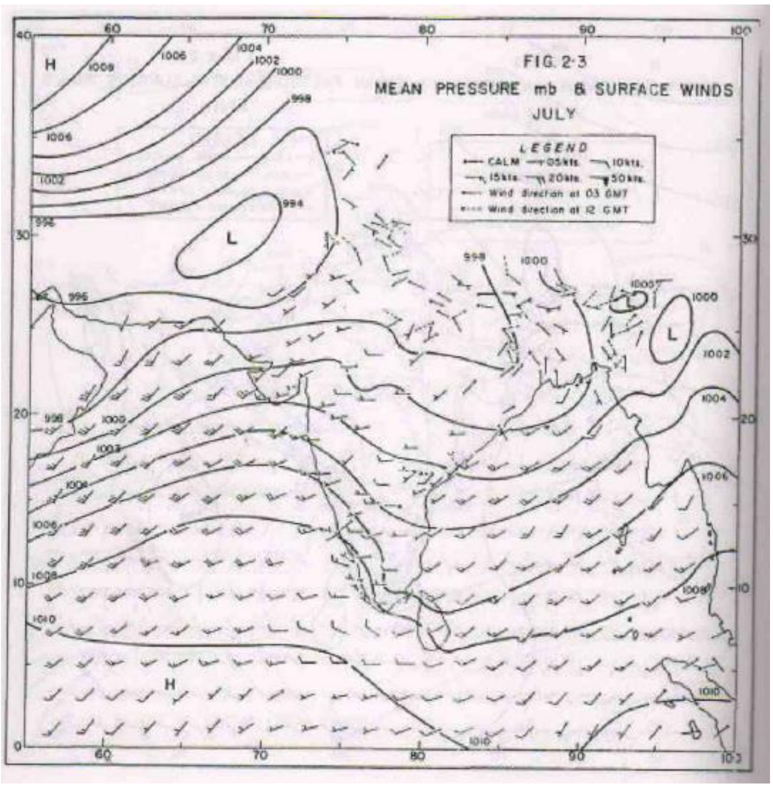


FIG. 2·3
MEAN PRESSURE mb & SURFACE WINDS
JULY

3.4.2 Surface winds (July)

Winds on the surface are westerly/southwesterly to the south of the monsoon trough and southeasterly /easterly to its north; winds are generally stronger over the sea areas than over the Land areas.

3.4.3 Upper winds (July)

The monsoon trough extends upto 500 hPa tilting southwards with height. It runs from Delhi to Calcutta at 900 hPa, along 23º N at 700 hPa and around 19º N extending from EC Arabian Sea to NW and adjoining west central Bay at 500 hPa. However, it is somewhat diffused at 500 hPa level.

Winds are westerly / southwesterly to the south and southeasterly / Easterly to the north o this trough region.

Westerly winds over Peninsula increase with height and reach a maximum speed of 20 – 25 kts between 900 and 800 hPa levels.

The warm surface low over Pakistan and neighbourhood is replaced by the subtropical high at 700 hPa. At 500 hPa this ridge runs roughly along Lat. 28º – 30º N and 300 and 200 hPa levels roughly along Lat 30 N over India and Pakistan. Winds are easterlies to the south of the ridge line and westerlies to its north. Easterly winds strengthen with height from 200 hPa reaching a maximum at 100 Hpa level. Speeds are between 60 and 80 kts. Over the Peninsula at 150 / 100 hPa levels and even at a lower height (around 200 hPa) in the southern latitude.

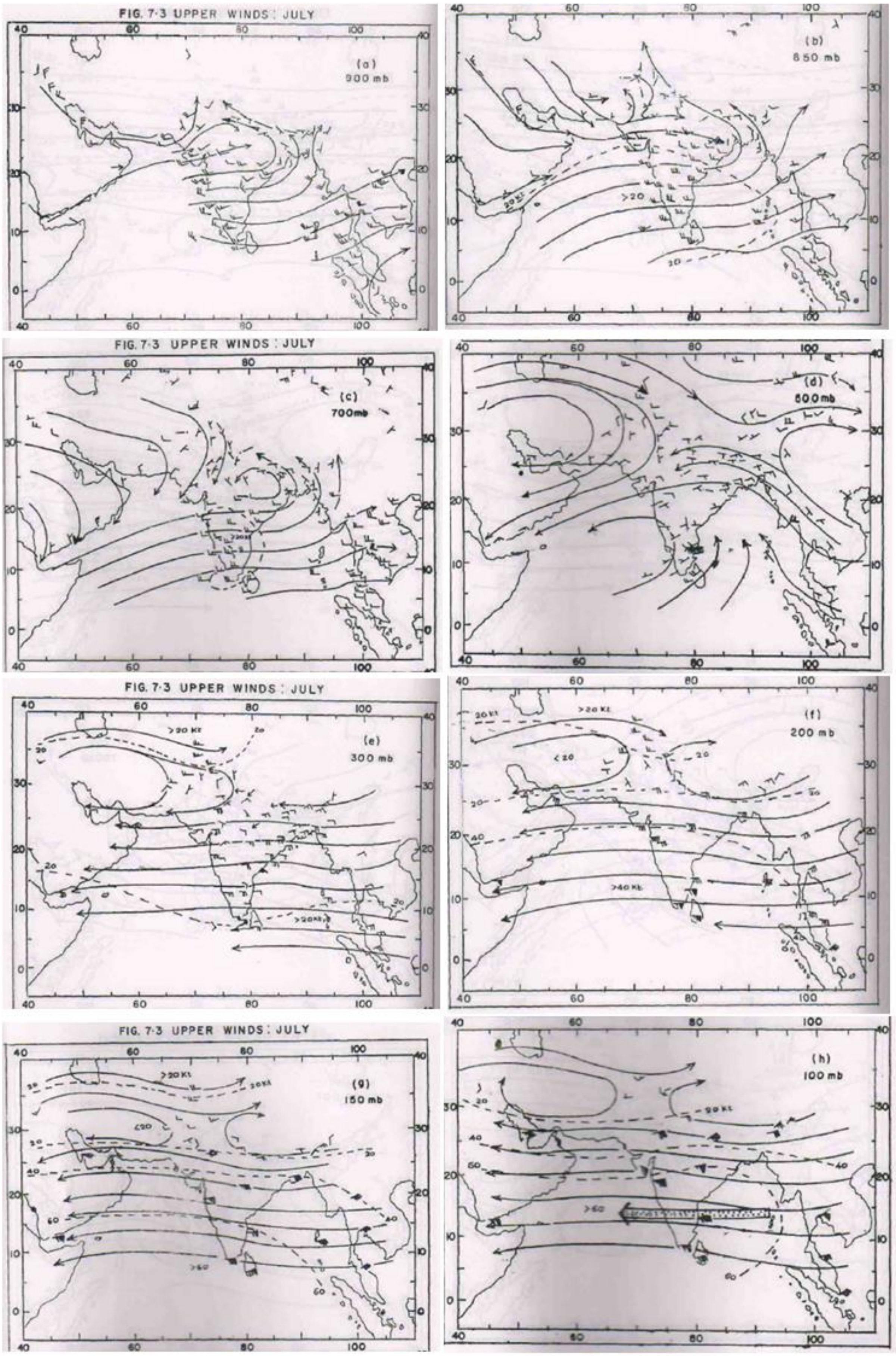


FIG. 7·3 UPPER WINDS: JULY

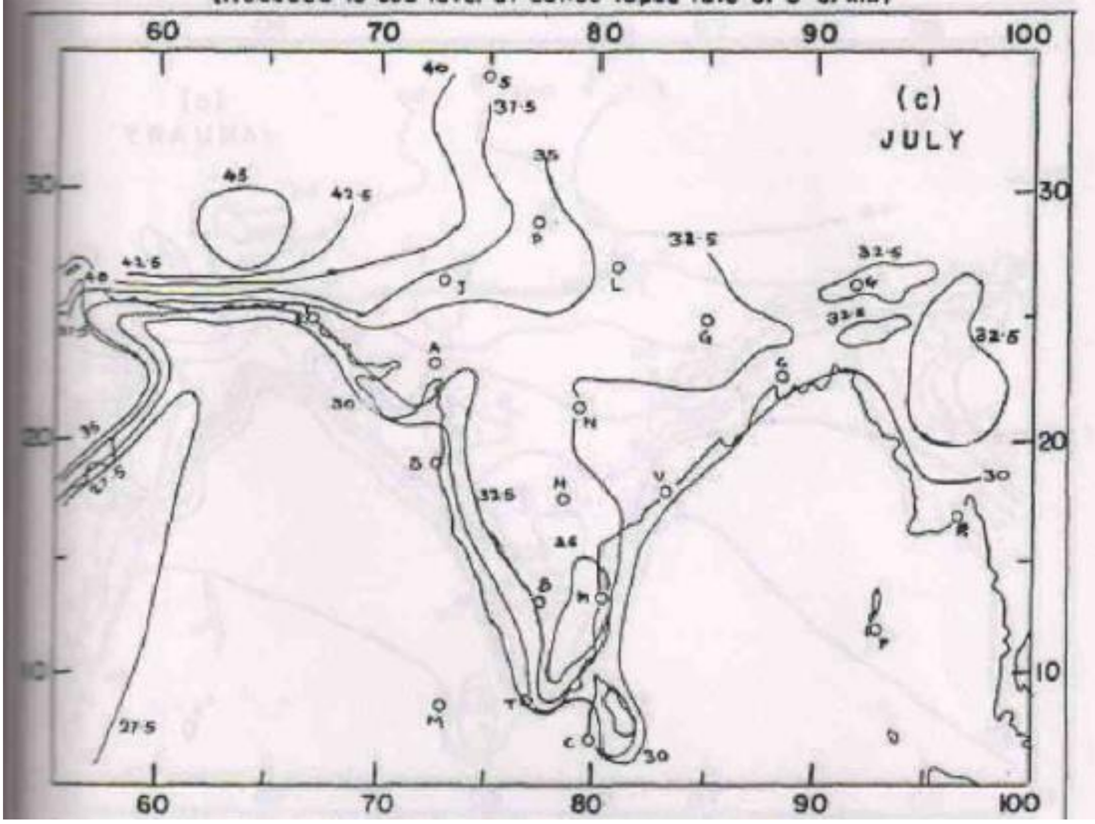
3.4.4 Temperature (July)

3.4.4.1Mean daily maximum temperature

Highest temperature occurs over west Rajasthan, where continental air mass prevails often and cloudiness is least. Temperature decreases both eastwards and southwards. However, high day temperatures prevail over Tamil Nadu and neighbourhood during this month. The warmest zone in the peninsula is between Lats 10º N and 15º N to the east of long 75º E and the east coast where clouds amount is less low.

FIG.4.2 MEAN MAXIMUM TEMPERATURE IN °C

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



3.4.4.2 Diurnal range of temperature

The diurnal range of temperature is maximum (about 10º C) over west Rajasthan, Western parts of Punjab and of Kashmir, where monsoon cloudiness and rainfall are last. The range is minimum (4º C to 6º C) over the coastal region of Gujarat, Maharashtra, Karnataka and Kerala and northeast India and east Madhya Pradesh, where number of cloudy days and rainfall amounts are comparatively high during the season. The diurnal range is between 6º C and 10º C over the rest of the country. The diurnal range of temperatures is generally small in monsoonal regions.

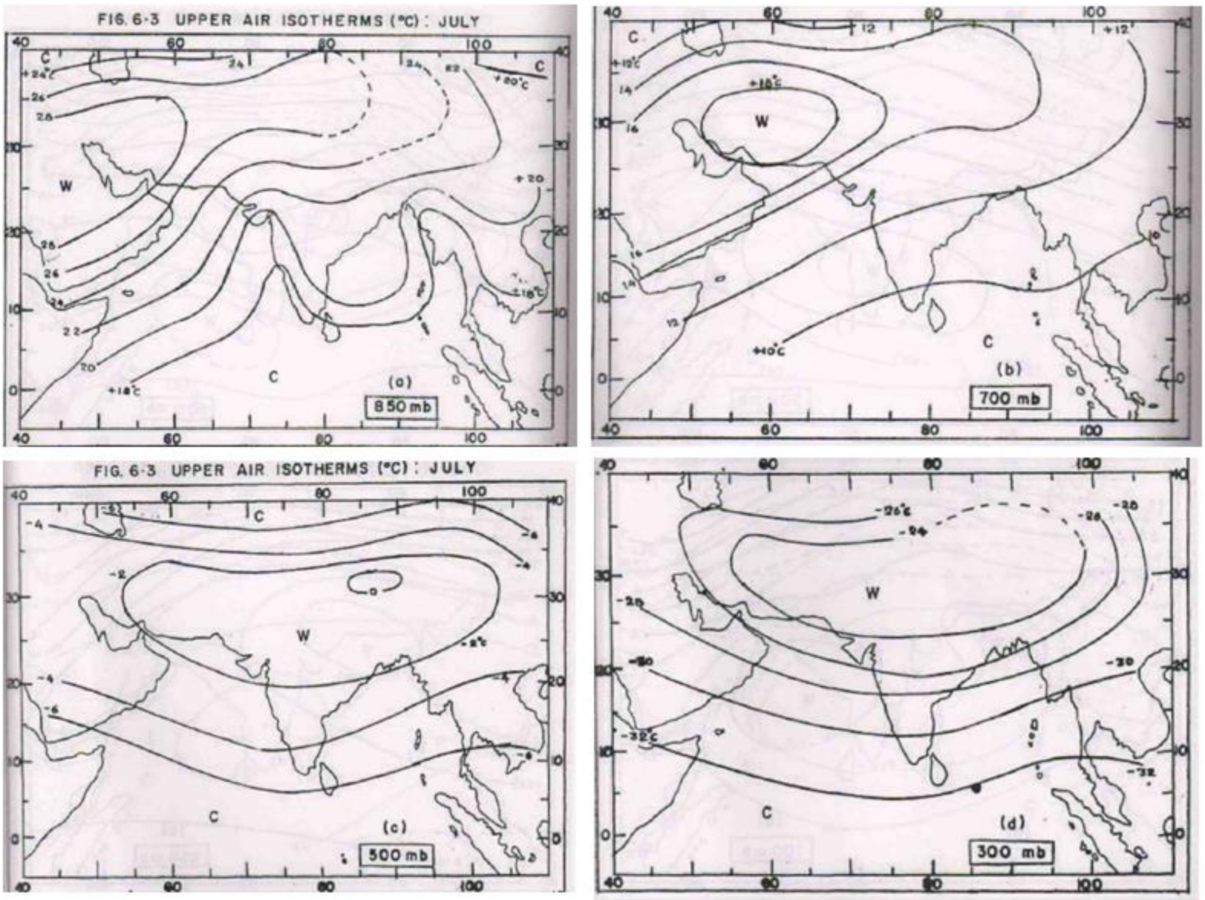
3.4.4.3 Upper Air temperature

In both the hemispheres, the mean temperature distribution is characterized by horizontal decrease pole ward at all levels of the troposphere except above 200 hPa in the tropics.

In July the thermal high shifts at northern latitude in Northern Hemisphere. The thermal high lies over Iran, Iraq and neighbourhood at 850 hPa level. A thermal ridge runs approximately along Lat. 35° N in the north India region and over West Bengal and neighbourhood in the east. A thermal trough runs along the west coast of India and another along the coastal Myanmar (Burma) at this level.

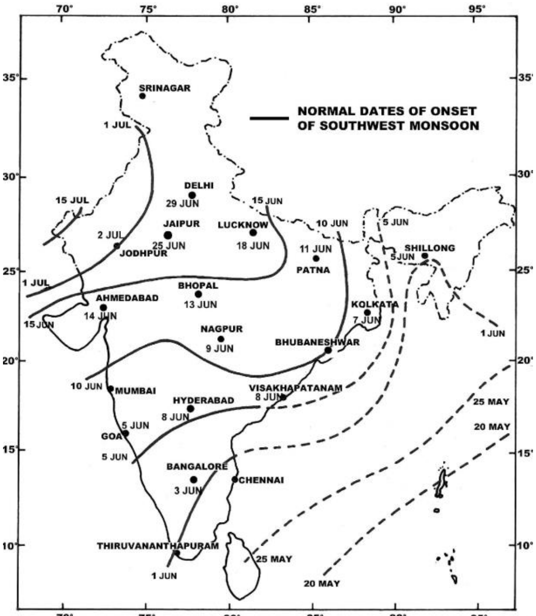
The thermal ridge runs along Lat 25° N and 30° N at 500 hPa level. However, it shifts northwards at 200 hPa level and runs along Lat. 35° N to 40° N

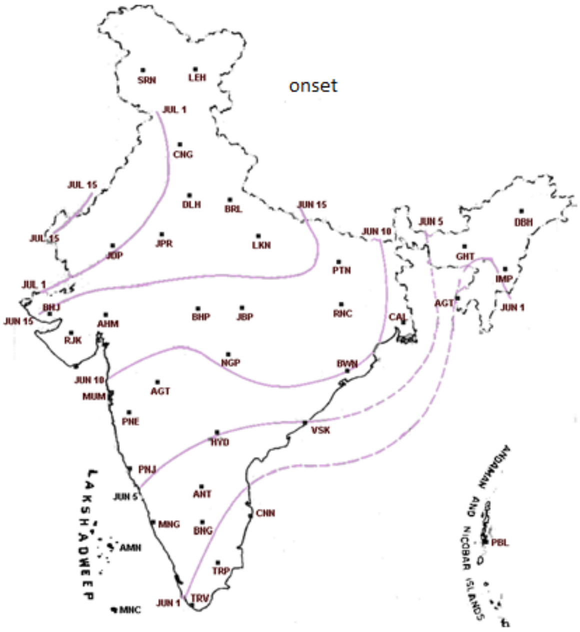
However, at 150 hPa and 100 hPa. The temperature increases from equator to pole.

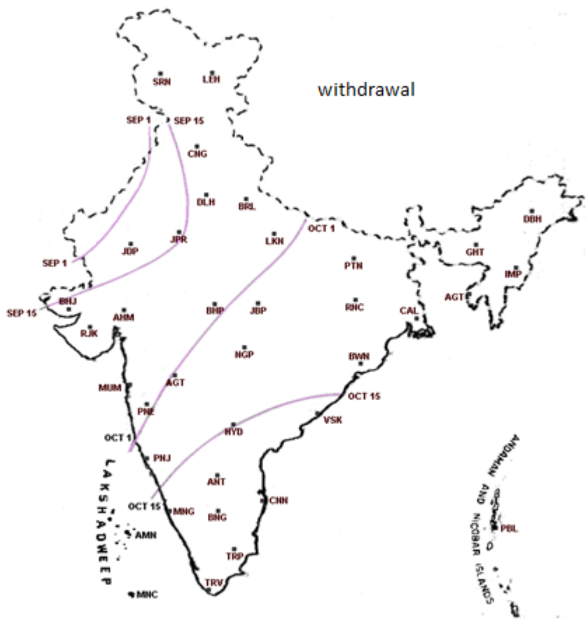


3.5 Onset and Advance and withdrawal of monsoon.

The onset of monsoon over the Indian stations is defined on the basis of commencement of rains. For a station, the middle date of Pentad normal rainfall which shows a sharp increase is taken as the onset date of monsoon. However, sometimes it is not easy to distinguish monsoon rains from the pre-monsoon thunder showers. The withdrawal dates are also similarly determined, when the pentad shows characteristic decrease of rainfall towards the end of monsoon.





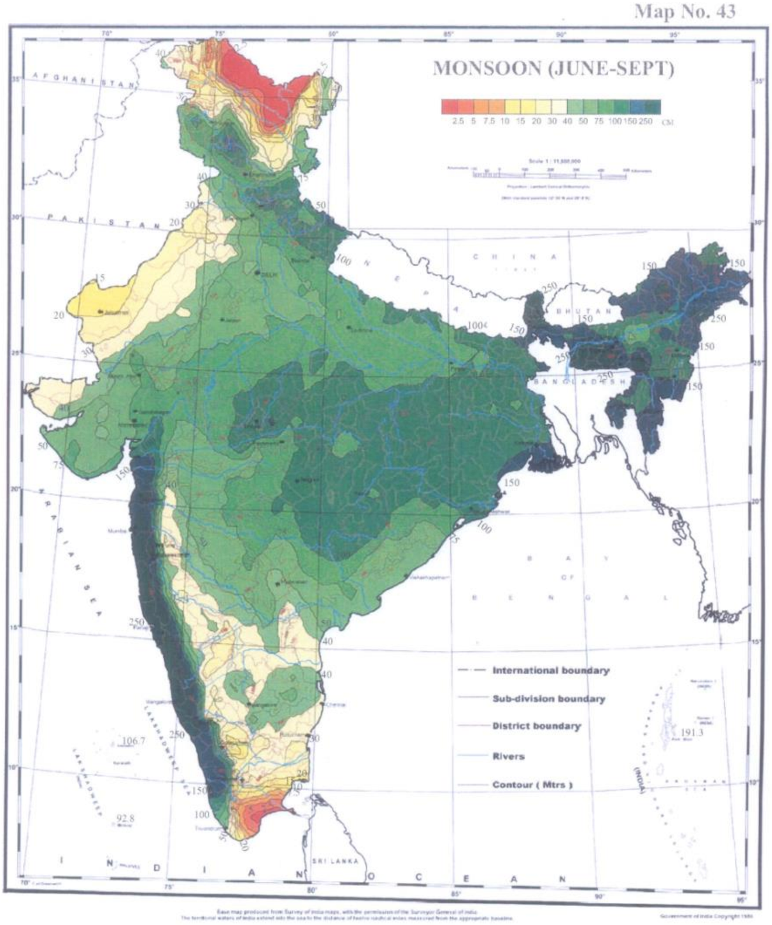


In the interior of the peninsula onset of monsoon may not happen with striking increase of rain.

There is a pronounced tendency for the formation of low pressure systems at the leading edge of the monsoon current. In 45 percent of years, a trough of low pressure or more intense system like WM lopar / depression is present in the Arabian Sea at the time of onset of monsoon along the west coast. Such vortex is often referred to as the onset vortex. The monsoon also may advance along the west coast in association with a disturbance in the Bay of Bengal.

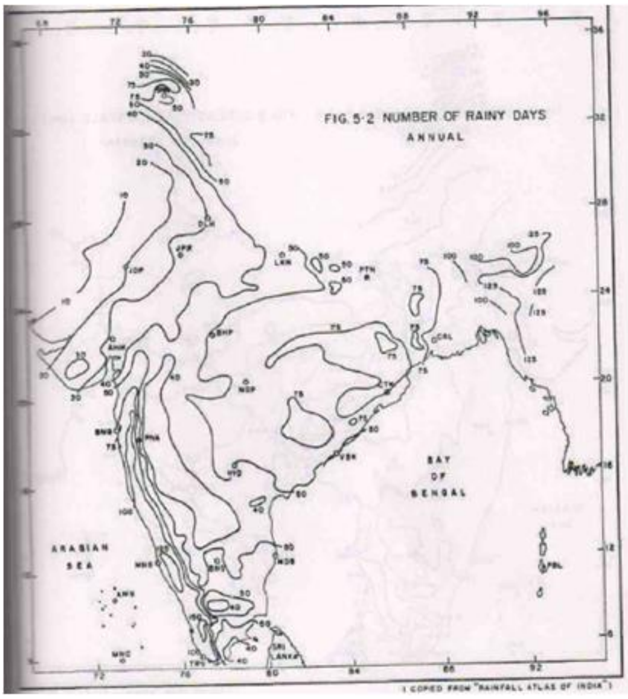
RAINFALL (cm)

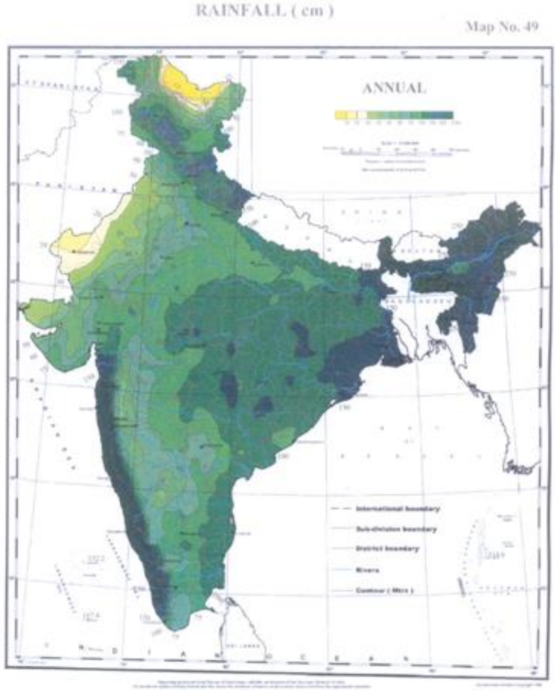
Map No. 43



Immediately prior to onset of monsoon over Kerala the following features may be observed:

i) Trough of low pressure in SE Arabian Sea.
j) Persistent heavy convection in the South Arabian Sea (Satellite picture)
k) Strengthening and deepening of the lower tropospheric westerly winds over extreme south peninsula and Sri Lanka and strengthening of upper tropospheric easterly winds to 40 – 60 kts.
l) Reports (ship) of squally weather and rough seas and moderate to strong westerly winds over south Arabian Sea.
m) Migration of sub tropical westerly jet to north of India





No definite criteria exist at present for declaring the onset of the monsoon However, the rainfall at the coastal stations of Kerala and the Arabian Sea islands is most important factor for declaring the onset.

<u>A working rule for declaration of the onset of monsoon</u>

A] <u>Onset of monsoon over Kerala</u>

1. Rainfall Criteria

i) To declare onset of monsoon over Kerala, rainfall amount over the 14 selected stations: Minicoy, Amini, Thiruvananthpuram, Panalur, Kollam, Alapuxha, Kottayam, Kochi, Trissur, Kozikode, Talassery, Cannur, Kasargode and Manglor is to be considered.

ii) If after ***10th May, 60% of the above 14 stations report rainfall of ≥ 2.5 mm for two consecutive days***, the onset of monsoon over Kerala be declared on 2nd day provided the **WIND FIELD** and **OLR criteria** are also in concurrence.

2. Wind Field Criteria

i) For winds, the RSMC wind analysis / satellite derived wind data is to be used.

ii) Westerlies up to 600 hPa level in the region bounded by latitudes Equator to 10^{0}N and longitudes 55^{0}E to 80^{0}E.

iii) Zonal wind speed of the order of 15 to 20 Kts at 925 hPa level over the region bounded by latitudes 5^{0}N to 10^{0}N and longitudes 70^{0}E to 80^{0}E.

3. OLR Criteria

- The INSAT derived Outgoing Long wave Radiation (**OLR**) value in the region bounded by latitude 5 ^{0}N to 10^{0}N and longitudes 70^{0}E to 78^{0}E should be **less than 200 W / m^{2}.**

If after May 10 any five out of these seven stations get rainfall (1 mm or more) for two consecutive days, the onset of monsoon over Kerala may be announced on the second day.

B] Further Advance of Monsoon over the country

i) Further advance is to be declared on the occurrence of rainfall over parts / sectors of the sub-divisions and maintaining the spatial continuity of the northern limit of monsoon.
ii) The following auxiliary features are also to be considered:
    a. Position of maximum cloud zone along the west coast, as inferred from the cloud imageries.
    b. The satellite water vapour imageries, to assess the extent of moisture incursion.

A study of Ananthakrishnan and Thiruvengadathan (1966) revealed that reversal of thermal gradient between 700 and 500 hPa takes place at the time of onset of the monsoon.

The normal dates of advance of monsoon over the country are determined by drawing smooth iso-lines of the pentad normal rainfall as described in para 1 monsoon advances over the country in two branches. The Arabian Sea branch which normally sets in monsoon rainfall over Kerala on June 1 advances rapidly northward along the west coast and reaches Gujarat by June 15. This branch brings monsoon rainfall over the entire Peninsula and central India. Simultaneously the Bay branch for monsoon advances northward and enters Bangladesh, Assam and adjacent states by June 5. The topography and orientation of the hills of Assam and Meghalaya obstruct the current in the north and east resulting the deflection of the current towards west under the influence of the Himalayas. The bay branch thus enters over the Gangetic plains of north India as a Souutheasterly/Easterly current. Both the branches meet over north India around longitude 80º E.

The normal date of advance of monsoon is May 20 over Andaman and Nicobar islands. It sets in ovr Kerala on June. 1. By June 10 the northern limit of monsoon (NLM) passes through Dahanu, Akola, Jagdalpur, Cuttack and Sabour. By June 15 it further advances into interior of the country and the NLM passes on that day through Naliya, Guna, Varanasi and Torakhpur. Further westward advance is rather slow. It takes abhout another 15 days to cover west UP and NW India excluding West Rajasthan, Monsoonh advances over West Rajasthan. Monsoon advances over West Rajasthan by July 15. It takes about one and half months from the onset of monsoon over Kerala to cover the entire country.

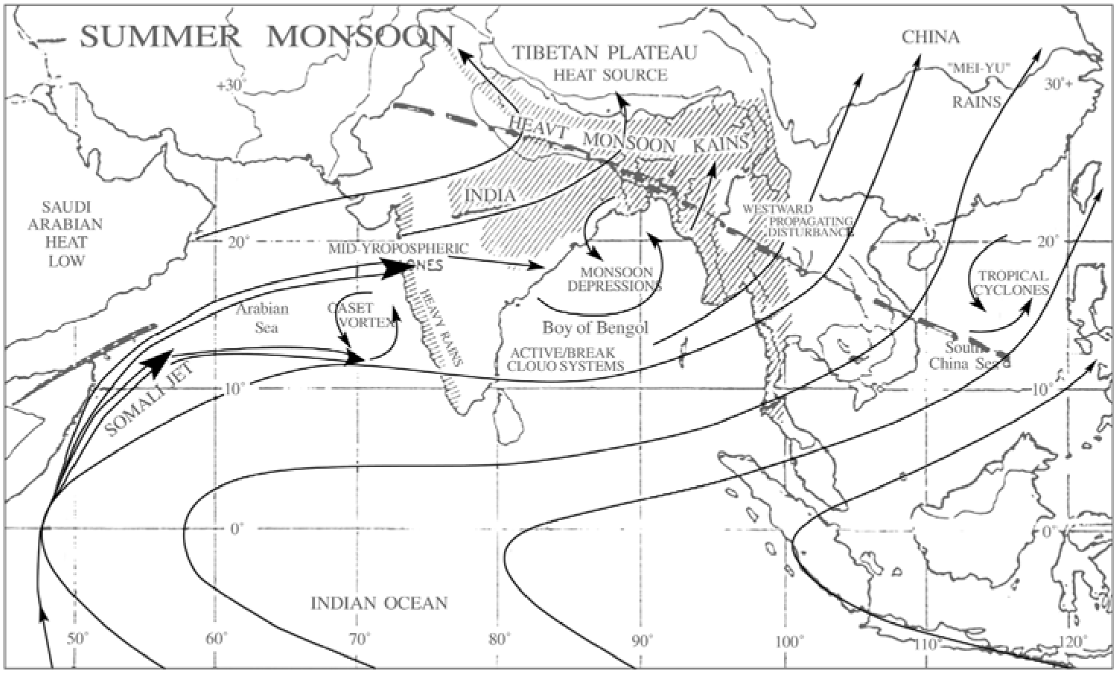
The withdrawal of monsoon commences from western parts of west Rajasthan by Sept 1. It withdraws from NW India by Sept 15 and the withdrawal is complete from the country outside Tamil Nadu and Kerala by Oct 15 when NE monsoon normally sets in over Tamil Nadu; SI and Kerala experience rainfall during postj monsoon season from the NE monsoon.

The duration of the SW monsoon over the country varies from two to two and half months over NW India to about four to four and half months over NE and adjoining peninsular India.

3.6 **The components of Indian Summer Monsoon**

The winter circulations of the N.H. undergo vast change during the summer period. The intense Siberian high of winter is replaced by an extended low pressure area covering SE Asia, North India, West Asia and the Sahara with an intense heat low over Pakistan and neighbourhood and the Aleutian Low and Icelandic Low are replaced by high pressure areas. The components of the Indian summer monsoon are:

i) Heat low (ii) Monsoon Trough (iii) Tjropical Easterly Jet Stream
(iv) Tibetan High (v) Low level jet, (vi) Mascarene High.



3.6.1 Heat Low

It develops, progressively over the Indian Sub continent and is located over central parts of Pakistan in July. It is the most important causative factor of the monsoon because surface air converges towards the minimum pressure and rises. This low is a part of the low pressure belt that extends from Sahara to central Asia across Arabia. The lowest pressure for the whole belt is over Pakistan and neighbourhood, which is not the place of the highest temperature. This heat low, extends only upto 1.5 km and is overlain by a well marked ridge above. The intensity of the heat low is correlated with the monsoon activity. However, under the influence of the subsidence aloft over this low, the weather remains fine in the area

3.6.2 Monsoon trough

From the seasonal low over Pakistan, a trough extends to Gangetic West Bengal,. The trough line on S.L.C runs from Ganganagar to Calcutta through Allahabad. In the upper air it extends upto 6 km (500 hPa) sloping southwards with height. The slope depends on both the horizontal temperature gradient and horizontal wind shear in the trough zone. The slope is small in the western part of India. The air temperature to the north of the trough is about 2° C higher than to its south

The position of the trough line varies from day to day, which has a vital bearing on the monsoon rains. When the trough line comes close to the foot hills of Himalayas the condition is referred to as 'Break in Monsoon' on account of drastic decrease of rains over the country. The northern shift of axis leads to concentration of rainfall over the north eastern parts of India and the foot hills of Himalayas.

3.6.3 Tropical Easterly Jet

South of the sub tropical ridge over Asia the easterly flow concentrates into a jet steam centred near about the latitude of Madras at 100 hPa in July. The jet stream runs from Vietnam to west coast of Africa. The location of the jet over Africa is around 10° N Position and speed of the Jet Stream fluctuates from day to day. The JET is a result of the influence of continents and oceans on the heat budget of the sub tropical region.

Easterly Jet is not found over Most of Atlantic Ocean, Continental America and the Pacific Ocean. Easterlies are much weaker in southern Hemisphere during southern summer.

The easterly jet stream over the Peninsular India is the effect of variation of temperature (Thermal Gradient) from North to South during the summer. This thermal gradient is effective in reversing the moderately strong westerlies in the lower troposphere into strong easterly current at higher elevations which reaches to its maximum strength at 150/100 hPa levels. At Madras, the mean wind is 085 /70 kts at 16 km (100 hPa) However, at Trivandrum the level of maximum wind speed is near 14.0 km above m.s.l. (150 hPa) and the mean wind is 080 / 65 kt which is higher than at Madras at that level. Aloft, the wind speed is less than that at Madras. At Bombay the mean wind speeds are 55 kts. At 14 km 70 kts at 16 km (150 hPa) at Colombo and Trivandrum but at 16 km (100 hPa) at Madras, Vishakhapatnam and Nagpur.

The horizontal shear at 100 hPa to the south of the Jet stream between Madras and Trivandrum is about 9 km/hr/100 km and to the north between Madras and Vishakhapatnam is about 8 km/hr/100 km. The vertical shear varies between 15 – 20 km hr per km. The maximum shear is in the layer 5 km below the core. Above the core, between 16 and 18 kms, the shear is about 22 km hr / km

3.6.4 Tibetan High

In the month of July an anticyclone appears at 500 hPa and aloft over the Tibetan Plateau. At 500 hPa it lies to the east of Long 80º E with its axis near about 28º N This high is more marked at 300 hPa and its extent is between70 E and 110 E. At the time of onset of monsoon over Kerala the Tibetan High is generally not established. The anticyclonic shear north of the Tibetan High is larger than the shear to its southern side. It is believed that the heating of the elevated Tibetan plateau in summer is responsible for the development of the anticyclonic cell over Tibet. The warming up of the plateau commences from March/April. The heating of Tibetan plateau due to its elevation accentuates the N – S temperature gradient causing upper tropospheric Easterlies to strengthen.

Low level jet stream (LLJ)

Banker (1965) reported the existence of 50 kts strong wind at 1.0 km near Socotra island in SW Arabian Sea. A low level jet stream with core speed 40-60 kts exists in the monsoon circulation field over SE Arabian Sea and adjoining Peninsular India (Joseph and Raman 1966) that this a part of inter hemispheric low level jet stream with core near 850 hPa was established by Findlater (1969) the jet appears to flow from Mauritius across Kenya. Ethiopia Somalia before reaching the coast again around 9 N It has been calculated that his current crossing the equator over the Western Indian ocean accounts for about half of the total cross equatorial transport of air in the lower troposphere in July (Findlater 1969) the location of the low level jet coincides with a zone of coastal upwelling such as off Somalia coast.

The persistence of LLJ over Peninsular India is of a few days at any latitude. Gradual south to north movement of the jet core is notices. The strengthening of the lower tropospheric westerlies in the Arabian Sea is associated with the increase of monsoon rains along the west coast of India (South of 20 with the increase of monsoon rains along the west coast of India (South of 20 N)

3.6.6 Mascarene High (30 S/50 E)

It is the high pressure cell on SLC over the Indian Ocean. It's name has been derived from the Mascarene island east of Malagasy Republic. The centre of this anticyclone is located near 30 S/50 E during July. Position and intensity of this high are found to be important in relation to the cross equatorial flow and the monsoon activity over India

3.7 Other Synoptic systems

The other synoptic systems in the Indian Monsoonal area are (i) Low pressure Area (ii) Monsoon Depression and C.S (iii) Mid tropospheric cyclone (MTC) (iv) Trough off the west coast (v) Trough in Monsoon Westerlies

3.7.1 Low pressure Area

Low pressure areas form quite frequently during the monsoon and are responsible for causing substantial rainfall. Normally the lows form either over north and adjoining central Bay or over land and move west to northwesterly direction. The average life span of these low pressure systems varies from 4 to 6 days.

The land lows are generally smaller in areal extent than the lows arriving from the Bay. The systems show slower movement. On occasion these low pressure systems concentrate into depression

3.7.2 Monsoon Depressions (MDs) and C.S

Monsoon depressions are intense low pressure systems with 2 to 3 closed isobars (2 hPa interval) covering an area of about 5 degrees square or more and the prevailing surface wind is in the range of 18 to 33 kts. When the maximum sustained surface winds exceed 33 kts/ hr, they are termed as Cyclonic storms.

3.7.2.1 Area of formation

Normally monsoon depressions form over North Bay, north of 18º N and west of 92º E. However, a few may form even up to Lat. 15º N. In September, the area of formation extends up to Lat. 14º N

In the Arabian Sea they develop over eastern parts of Arabian Sea to the north of 12 N in June and in rare cases close to Gujarat coast in later months. Some of these depressions develop over the land areas of GWB, Bihar, northeast Madhya Pradesh and east Uttar Pradesh which are termed as land depressions. About 25 % of the depressions that develop over the sea intensify into cyclonic storms over the sea areas.

Most of the monsoon depressions do not develop into Tropical cyclones for the following reasons.

i) As the monsoon trough is confined to the head Bay of Bengal, the sea cannot effectively supply the massive amount of sensible heat essential of a tropical cyclone and

ii) The presence of strong vertical shear (approx. 15 mps between 8850 and 200 hPa) inhibits the formation of wall cloud of a tropical cyclone.

A monsoon depression may develop when the seasonal trough dips into North Bay and westerly winds in the lower tropospheric levels over Peninsula strengthen. It also develops, when simultaneously a surface isallobaric low pressure wave moves from Myanmar (Burma) to the North Bay beneath a layer of westward moving trough in easterlies or a et maximum in the upper tropospheric easterlies. Formation of some depressions/storms in the Bay traced to the remnants of Pacific cyclones, which have moved across Indo China and emerged into the Bay of Bengal and reintensified.

3.7.2.2 Frequency and Life Span.

Average number of monsoon depression is 2 per month during the season and monthwise the number is June and July 1 to 2 and August and September 2 to 3 per month.

On an average, 2 cyclonic storms form during the season. Number of these storms is maximum June and least in August.

The number of the monsoon depressions and cyclonic storms in a year ranges from 1 to 14.

Average life span of the monsoon depression is 2 to 5 days but there are some cases when they lived beyond 6 to 7 days.

3.7.2.3 Movement

They have a very narrow belt of tracks during July and August. Depressions and storms in July move mainly west to west northwest over Bay and north India up to 25 N and more northwards at higher latitudes. In June the movement is more spread out (northwest to northeast). Movement in September is more or less like June.

70 percent of the depressions cross coast between 20º N and 22º N and half of them fill up by the time they reach 80º Deg. E 10 to 20 percent cross long 75º E and a few emerge into NE Arabian Sea and re-intensify. Some of these depressions move across Madhya Pradesh, Rajasthan and merge with the seasonal low over south Pakistan.

Occasionally, under the influence of westerly troughs the depressions recurve north-eastwards. Average speed of a depression is 5 to 10 km per hour to the east of Long 85º E and 10 to 20 Km per hour to its west.

3.7.2.4 Structure of MDS

The diameter of a monsoon depression extends upto 1000 km in the horizontal (in the lower troposphere) and 7.0 to 9.0 Km in the vertical

Maximum tangential winds (cyclonic) are at a height of 0.9 to 1.5 km at a radial distance of 300 to 400 km from the surface centre. There is considerable asymmetry in the wind field around the centre of a monsoon depression with highest wind speeds occurring in the southern sector and lowest speeds in the NW sector. The depression axis has a small southern tilt in the vertical from surface to 500 hPa but the tilt is more marked between 500 and 300 hPa levels. MD has a cold core in the lower troposphere upto about 600 hPa levels and a warm core above.

3.7.2.5 Associated Clouds and Rainfall

In the southern sector of a MD extensive cloud mass (thick AS, NS, CB and stratus clouds) extends 5 to 7 while in the northern sector generally broken cumuliform clouds are observed However, the cloud belt shifts to the northern sector fin the northward moving depression.

Heavy rainfall is mostly confined to the SW sector of a westward moving MD within a radius of about 400 km. The rainfall in the northern sector is generally light to moderate in the form of shower while in the southern se4ctor the skies remain overcast with thick clouds without any sunshine and there it rains almost continuously

3.7.3 Mid Tropospheric Circulation (MTC)

It is a synoptic system found over south Asia during the summer monsoon months. These vortices are observed between 3 and 6 km. and their largest amplitude is observed near 600 hPa level. They develop over NEn Arabian sea and adjoining land areas and occasionally over Indo China. These systems exhibit little movement and appear to remain quasi stationary for several days.

As these systems are located between westerly winds in the lower troposphere and easterly winds in the upper tropospheric levels. It is believed that large scale vertical shears are responsible for their formations.;

Contion is found to be most intense, away from the centre in the western and southern quadrants of a MTC. In association with it rainfall of 5 –110 cm per day occurs with isolated falls often reaching to 30 cm per day.

MTCs are not as frequent or regular a phenomenon as monsoon depressions. MTCs are more common in the first half of the monsoon season. The usual life span of a MTC is 3 – 7 days.

3.7.4 Trough off West coast and off – shore vortices

During the monsoon months a weak trough develops off west coast of India anywhere from Kerala to south Gujarat and is responsible for the strengthening of the monsoon rainfall along the west coast. They may appear and disappear in situ. Pressure gradient increases to the south of the trough particularly when it shifts to the north. Upper winds are affected mainly up to 1.0 km.

Nearly half the number of active to vigorous monsoon conditions in Konkan and three quarters in coastal Karnataka are in association with tr5oughs off the west coast.

Jayaram (1965) has illustrated that heavy rainfall associated with a trough off the Maharashtra coast is to the south of the apex jof the trough.

On the many occasions, when the monsoon westerlies strike the Ghats along the west coast they do not have enough energy to climb over it. Consequently they tend to deflect and a return current forms an 'off – shore vortex' in this trough. This vortex is effective in bringing about a spell of very heavy rain in their vicinity.

3.7.5 Trough in Monsoon Westerlies

During the weak monsoon conditions, weak troughs are noticed to develop in the lower tropospheric levels over the plains mainly to the east of 80º E. They cause increased rains for about 2º longitude on either side of its axis and further to the east,. These troughs also appear to move westwards if they come under the influence of westward moving troughs in mid tropospheric easterlies.

3.8 Effect of Middle Latitude Westerly Systems on Monsoons

During the monsoon season the mid latitude westerlies (middle and upper troposphere) shift to the north of Latitude 35 N. However, when these westerlies penetrate to Indian latitudes they exercise considerable influence on the monsoon weather over northern India.

i) Passage of western disturbance across extreme north of the country often enhances monsoon activity over Punjab and west Uttar Pradesh. However, their passage across eastern Himalayas shifts the monsoon trough to the foot hills of Himalayas causing break monsoon situation.

ii) Under the influence of a deep trough in westerlies the Tibetan High may weaken or even become an area of a trough of low pressure.

iii) The deep trough in middle tropospheric levels when extends to Bihar or further south rainfall in NE India increases.

iv) Such trough causes recurvature of depressions and lows.

3.9 Rainfall

SW monsoon is the principal rainy season in India except in Jammu and Kashmir and Tamil Nadu.

Precipitation during the monsoon could be in the form of thundershowers, showers or rain. However, the most striking feature of monsoon rain is the almost complete absence of thundershowers along the west coast to the south of 20 N

Orography around India influence monsoon circulation and thus the spatial distribution of rainfall in the season. Hills and mountains get more rainfall than the neighbouring plains. Mawsynram (1401 m) in Meghalaya experience the season's highest rainfall 918 ml) followed by Cherrapunji, also in Meghalaya (835 cm) Regionwise the rainfall during the season is maximum over western ghats and adjoining west coast between 13 N and 20 N where it is 250 cm or more. Coastal Karnataka rainfall during the season exceeds 300 cm. High rainfall (around 250 cm) also occurs in the southern parts of Meghalaya and in Mizoram; Rainfall is considerably high (100 – 150 cm) over NE India, Madhya Pradesh, Vidarbha, Hills of West U.P. HP and Telangana. The rainfall gradually decreases from the east to the west It is less than 20 cm over western parts of West Rajasthan. Rainfall drastically decrease dint he lee ward side of the western Ghats and over mountainous region of Kashmir Variation of rainfall with elevation, topography etc in different areas bring out the complexity of the problems.

During the season rainfall varies from day to day from one spell to another and from month to month. Intra seasonal variations of monsoon rainfall is associated with the

i) Position of the monsoon trough
j) Formation of lows, depressions and mid tropospheric cyclones and
k) Movement of large amplitude troughs in the westerlies across north India

There is active and weak monsoon spells during the summer monsoon season. Spells of heavy rainfall along foot hills with very low rainfall over the central parts of the country are known as 'Breaks in the monsoon'. Break may occur any time during the season. On an average, the duration of a break is 4 to 6 days. Though there are several instances of larger break period. Monthly rainfall during the season is highest over the most parts of the country in July. The next highest rainfall occurs in August. However, South Kerala receives highest rainfall during June.

Year to year (inter annual) variation in the monsoon rainfall is equally important. The seasonal rainfall over the country excluding high altitude stations is about 92 cms this amount varies considerably from year to year and is known as inter annual variability. There were several years when monsoon rainfall was low causing droughts as well as years when it was excessive causing severe floods in the country.

During these years when the Southern Oscillation Index (SOI) is negative and there is also the occurrence of EL-Nino, the Indian summer monsoon rainfall is below normal. The snowfalls in the Himalaya ranges during the pre-monsoon months were found to be inversely related to the summer monsoon rains by Bland ford.

3.10 Breaks in Monsoon

When there is striking decrease of rainfall over most part of the country but increase along the foot hill of Himalayas and parts of NE India and southern peninsula, such a synoptic situation is referred to as Break in Monsoon

The synoptic situations normally observed during the break as given below

i) Axis of the monsoon trough shifts to the foot hills of the Himalayas. Consequently lower tropospheric westerlies extend lupto the foot hills.

j) The pressure departures from normal over the central parts of India extending from Gujarat to North Bay become positive (2 to 4 hPa even 8 hPa) and become negative from Punjab eastwards along the foot of Himalayas. There can be negative pressure departures over the extreme south peninsula.

iv) Strengthening of lower tropospheric westerlies to the north fo 20^{o} N

v) Westward moving lows in the lower and middle tropospheric levels develop at southern latitude (around 10 N) in the Bay of Bengal.

vi) Weak troughs appear in the lower tropospheric westerlies over Bay of Bengal and south peninsula

vii) Large amplitude westerly trough in middle and upper tropospheric level moves across north India

viii) Sub tropical ridge in middle and the upper tropospheric levels (500-150 hPa) shifts southwards

The strongest easterlies in the upper troposphere shift northwards (to 19º N) from its normal position of 10º to 13º N

Break condition may occur in association with the combination of a few of the above features. During the breaks there is heavy rainfall along the foot hills, which causes floods in Assam, Bihar and Uttar Pradesh. The breaks may occur any time during the monsoon season. However breaks are most prevalent during July and August. The duration of a break is 4 to 6 days though there are instances of longer period breaks.

Monsoon most often revives after a break in association with the development of low pressure system in the North Bay.

Variability in monsoon onset and withdrawal (Ref. Climate Profile of India)

A study of mean dates of onset of monsoon for the period 1941-2000 (Mazumdar et al 2001) revealed that the mean onset dates over majority of subdivisions have been later than normal in both the 30 years' time slots of 1941-1970 and 1971-2000.The magnitudes of late onset during 1941 – 1970 have been higher than those during 1971 – 2000. Some of these deviations are statistically significant. The maximum deviation being 11 and 7 days over Andaman & Nicobar Islands during 1941 – 1970 and 1971 – 2000 respectively. Since, for India as a whole, the commencement of onset starts from Andaman & Nicobar Islands, the SW monsoon had a late start by about a week during the period of study.

Based on 100 years (1901 – 2000) of data, the onset dates for the twentieth century, when compared to the existing normals, the differences for the period are marginal except for Andaman Nicobar Islands where it has been greater (late onset) by about 5 days.

The lowest Standard Deviation (SD) of date of onset of about 5 days is over Andaman & Nicobar Islands during 1971-2000 and the highest of 14 days is over Jammu and Kashmir. For every subdivision of India, the values of SD are higher during 1941-1970 as compared to 1971-2000. Generally, the SDs of onset dates are about one week over high rainfall area and North Eastern parts, increasing to one and half week towards low rainfall areas of West and North Western parts of India.

Generally, decreasing trends are found over northern parts (North of 25ºN) and increasing trends over southern parts of India. The mean withdrawal dates are found to be later than the existing normal, in both the 30 years slot of 1941 – 1970 and 1971 – 2000, by about one to one and a half week. A general late onset, as concluded earlier coupled with late withdrawal

Suggests a shift in the monsoon activity. The SDs of withdrawal dates range from 11 to 14 days during 1941 – 1970 and from 7 to 10 days during 1971 – 2000. This indicates that the variability in the withdrawal of monsoon has been greater during the first 30 years period as compared to the later half, not only in temporal but also in spatial scales.
The duration of southwest monsoon is found to be higher than normal almost in all meteorological sub-divisions in both the 30 years' period. The duration is much higher in the first half as compared to that during the second half. The SDs of duration of monsoon varies between 13 and 19 days and 7 to 15 days during 1941- 1970 and 1971-2000, respectively.

Decadal and epochal variability indicates near 30 year's periodicity in onset, withdrawal and duration of the monsoon. Trends in the sub divisional rainfall data for the individual monsoon months are depicted as under:

• June rainfall has shown significant increasing trend for the western and southwestern parts of the country, whereas significant decreasing trend is observed for the central and eastern parts of the country.
• July rainfall has significantly decreased for most parts of the central and peninsular India but has increased significantly in the northeastern parts of the country.
• August rainfall has increased significantly for the subdivisions Konkan & Goa, Marathwada, Madhya Maharashtra, Vidarbha, West Madhya Pradesh, Telengana and West Uttar Pradesh.
• September rainfall has shown significantly decreasing trend for subdivisions Vidarbha, Marathwada and Telangana and increasing trend for the subdivision Sub Himalayan Gangetic West Bengal (Guhathakurta and Rajeevan, 2008).

Trend in Withdrawal of monsoon

The mean withdrawal dates are found to be later than the existing normal, in both the 30 years slot of 1941 – 1970 and 1971 – 2000, by about one to one and a half week. A general late onset, as concluded earlier coupled with late withdrawal suggests a shift in the monsoon activity. The SDs of withdrawal dates range from 11 to 14 days during 1941 – 1970 and from 7 to 10 days during 1971 – 2000. This indicates that the variability in the withdrawal of monsoon has been greater during the first 30 years period as compared to the later half, not only in temporal but also in spatial scales.

Duration of SW monsoon

The duration of southwest monsoon is found to be higher than normal almost in all meteorological sub-divisions in both the 30 years' period. The duration is much higher in the first half as compared to that during the second half. The SDs of duration of monsoon varies between 13 and 19 days and 7 to 15 days during 1941-1970 and 1971-2000, respectively.
Major findings of analyses of onset, withdrawal and duration of SW monsoon as during the period 1941-2000 are:

(i) Slight shift of monsoon activity with late onset and late withdrawal.
(ii) Increase in the duration of the monsoon by about a week, as compared to normal duration.
(iii) Decreasing trends in onset dates, roughly north of 25 N and general decreasing trends in both withdrawal and duration of the monsoon;
(iv) Decadal and epochal variability indicate near 30 year's periodicity in onset, withdrawal and duration of the monsoon.

CHAPTER 4

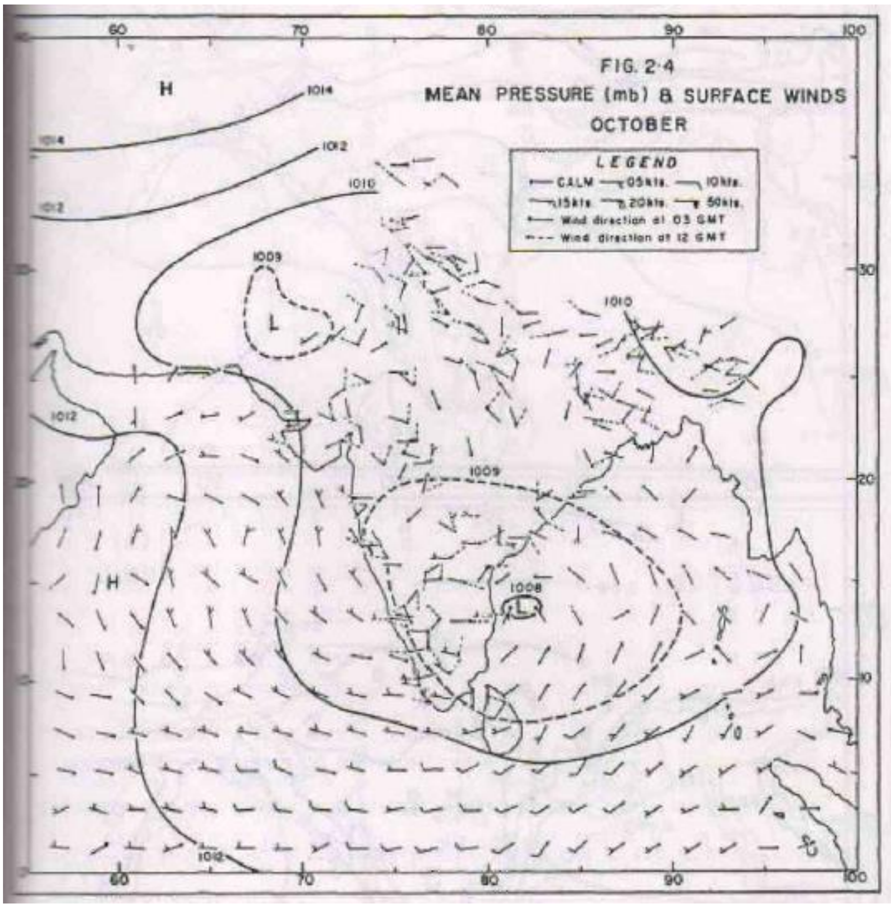
POST MONSOON SEASON

Climatic Features

Post monsoon season is the transition period from summer monsoon circulation to winter circulation. The pressure and upper wind circulation patterns over India rapidly change from the summer monsoon type: and the winter monsoon type flow pattern makes it's appearance. During the first half of October SW monsoon withdraws from the country outside the south peninsula. NE monsoon rainfall continues over south peninsula from mid October to December.

4.1.1 Pressure (October)

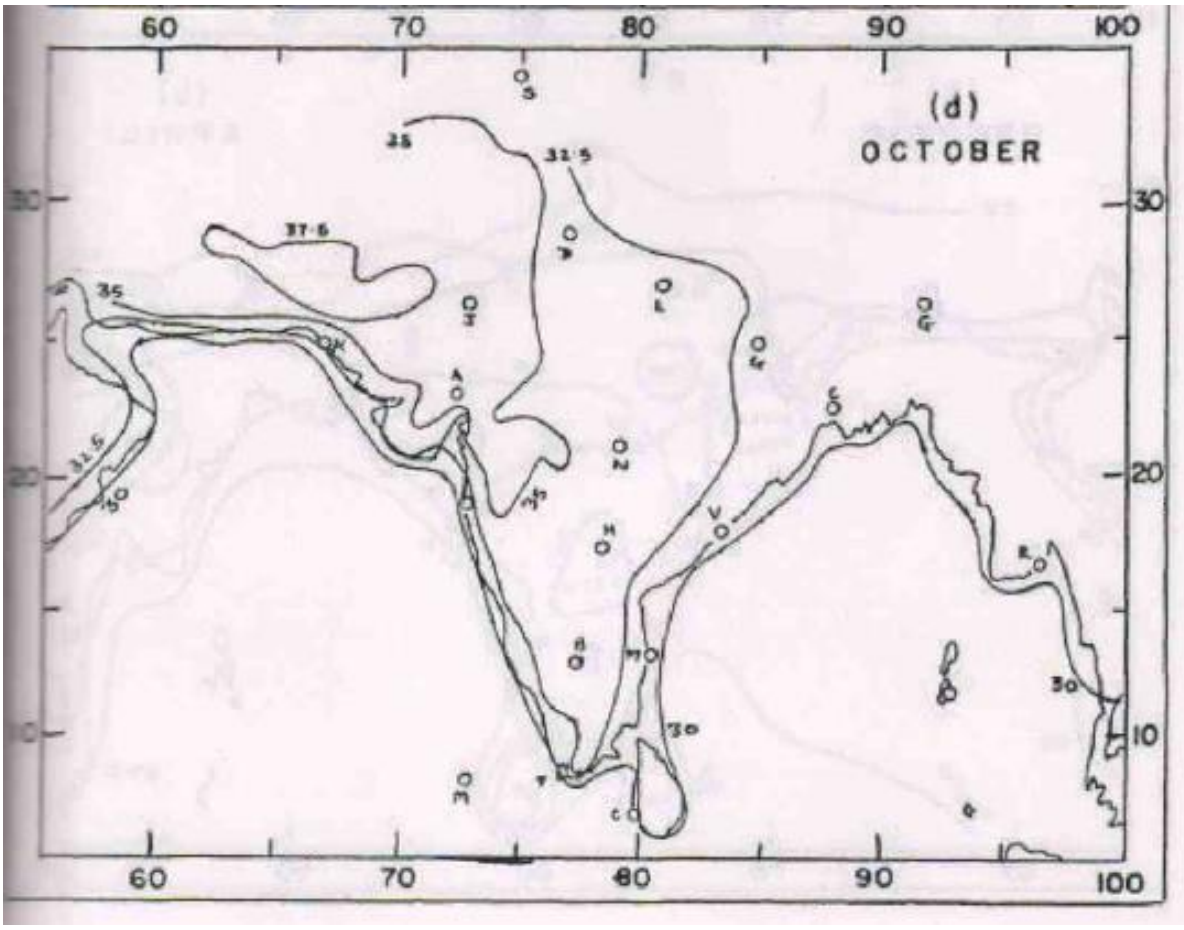
The pressure pattern during October is rather diffused. The monsoon trough over the northern India shifts southward. In October a low pressure area is established over the central and adjoining south Bay of Bengal with the trough line along 13° N. This low pressure area shifts further equator ward with the advance of season. In the Arabian Sea no low pressure is seen during this season.



4.1.2 Temperature (October)

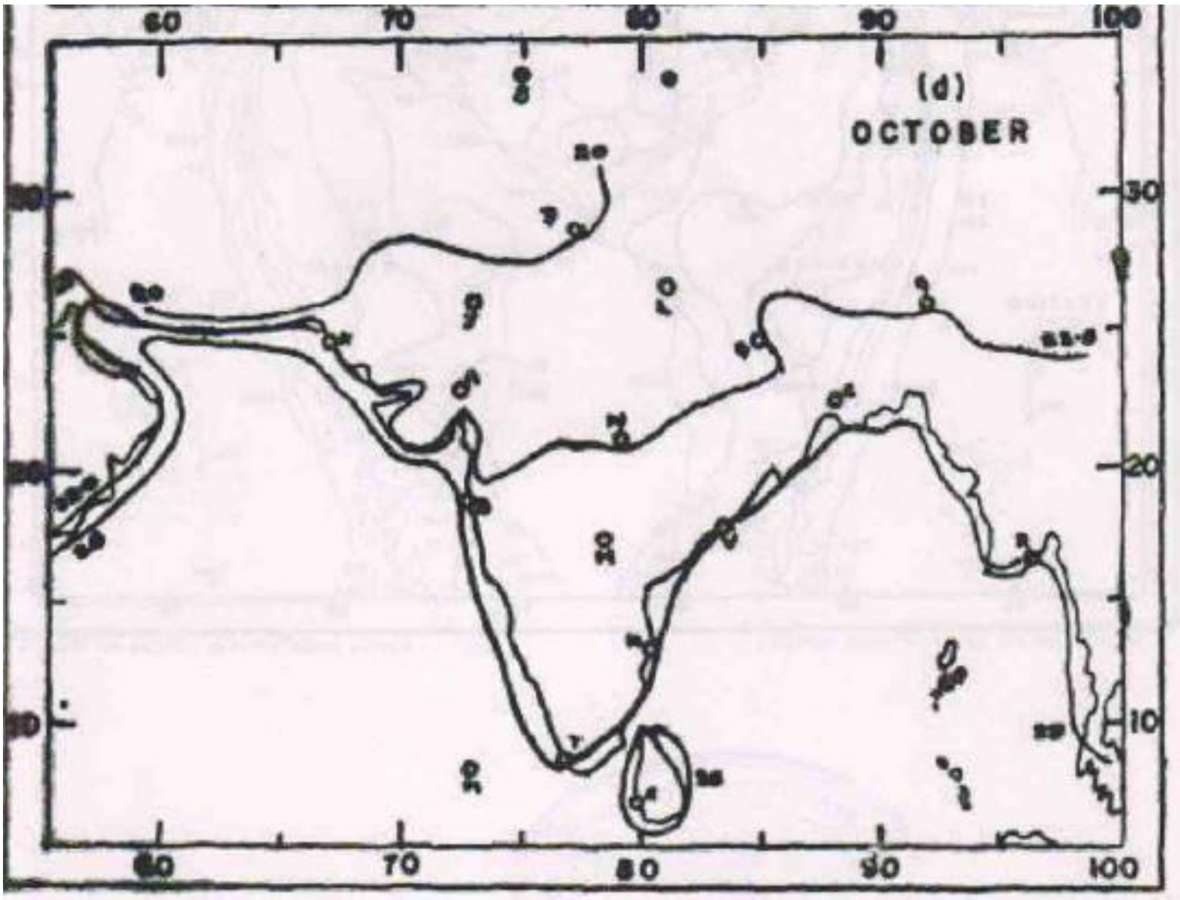
4.1.2.1 Mean Daily Maximum Temperature

Like July, the day temperatures are maximum during October over West Rajasthan and adjoining Gujarat (> 35° C). It decreases eastward, becomes < 30° C over eastern parts of Assam. Over the peninsular India day temperatures are more less uniform (about 31° C) but they are lower over coastal Kerala due to maritime influence and slightly higher over coastal Tamil Nadu and adjoining south coastal Andhra Pradesh



4.1.2.2 Mean Daily Minimum Temperature

Night temperatures during October begin to decrease almost everywhere in India and especially over NW and central India from the July values. NW India, MP, West UP and northern parts of Maharashtra. It ranges between 16° C to 19° C. They are comparatively higher (23° C to 25° C) along the coastal areas of the country due to maritime influence.



4.1.2.3 Diurnal Range of Temperature

Diurnal range of temperatures starts increasing over most part of the country. It is 15° C or more over NW India and between 10° C to 14° C over UP. MP, Maharashtra, Telangana and NIK. It is less than 10° C elsewhere. However, it is minimum (about 4° C) over south coastal Tamil Nadu and coastal Kerala where NE monsoon rainfall prevails. With the advance of the season the diurnal range of temperatures become larger over the country

4.1.3 Upper Winds (October)

There is a large change in the upper air circulation pattern over India from the summer monsoon type circulation. Sub-tropical ridge and the equatorial trough starts shifting equator ward from the beginning of the season

i) In place of the monsoon trough over north India at 850 hPa level sub tropical ridge extends roughly along Lat 23° N Westerly winds are present only south of Lat. 10° N and a trough runs roughly along Lat. 12° N more prominently over the Bay of Bengal. The trough at higher levels is diffused.

ii) At 500 hPa level the ridge, which runs along 30º N in July runs along 18º N over the country in October.

iii) Aloft the westerly winds over northern India strengthen with height becoming 50 – 60 kts. Around 200 hPa level over NW India and Pakistan. The 200 hPa ridge, which runs along 30º N in July, shifts southwards and runs roughly along 17º N over the country during October.

In the upper levels winds are westerlies to the north of the sub tropical ridges and easterlies to its south. With the advance of the season the upper air ridge and the equatorial trough in the lower tropospheric levels shift further equatorward.

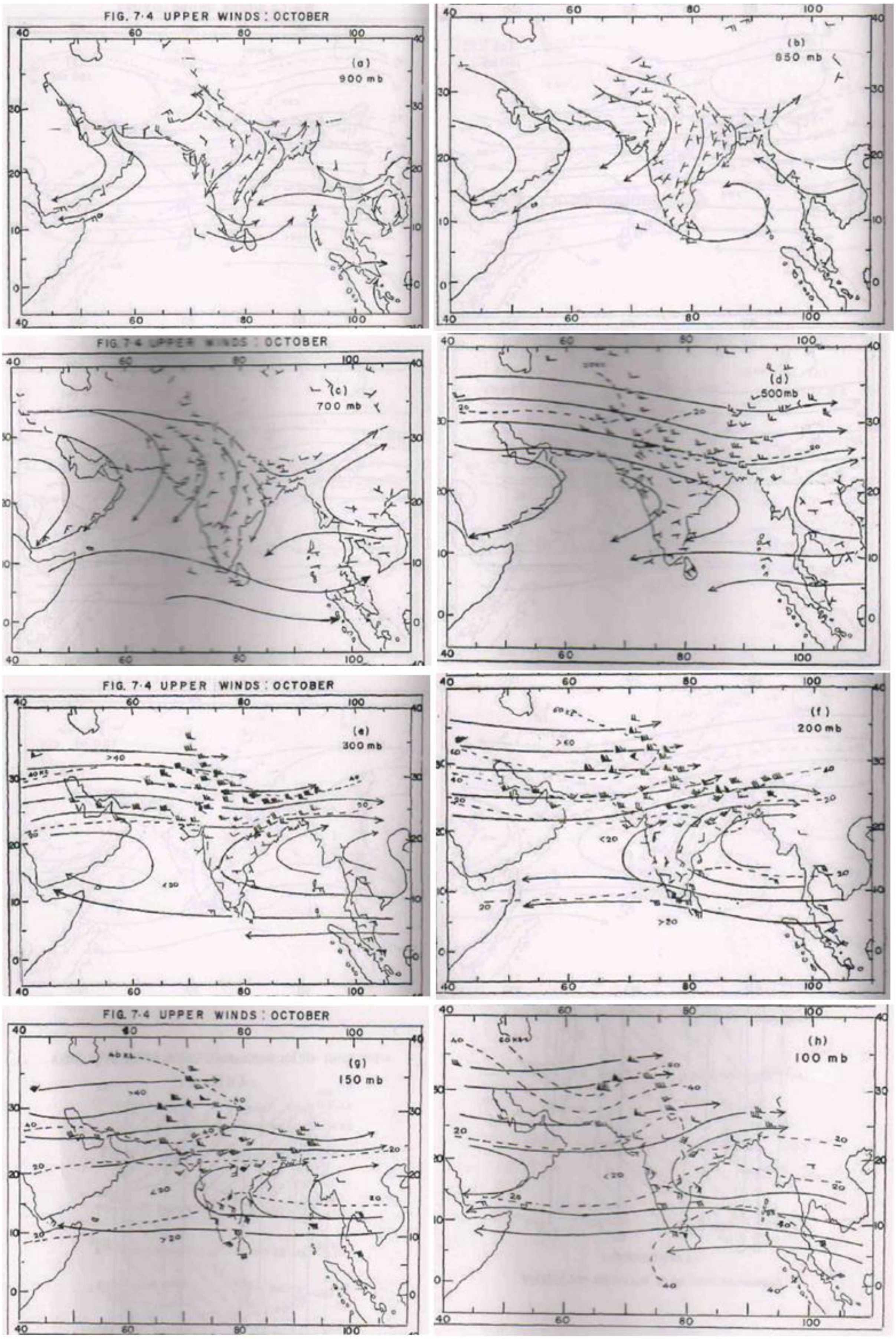
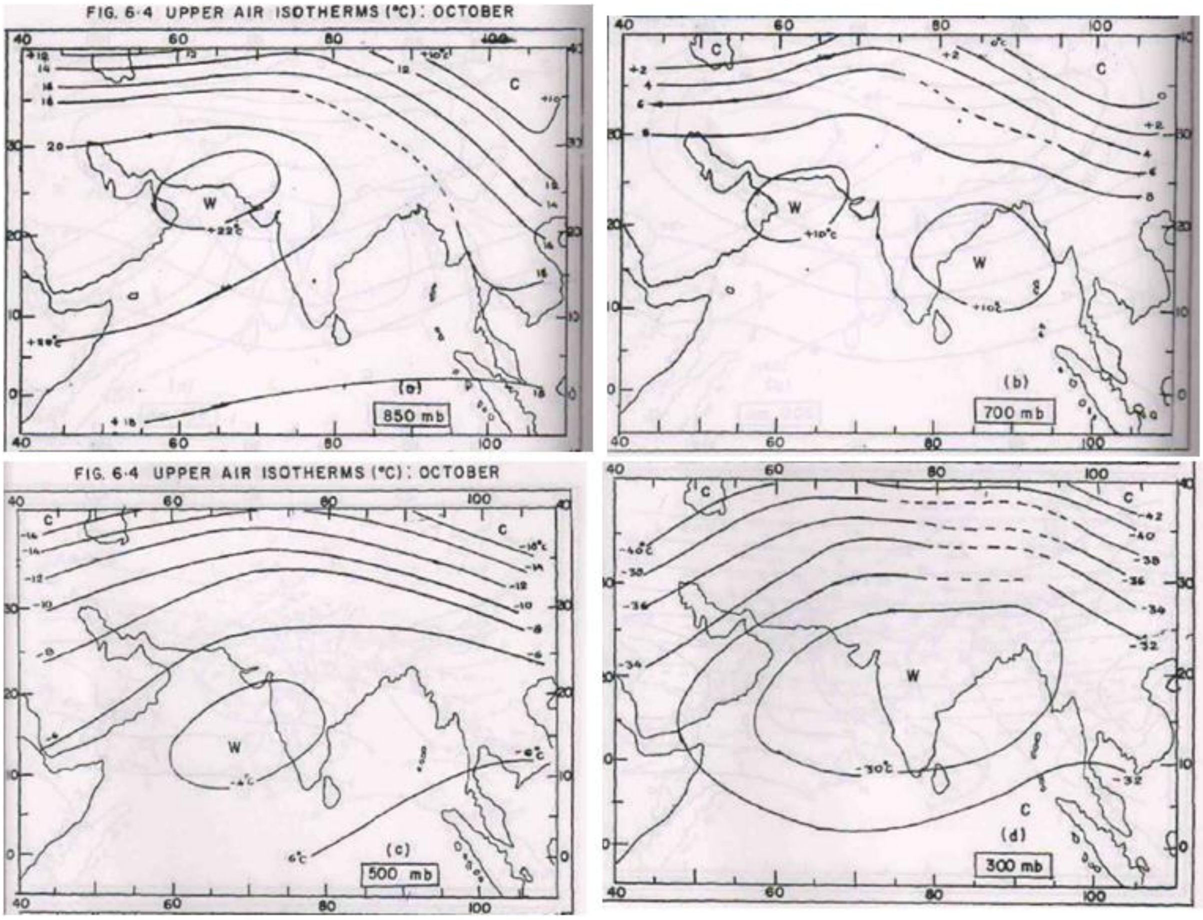


FIG. 7·4 UPPER WINDS : OCTOBER
(a) 900 mb
(b) 850 mb
FIG. 7·4 UPPER WINDS : OCTOBER
(c) 700 mb
(d) 500mb
FIG. 7·4 UPPER WINDS : OCTOBER
(e) 300 mb
>40
<20
(f) 200 mb
>60
<20
>20
FIG. 7·4 UPPER WINDS : OCTOBER
(g) 150 mb
>40
<20
>20
(h) 100 mb
<20

4.1.4 Upper Air temperature (October)

Normally the regions of sub tropical anticyclones are warm areas (i) In the month of October the upper air thermal gradient is weak to the south of Lat. 25° N Upto 300 hPa (ii) temperatures decrease poleward to the north of Lat. 25° N (iii) at 200 hPa the thermal field is very flat over Asia (iv) At 150 hPa level the temperatures increase poleward to the north of 20° N and at 100 hPa level from 15° N (v) At 100 hPa the temperature increase is as much as 11° C between 15° N and 30° N.



4.1.5 Seasonal Rainfall (Oct – Dec)

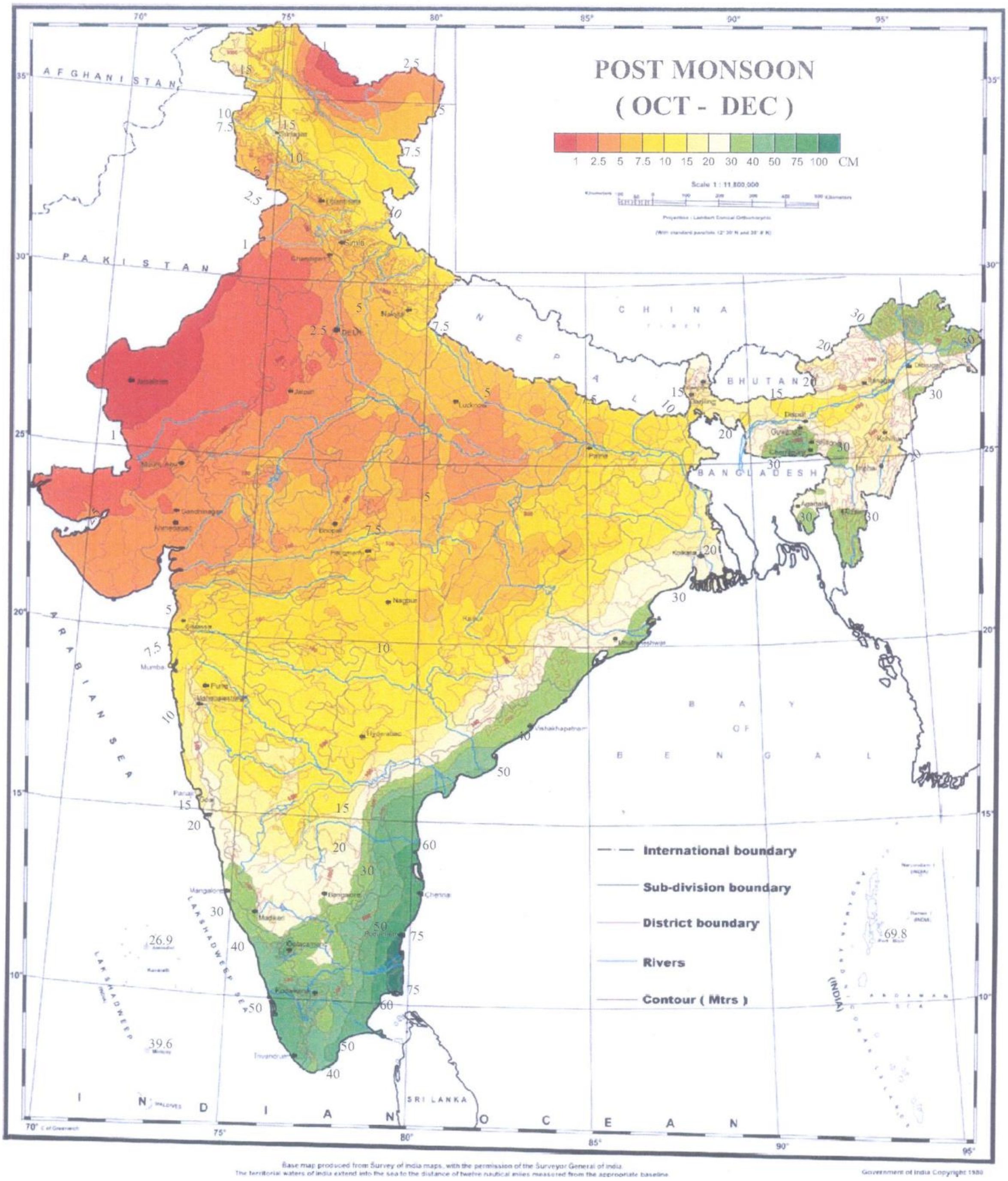
In the post monsoon season precipitation is highest (30 – 100 cm) in the south peninsula. East coast, Assam and adjacent states and Kashmir also receive considerable precipitation (15-20 cm) during the season.

Along the east coast, rainfall decreases inland from the coast. The coastal areas of the east coast north of 10 N receive 20 -30 cm of rainfall while it is less than 10 cm over the central parts of the peninsula. There is hardly any rainfall over Rajasthan, Haryana and Saurashtra and Kutch during the season.

South of 15 N rainfall increases due to NE monsoon activities. Coastal Tamil Nadu and south Kerala receive 50 – 100 cm and the remaining parts of the peninsula south of 15 N receive 20 – 40 cm of rainfall during the season. It is the principal rainy season in Tamil Nadu.

RAINFALL (cm)

Map No. 46



4.2 Major weather Systems during the post monsoon period

i) Depression and cyclonic storms in the Indian seas

ii) Westward moving low pressure areas in the Indian Seas.

iii) Well marked seasonal trough

iv) Western Disturbances

v) Trough in the middle and upper tropospheric westerlies.

4.2.1 Depression and cyclonic storms

In the following table, statistics of depressions/cyclonic storms/Severe cyclonic storm for 86 years (1877 – 1972) during post monsoon season are given.

Table: Depressions/Cyclonic Storms 1877 – 1972 (86 years)

BAY OF BENGAL							
Month	Depressions		CS		S.C.S		Total
	1-15	16-31	1- 15	16-31	1-15	16-31	152
October	41	38	19	23	11	20	152
November	20	17	28	13	25	18	121
December	14	10	11	11	12	5	63
ARABIAN SEA							
October	5	4	2	9	3	3	26
November	4	3	2	2	7	3	21
December	1	-	3	-	-	1	5

The primary peak of the storms in the Indian seas is found in the month of November. From the above table the following features are revealed.

i) During the season. The month of October has more number of storms and depressions and the December has the least

ii) Maximum number of storms develops during the month of November. The number of cyclonic storm and severe cyclonic storms is more in the first half of November than in the later half. Thus, earlier half of the post monsoon season constitutes major storm season for India.

iii) The number of storms and depressions in the Arabian Sea is comparatively much less than in the Bay of Bengal

iv) In October the number of depressions is more than the C.S and S.C.S. In the subsequent months, the storms are more than the depressions.

PLACE OF ORIGIN		
Month	Bay of Bengal	Arabian Sea
October	The whole of Bay of Bengal is susceptible for cyclogenesis. Some of depressions of the early part of October may be of monsoon type. The western part of the Bay (i.e NW, WC and adj. South Bay) is the place : 1^{st} half – North of 13° N 2^{nd} half – South of 15° N.	Eastern Half to the west of Long. 70° E between 12° N and 17° N
November	South of Lat. 15° N and to the west of Long 90° E	Depressions over SE Arabian Sea. However their intensification is much spread out (8° N to 13° N)
December	South Bay to the South of Lat. 10° N	Negligible in number

The climatologically favourable areas of formation agree well with the location of the seasonal trough during the season. Intensification of the depression into a cyclonic storm occurs over area. Where sea surface temperature is about 28.3° C (83° F) in October, 27.8° C (82° F) in November and 26.7 C (80 F).

This is because the value of the corioli's parameter should be larger than a critical value for the formation of storm or depression. The corioli's parameter is negligible within $\pm$ 5° of the equator.

Movement of Storms and Depressions

About 60-70 percent of the post monsoon storms strike the Indian coast. The storms move towards the coastal areas of the Indian subcontinent following some characteristic tracks. Thus the likely track of a C.S can be assessed to some degree of confidence based on the climatology of storm tracks. However, May storms and post monsoon storms show considerable variations in their track.

Majority of the disturbances (60-70 percent), that form over the Bay of Bengal during October and November affect the east coast of India. However, in December only about 20 percent of them affect the coast. During this month half of them dissipate over the Sea as they move north or recurve eastwards. With the advance of the season the storms strike east coast at more southerly latitude.

During October more than 80 percent of storms strike east coast to the north of Lat. 14º N In November about 70 percent strike coast between 10º N and 16º N and in December 80 percent of them strike coast to the south of Lat. 14º N.

Some of the Bay storms are likely to cross south Peninsula and re-intensify into C.S over Arabian Sea. About 20-25 percent of the disturbances that form in the Arabian Sea affect west coast of India, Majority of them (80 percent) strike the Gujarat – North Maharashtra coast between 18º N and 23º N.

The majority of the Bay storms and depressions of the Post – monsoon season move WNW/NW wards during October and November. However storms that develops over Arabian Sea in November recurve N to NNE wards. The probability of recurvature is maximum in the month of December for both the Bay of Bengal and the Arabian Sea storms. In the month of October the systems move more towards we3st than to the north.

Also it is evident that in the east coast of India, north Tamil Nadu – South Andhra Coast and Gujarat coast in the west coast are most vulnerable areas from storms threat during the post monsoon season

Size of the Storm

The outermost closed isobar is considered as the areal extent of a cyclonic storm. The diameter of the outermost closed isobar varies from 200 to 1500 km

Generally the size of the post monsoon storms is large than the pre-monsoon season storms. The average diameter of the Post monsoon storms is about 1200 km whereas in pre monsoon season it is about 80-0 km

Life cycle of Tropical cyclones

The average life period of storms and depressions in the North Indian Ocean is about 4 – 5 days in the post monsoon months. However, considering all the storms and depressions in the North Indian Ocean, the life period works out to be about 3.5 days (18977-1974). The entire life period of a storm is divided into four stages namely (i) Formative stage (ii) immature stage (iii) Mature stage and (iv) Terminal or decaying stage.

Disastrous Weather associated with a storm

a. Torrential rain (ii) Gale force winds and (iii) Storm surge/Tidal wave Details of the above weather features are given in pre-monsoon period.

4.2.2 Low Pressure Areas

In the equatorial trough region over Bay of Bengal and the Arabian Sea storms and depressions develop out of low pressure areas. However, all the low pressure areas that develop during the season do not intensify into depression or storm. The low pressure areas, which form over SW Bay, move westwards without further development and affect weather over South Peninsula. Some of the low pressure areas can be traced from Andaman Seas. However, they often storm in situ over SW Bay. On an average two each in October and November and one in December may be expected. These low pressure areas are shallow and occupy wide areas. To track them from chart to chart is difficult. The associated circulation hardly extends beyond 700 hPa level. Some of these shallow systems may be identified as waves in the low level easterlies. From satellite imageries their westward propagation can be traced. They generally form between 1º N to 10º N. They develop at higher latitude in October and the area of formation shift equatorward as the season advances. They generally cause rain over a narrow coastal belt.

4.2.3 Well marked seasonal trough

The east west oriented seasonal trough (surface and upper air) passes across south peninsula during October. It shift southward with the advance of the season. Low pressure systems form in this trough and move westwards along the trough. The trough generally extends upto 70 hPa level sloping southward with height This trough becomes well marked when low pressure systems in the Southeast Arabian Sea and in the south Bay of Bengal become prominent. Rainfall occurs mostly along the coastal belt and to the south of the trough. The area to the north of the trough gets relatively much less rainfall.

4.2.4 Western Disturbances (Dealt in detail in Winter Season

Western disturbances seem to affect extreme north India from November though there are several cases of W.Ds. In October, as the season advances their intensity and number increases. They are the chief rain producing systems over western Himalayas and neighbourhood during the season.

4.3 NE Monsoon

Post monsoon season (October to December) is the principal period of rainfall in Tamil Nadu. However coastal Andhra Pradesh, Rayalaseema and south interior Karnataka receive considerable rainfall during the first half period of the season. Coastal districts of Tamil Nadu receive nearly 60 % and the interior districts about 50 % of their annual rainfall during this period. South Interior Karnataka, Kerala and Arabian Sea islands also receive about 20 % to 30 % of their annual rainfall during the post monsoon season.

Monsoon starts withdrawing from northwest India from mid September. As the monsoon retreats from India and adjoining sea areas, NE monsoon sets in It is also known as the Retreating Monsoon for that reason. There is spectacular change of direction of winds between the two monsoons. SW winds of the SW monsoon period change to NE winds over the Bay of Bengal, Peninsular India and the Arabian sea during the NE monsoon period (i.e Post monsoon season). It is often difficult to identify the withdrawal of SW monsoon and the arrival of NE – monsoon over Tamil Nadu and neighbourhood. However, for declaring the onset of NE monsoon over Tamil Nadu, the following criteria have been advanced (evolved on the basis of Tenth F.Os Conference – Tec. No. 29 in 1988)

i) Withdrawal of SW monsoon upto Lat. 15º N
ii) Onset of persistent surface easterlies over Tamil Nadu coast
iii) Depth of easterlies upto 850 hPa level over Tamil Nadu coast.
iv) Occurrence of fairly widespread rainfall over Tamil Nadu and adjoining areas
v) Onset of NE monsoon is not to be declared before 10^{th} October, even if the above conditions exits

NE monsoon rainfall is mainly derived from (i) westward moving low pressure areas, (ii) well marked seasonal trough of low in the Bay of Bengal and also from (iii) depressions and storms that strike Tamil Nadu coast.

NE monsoon rain occurs over the south Peninsula during October and November but in December the rainfall activity shift mainly to coastal Tamil Nadu and south Kerala. During SW monsoon period the rainfall along the west coast increases progressively inland reaching a maximum in western face of the Western Ghats whereas the NE monsoon rainfall decreases from coast to the interior. Generally the rainfall spells during the season extend up to 3 – 4 days However; longer spells of rainfall are not uncommon.

Heavy to very heavy falls occur in Tamil Nadu and coastal Andhra Pradesh during the months of October and November. In December they are very rare. Thunderstorms are common in South Peninsula during the northeast monsoon season.

NE Monsoon activity over south peninsula as a whole is maximum in October. However, active monsoon conditions occur over Tamil Nadu up to the month of December

5 INTERACTION OF HIGH AND LOW LATITUDE DISTURBANCES

The mid latitude westerlies are characterized by wave like motion (troughs & ridges). The mid latitude troughs in middle and upper tropospheric westerlies affect tropical weather almost throughout the year. These troughs extend most equatorwards into the tropical latitudes from December to April

During the winter the consequence of mid latitude weather systems affecting the tropical weather may be seen in the formation of 'Western Disturbances'

The origin of western disturbances is traced to the deep troughs in mid latitude westerlies. When such trough develops large amplitudes thus extending into the northern boundaries of the tropical areas it induce weak low pressure system much to the south of the main upper air trough with associated low level circulation.

Also it has been observed that when a wave in the westerlies in the northern latitudes comes in phase with a wave in the easterlies. They often interact causing intensification of both the troughs and sometimes lead to the formation of tropical storms in the easterly regime.

In some regions the deep trough in upper tropospheric westerlies may induce the formation of a trough in the tropical easterlies. The trough in easterlies move eastwards along with the upper level trough. Such situation is sometimes noticed over the Indian Peninsular region.

Beside such direct interaction of midlatitude systems in producing weather systems in the low latitudes several other interactions of these systems on tropical weather can be traced. During the monsoon season the Tibetan High is formed due to the high altitude heating of the plateau. Occasionally a deep trough in mid latitude westerlies overtakes the Tibetan high resulting in the weakening or shifting of this high or even replacing it by a trough of low pressure. Such interaction generally weakens the monsoon trough and thus the monsoon activity over the monsoon regime.

The recurvatures of storms and depression, in all seasons, are mostly influenced by the deep westerly troughs. The influences of these troughs are rather pronounced in NW Pacific. Under their influence a number of tropical cyclones in NW Pacific recurve and develop extratropical characteristics at higher latitudes.

The END