# M.A. GEOGRAPHY
# SEMESTER I (CBCS)

# GEOGRAPHY PAPER - 102
# PRINCIPLES OF CLIMATOLOGY

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**M.A. Part – I; Semester I**
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**1. Unit – I (15 hours)**
1.1 Nature and scope of Climatology
1.2 Relationship of Climatology with Meteorology
1.3 Structure and composition of Atmosphere
1.4 Weather elements and climatic controls

**2. Unit – II (15 hours)**
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2.2 Temperature - Vertical, horizontal and seasonal variations
2.3 Processes of heat energy transport
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**References:**


1. Barry, R.S. & Chorley, R.J. (1971): Atmosphere, Weather and Climate, ELBS, Methuen & Co. Ltd., U.S.A.
2. Griffiths, J.F.(1966): Applied Climatology-An Introduction, Oxford University Press, London.
3. Lal, D.S.(1997):Climatology, Sharda Pustak Bhawan, Allahabad.
4. Mather, J. R.(1974): Climatology: Fundamentals and Applications, McGraw Hill Book Co. New York.
5. McBoyle, G.(1973): Climate in Review, Houghton Mifflin Co., Boston.
6. Subrahmanyam, V.P.(ed)(1983):Contribution to Indian Geography, Heritage Publishers, New Delhi , a) Vol. III - General Climatology b) Vol. IV-Applied Climatology

7. Harp, H.J. and Trinidade, O.D. (eds) (1990): Climate and Development, Springer Verlag, U.S.A.
8. Oliver, J.E. and Hidose, J.J. (1984): Climatology - An Introduction, Charles and Merrill, U.S.A.
9. Robinson, P.J. and Hendersen-Sellers, A.(1999): Contemporary Climatology, Pearson Education, London

**Further Reading:**

1. Bhutani, Smita, Our Atmosphere, Kalyani Publishers, Ludhiana, 2000.
2. Critchfield, H.J., General Climatology, Prentice Hall, N.J., 1975.
3. Frederick K. and Edward J. Tarbuck, The Atmosphere: An Introduction to Meteorology, Prentice Hall of India Pvt. Ltd., New Delhi, 1995.
4. Strahler, A.N., Modern Physical Geography, John Wiley and Sons, New York, Singapore, 1987.
5. Trewartha, G.T., An Introduction to Climate, McGraw Hill, New York, 1980, Fifth Edition (International Student Edition).
6. Lydolph, P.E., The Climate of the Earth, Rowman Nad Allanheld, Totowa, New Jersey, 1985.
7. Rumney, G.R., Climatology and the World Climates, Macmillan, London, 1968.
8. Thompson Russell D., Applied Climatology - Principles & Practice, John Willey, New York, 1997.

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# 1

# WEATHER AND CLIMATE

**Unit Structure:**

1.0 Objectives

1.1 Nature and scope of climatology

1.2 Relationship of Climatology with Meteorology

1.3 Structure and composition of Atmosphere

1.4 Weather elements and Climatic controls.

## 1.0 OBJECTIVES

Weather and Climate have become crucial part of our survival due to human activities and climate change.
The objectives of this unit are as follows.

- To understand nature of Climatology, definitions given by various weather scientists.
- To understand scope of this subject.
- To know the relationship of Climatology with Meteorology.
- To understand structure of the Atmosphere.
- To study in detail about the composition of our atmosphere.
- To understand difference between Weather and Climate.
- To understand difference between Weather elements and Climatic controls.
- To study various Weather elements.
- To study various Climatic controls.

## 1.1 NATURE & SCOPE OF CLIMATOLOGY

We live on the surface of the Earth. Atmosphere covers the entire Earth. We are at the bottom part of the atmosphere. Atmosphere provides us essential elements required for our survival. e.g. Air - Oxygen, Water - Hydrological cycle. Water is required for agriculture, vegetation, which provide us food and oxygen.

**Climatology - Definition:**

Climatology is formed by combination of two Greek words, Klima - and logos. 'Klima' means slope of the earth. The concept of slope is related to Latitude logos means study.

Hence climatology can be defined as the scientific study of climate.

Climatic conditions are related to location of place with respect to Latitude. So it is study of the varieties of climates found on different parts of the world. Definitions of climatology given by different experts are as follows.

**1) C.S. Thornthwaite:**

Climate of any region depends on the nature of exchange of heat and moisture between the earth's surface and the atmosphere. Hence climate of any place or region indicate equilibrium between the receipt & the expenditure of the radiant heat as well as moisture. It is the moisture and heat budget of a region, which is represented by the climate of the region.

**2) G.F. Taylor:**

Climate is the integration of weather and weather is the differentiation of climate. The distinction between weather & climate is therefore mainly of time.

**3) Critchfield:**

The process of exchange of heat and moisture between the earth and the atmosphere over a long period of time result in conditions which we call climate. Climate is more than a statistical average, it is the aggregate of atmosphere-atmospheric conditions involving heat, moisture and air movement.

**4) Trewartha:**

Climate represents a composite of day-to-day weather conditions and of the atmospheric elements, within a specified area over a long period of time. It is more than 'average weather' for no adequate concept of climate is possible without an appreciation of seasonal and diurnal change and of the succession of weather episodes generated by mobile atmospheric disturbances. While in a study of climate emphasis may be given to the averages, still departures, variation and extremes are also important.

**5) Koeppe and De Long :**

Climate is a summary a composite of weather conditions over a long period of time; truly portrayed, it includes details of variations - extremes, frequencies, sequences - of the weather elements which occur from year to year, particularly in temperature and precipitation. Climate is the aggregate of the weather.

**6) Kendrew :**

Climate is a composite idea, a generalization of the manifold weather conditions from day to day throughout the year. Certainly no picture of it is at all real unless it is painted in all the colours of the manifold variations of weather and the rounds of the seasons which are the really prominent features; it is quite inadequate to give merely the mean state of any element.

**7) Riley and Spolton :**

They consider the science of climatology as the study of weather conditions over a long period of time.

**8) Austin Miller :**

According to him climatology is that branch of science which discusses the average conditions of weather.

**9) Arnold Court :**

According to him climatology is related to three other modern disciplines - statistics, Meteorology and Geography. In his opinion each of these disciplines, to certain extent, is a child of climatology.

The following five growing fields are the major study areas of climatology.

1) Study of climate as the direct environment of man.
2) Study of climate as the environment of living organisms.
3) Energy and moisture balances of the Earth.
4) Theory of climate.
5) Climatological records.

**Nature, Scope and Objectives of Climatology :**

Different types of climatic conditions are found in different parts of the world. Climatology seeks to explain the causes of different types of climates, their specific & general locations, reasons for their variations, their effects on natural vegetation, and the processes that produce different climates.

Climatology also study & detailed analysis of the interactions of the weather & climate elements with human societies.

Hence the ultimate goal of climatology is to discuss various climatic elements as well as factors that control the distribution of climate on the surface of the Earth.

According to F. K. Hare the main purpose of Geographer is to study the impact of temperature, humidity and rainfall on the distribution of human population and various economic activities practiced by man. The geographer should focus his attention on how human societies have colonized on the Earth.

Climate has direct psychological and physiological impact on man. Growth of crops & vegetation / forest is associated with climate.

**Impact of climatic elements on human life :**

The elements of weather & climate have great impact on human life. Temperature, pressure, direction and velocity of wind, humidity, cloud amount and precipitation.

**1) Temperature :**

Some scientists feel that the countries in the tropical belt are backward due to excessive solar radiation in this region.

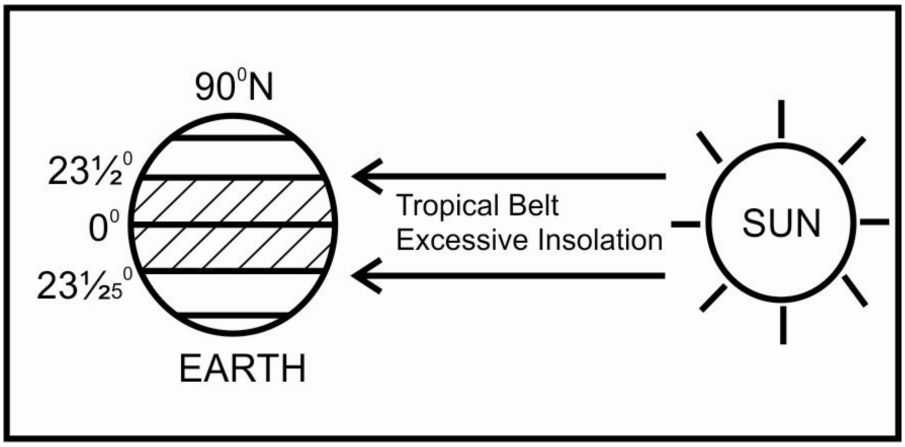



**Fig. 1**

Solar rays stimulate our cells, and are useful for us. But excessive amount of insolation causes cells to break down. The amount of solar radiation in summer in Tropical countries is far more than that is required for our body.

This has direct impact on the health of people and their efficiency two work.

On the other hand almost all industrially advanced countries of the world are in the temperate belt where the mean annual temperature is about $11^0$C, and mean summer temperature near $18^0$C. e.g. Temperature in the major metropolitan cities like New York, London, Paris.

**2) Humidity - Relative Humidity :**

Sultry weather is a result of high temperature combined with high relative humidity. Such type of weather has an adverse impact on our physical and mental efficiency. Extreme dry weather during winter is also harmful to our body.

Our physical comfort and efficiency are closely related to temperature and relative humidity.

**3) Strong wind - storms :**

Civilizations and culture have more developed in the areas of adverse climatic conditions. e.g. U.K., France, Germany, Japan & part of the U.S.A. - are industrially advanced countries. People in this region, with the help of science and technology found innovative ideas to face the severe storms and other climatic hazards. (Need is the mother of invention) which occur in these areas.

Soil, crops, trade & commerce, various diseases human efficiency and health all these and many more factors are associated with climate.

Nature of land is modified as per the changes in the climatic conditions. natural vegetation, plants in any region are modified and these adaptations help them to survive and grow even in harsh environment.

Climatic conditions are not same everywhere on the earth & so agricultural products, which are produced in different regions are also different. e.g. Tea, Rubber, Cocoa, Coffee are grown in the tropical region as they require warm climatic condition. But the demand for these products is more in the temperate belt. Such unequal distribution of production is responsible for the development of trade and commerce in the world.

Few important aspects related to climatology are as follows.

- Normal cycle of Indian monsoon is affected by the emergence of El Nino Ocean current. Rainfall amount is reduced considerably.
- World's ecosystems are closely associated with climatic conditions in that region or classification of climate.
- Biomes & ecosystem adjust themselves according to the changes in the weather conditions.
- No two places on the Earth can have exactly same climate. Classification of climate helps us to simplify study of climates in different parts of the world on the basis of selected major characteristics.
- Development of computer models with advanced software technology have helped us to study simulate complex situations with the help of computer.

**Sub-divisions of Climatology :**

There are three major sub divisions of climatology according to critchfield.

1) Physical Climatology
2) Regional Climatology
3) Applied Climatology

**1) Physical Climatology :**

Temperature, pressure, wind, humidity, precipitation, insolation are the elements of weather and climate. Physical climatology deals with the temporal (related to time) and spatial (related to area or places.) variations of these elements and factors responsible for such variations in different part of the world.

There are certain climatic factors as latitude, altitude, distance from sea, local relief, nature of surface, winds etc. which control processes related to weather and climate. Physical climatology is directly related to all these factors & weather processes, which cause different type of climae in different regions.

Physical climatology is closely related to Meteorology, which includes chemistry, Physics, dynamics of the atmosphere and its impact on the earth's surface, oceans & life on earth.

**2) Regional or Descriptive Climatology :**

It is related to identification of climatic characteristics of different regions and the classification of climate.

Regional climatology acts as a link between the problem in applied climatology and the physical basis of climate.

As this branch of climatology deals with area or region it is sub-divided into three categories on the basis of their areal extent.

a) Macro climate
b) Meso climate
c) Local climate

**a) Macro climate :**

As this is the largest among three divisions, it is known as Geographical Climate or Geo Climate. It's areal extent varies from more than twenty km. to thousand km. It may cover entire continents like N. America, S. America, Africa, Asia, Australia.

**b) Meso climate :**

Areas covered in Meso climatic regions are smaller than the Macro climate regions. It may be from about 100m to 20 kms. e.g. Sundarban delta, Godavari delta, Kaveri delta, Kashmir valley, Tarai region etc. are the examples of Meso climatic regions.

**c) Local climate :**

This region is about 100 m to 1000m e.g. climate of a village, Urban area, a wet land, a forest area etc. Depending upon the local factors we can get variations in these categories e.g. a village located at coast, or in the interior part or at the hill top may experience different climatic conditions.

**3) Applied Climatology :**

This branch of climatology deals with the use of the principles of climatology and their application for solving problems of the society and resources. It also studies the relation ship between environment and biosphere with the climate.

This being applied branch of climatology it covers many interesting areas as

1) Air pollution
2) Climate & Agriculture
3) Climate change
4) Industries

5) Transport & Communication
6) Climate & Architecture like floods, cyclones etc.
7) Extreme weather events
8) Climate & human comfort
9) Climate and health
10) Climate and recreation

Applied climatology is further subdivided into following three areas.

a) Geo climate or Geographical climate, which is related to larger areas, and for the longer period of time.
b) Ecological climate : It is related to the weather conditions of the different habitats of the organisms. e.g. ecological climate in mine, forest or factory.
c) Micro climate : It represents very small area and climatic elements associated with it.

**Important events in the development of climatology :**

| **Year** | **Development** |
|---|---|
| 400 BC | Hippocrates discussed about the influence of climate on health. |
| 350 BC | Aristotle discussed about weather science |
| 153 | Galileo invented thermo scope (First Thermo meter) |
| 1662 | Francis Bacon wrote about wind |
| 1643 | E. Torricelli invents the barometer |
| 1664 | Weather observations started in Paris |
| 1668 | E. Halley prepared map of the trade winds |
| 1714 | Fahrenheit introduced temperature scale |
| 1735 | George Hadley wrote about the trade winds and rotation of Earth |
| 1736 | Centigrade scale was introduced |
| 1783 | Invention of hair hygrometer. |
| 1802 | Lemark & Howard proposed the cloud classification system |
| 1817 | Alexander von Humboldt prepared world map of mean annual temperature |
| 1825 | August designed psychrometer |
| 1844 | Gaspard de coriolis promoted idea of 'Coriolis Force' |

| | |
|---|---|
| 1845 | Barchan developed map of precipitation in the world |
| 1879 | Supan prepared map of Temperature regions of world |
| 1892 | Use of balloons for scientific measurements in upper air |
| 1900 | Koppen discussed about classification of climate |
| 1902 | Stratosphere discovered |
| 1913 | Ozone layer discovered |
| 1918 | V. Bierknes developed Polar Front Theory |
| 1940 | Jet Stream discovered |
| 1960 | First meteorological satellite by U.S. |
| 1985 | Vienna convention - protection of Ozone layer |
| 1987 | Montreal protocol - CEC |
| 1992 | Rio Earth Summit - on climate change |
| 1998 | Kyoto Protocol on climate change |
| 2021 | At present there are three weather satellites of India<br>1) Kalpana - 1,<br>2) INSAT - 3A<br>3) INSAT - 3D |

**Climate and Natural Vegetation :**

Plants are not able to move from one place to another like animal and man. Hence plants modify themselves according to the climatic conditions of that area. Hence natural vegetation is known as an indicator of climate.

Temperature of forested area is less than the surrounding open area due to evapo-transpiration & obstruction of direct sunlight. The range of temperature is also less in the forests.

Trees obstruct strong wind and hence trees are used as the wind-breakers to protect plants, fertile soil and to check or reduce advancement of deserts.

Forest reduces speed of wind by obstructing it. So temperature and transpiration is less in forest areas. Relative Humidity is more.

**Climate and Agriculture :**

It is found that there is also the close association between climate, and uncertain weather, soil, natural vegetation, crops, pests and diseases.

Solar radiation is the most essential climatic elements for the proper growth of crops. Temperature is the most critical factor in growth of different types of crops. Production or yield of crop is more when the temperature is most suitable. e.g.

| Crop | Temperature |
|---|---|
| Pineapple | $21^0C$ |
| Coconut | $21^0C$ |
| Maize | $72^0C$ |
| Cotton | $15^0C$ |
| Sugarcane | $15^0C$ |
| Rice | $15^0C$ |
| Citrus fruits | $15^0C$ |
| Vegetables | $8^0C$ |
| Wheat | $3^0C$ |
| Potato | $18^0C$ (8 - $28^0C$) |

Different crops need different temperature, moisture and other weather elements. Hence climatology - weather & climate elements provide useful information to the farmers. They can decide type of crop, and agricultural operations on the basis of this information.

**Frost** is very harmful to different types of crops and so the knowledge of the frost-free season is essential in agricultural planning.

**Drought -** It is a very serious agricultural problem. Droughts are related to Climatological factors as higher temperature, windy weather and decreasing relative humidity.

## 1.2 RELATIONSHIP OF CLIMATOLOGY WITH METEOROLOGY

Man is considered as most intelligent among all living organisms. He observed nature & develop science which explains us how natural forces work. Man also develop technology. Technology is the use of science for the benefit of man. Hence science is the base of technology and technology is the application of science.

Meteorology and climatology these two scientific fields are related to the atmospheric elements and changes in them - both temporal and spatial.

Meteorology covers the technical - scientific aspect of atmospheric elements & processes - i.e. atmosphere’s physical & chemical characteristics and motions, interrelations among the atmospheric systems, weather forecasting research and development in atmospheric science.

Climatology makes use of information obtained in Meteorology and use it for the benefit of man and his economic activities. So Meteorology provides strong scientific base for climatology. Development in climatology is related to this information for solving various problems related to the ever changing atmospheric conditions which affect man and his activities and also on the environment, leading to the changes in the climate etc.

Hence Meteorology is source of scientific information related to atmosphere - its elements & processes. While climatology is the application of this information for the benefit of man and environment on the Earth.

Let us understand nature of Meteorology :

Meteorology is the study of atmosphere. This term was coined by the Greek Philosopher Aristotle in his book on Natural Philosophy entitled Meteorologica in 340 B.C.

In those days anything seen in the sky and all substances coming to earth from the sky were termed as Meteors. Hence Meteorology has its origin in the Greek word Meteoros which means ‘high in the air’. Today we use term Meteor as the material / rock that comes from the extraterrestrial sources outside our atmosphere (Meteoroids).

Similarly the particles of ice and water coming to earth are termed as Hydrometeors.

Aristotle explained the atmospheric phenomena in a philosophical and speculatire manner in his book Meteorologica. After many years student of Aristotle wrote book on weather forecasting - Book of signs, which was attempt to forecast weather with the help of weather related indicators.

There was not much progresses in this field for about two thousand years.

In 1500 Galileo designed water thermometer. In 1643 E. Torricelli invented mercury barometer for the measurement of air pressure.

After few years Pascal and Descartes demonstrated that atmospheric pressure decreases with increasing height by using a barometer.

In 1667 Robert Hooke invented anemometer for the measurement of wind speed.

In 1719 Gabriel Daniel Fahrenheit developed temperature scale.

In 1735 Hadley explained how winds in the tropics are influenced by the rotation of the Earth.

In 1742 Celsius developed centigrade (Celsius) temperature scale.

In 1752 Benjamin Franklin demonstrated the electrical nature of lightning.

In 1780 Horace de Saussure invented hair hygrometer.

The development of these scientific instruments helped researchers to take accurate measurements & compile data related to various weather elements for further analysis and research.

In 1787 Jacques Charles discovered the relationship between temperature and volume of air.

It was possible to draw crude weather map in 1821 due to availability of information.

In 1835 G. Coriolis demonstrated the effect of earth's rotation on atmospheric motions.

In 1843 the invention of the telegraph helped Meteorology to develop more rapidly. Now it became easy to collect data from different regions; for the preparation of weather maps. In 1869 isobars were drawn on the weather maps, joining places having equal atmospheric pressure. Around 1920 the concepts of weather fronts & airmasses were developed.

In 1940 hot air ballons helped to collect data related to weather elements - Temp Humidity, pressure etc. from upper air.

Military aircrafts discovered the existence of upper level high speed jet streams.

After 1950 development of computers helped tremendously in the research and progress in the field of Meteorology.

Doppler radars were used since 1990 which could collect information from severe thunderstorm.

The first weather satellite Tiros 1 was launched in 1960.

Today satellites provide us wide range of useful information related to atmospheric elements & weather.

Satellite imageries are available for different periods and for different regions. There is a vast scope for geographers in the field of remote sensing and GIS.

Preparation of thematic map with the help of satellite immegaries is a skilled job. Such maps are very useful for weather forecasting & research related to weather & climate in the field of climatology. Computers and development of different software's, satellites, rocket technology, imaging techniques, computer cartography all have helped us tremendously in obtaining, valuable and accurate data related to weather elements, its analysis - both qualitative and quantitative, preparation of weather maps etc.

The role of Meteorolist is to obtain more accurate information about different weather & climate elements like Temperature, Atmospheric pressure, Wind-its direction and speed, Humidity - its variation - Precipitation - various types, condensation - its forms, cyclones & weather disturbances etc.

Due to uncontrolled development of industrialization & human activities severe environmental problems related to atmosphere have emerged in last few decades like depletion of Ozone, Ozone hole in the atmosphere, Global warming, climate change, problem of chemicals like CFC, different types of pollutions, increase in the amount of carbon di Oxide etc.

These are very serious problems related to the existence of man and environment on the Earth.

Unfortunately these changes are ignored by the political administrative authorities and by the industrial lobby in many countries. Many NGO like Green Peace are spreading awareness about it in the different parts of the world.

Modern developments in the field of science and technology can help Meteorologist to understand these problems scientifically and find out solution for them.

Climatologist are concerned more with the elements & controls of weather & climate and their impact on man, his life, human societies and the activities of man.

Climatologist can make use of the data, analysis or research obtained in Meteorology for weather forecasting, providing suggestions to the farmers related to crops w.r.t. the weather conditions in that area. Hence Meteorology is the theoretical base of climatology and climatology is the practical application of Meteorology.

The symbiosis of these two scientific fields is essential to face severe problems of weather & climate in the future.

## 1.3 STRUCTURE AND COMPOSITION OF ATMOSPHERE

**Structure of the Atmosphere :**

**Introduction :**

Atmosphere is the gaseous envelop which surrounds Earth. There is no atmosphere on moon & so there is no life. Different forms of life on the Earth are closely associated with the atmosphere.

Most of the gasses in the atmosphere are heavy (except Hydrogen and Helium) and hence due to the pull of gravity these gases are concentrated near earth's surface. These gases exert pressure on the earth's surface. So the atmospheric pressure is maximum near to surface of earth 100% it is about 1013 mb (millibars) at Sea level. As we move in the upward direction from the earth's surface atmospheric pressure decreases rapidly.

| Altitude (km) | % of sea level pressure |
|---|---|
| 0 | 100% |
| 5.6 | 50 |
| 16 | 10 |
| 30 | 1 |
| 80 | 0.001 |
| 100 | 0.00003 |

From the table it is clear that the traces of the atmosphere extend upto thousands of kilometers beyond the earth's surface but most of the atmosphere is below 30-80 kms.

From the beginning of 20$^{th}$ century along with the invention of weather balloons, aeroplanes, rockets, sound and radio waves, and recently satellites have helped to gather information about the atmosphere found at different elevations.

Sir Napier shaw, picardy, Bort, Kennelly, Heviside, Ferrel were some of the eminent scientists who have helped to reveal secrets of atmosphere.

Different zones of the atmosphere are classified on the basis of their physical and chemical properties. e.g. Density, atmospheric pressure temperature, chemical and electrical properties.

The structure of the atmosphere according to petterssen is as follows, which is on the basis of temperature

1) Troposphere
2) Stratosphere
3) Mesosphere / Ozonosphere
4) Ionosphere
5) Exosphere

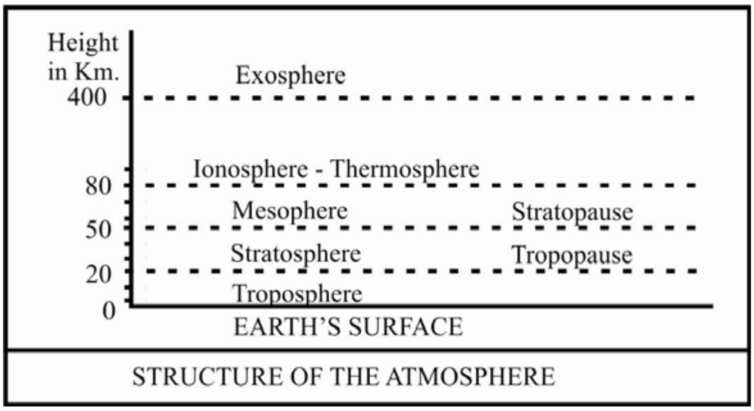
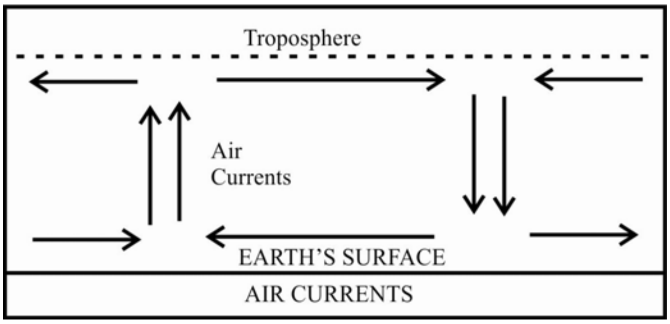



**Fig. 1**

**1) Troposphere :**

The term Troposphere was suggested by Tide Bort. It is derived from the Greek word 'tropos' which means mixing. This is also called as convective region as all ascending and descending air currents, mixing of air is confined to this lowest layer of the atmosphere. All these convective activities stop at the upper limit of the Troposphere known as Tropopause.




We live in the Troposphere, layer of the atmosphere close to the Earth. Height of the highest mountain on Earth - Everest is about 8 kms, but height of the troposphere is about 16 km at the Equator and about 8 kms. Near the pole.

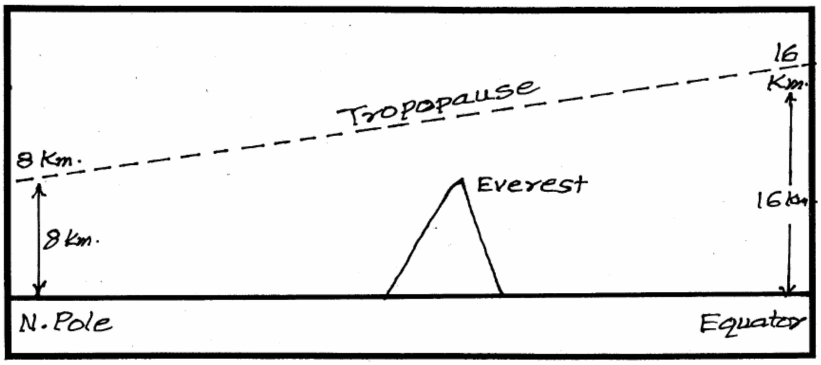



**Fig. 3**

Almost all water vapour, clouds, rainfall, precipitation, cyclone, dust particles - aerosols etc. are confined to this layer - Troposphere. It contains about 75% of the total gaseous mass of the atmosphere.

Velocity of wind increases with height and is maximum at the top portion of this layer.

In this zone temperature decreases with increases in height. This rate of decrease in temperature is about $6.5^0$C per kilometer. It is known as N.L.R. or Normal Lapse Rate. This decrease in temperature, with increase in height stops at the upper limit - at the tropopause.

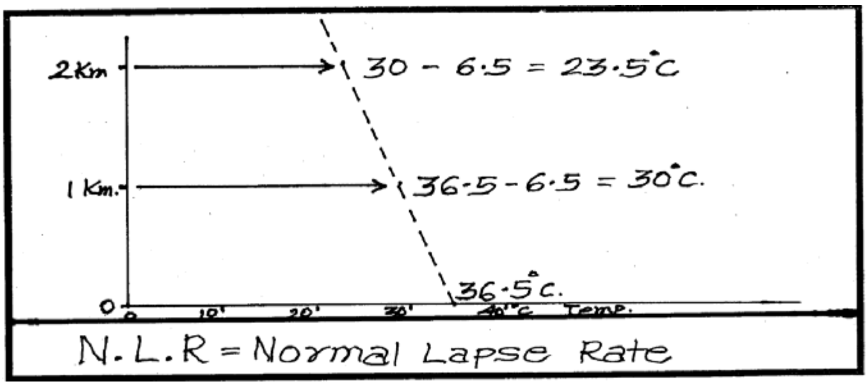



**Fig. 4**

The boundary between Troposphere and next layer stratosphere is marked by a thin layer called as Tropopause. It was used by Sir Napier shaw.

It is a Greek word which means ‘where the mixing stops.’

Height of the tropopause is about 16 km. at the equator, due to strong vertical convectional currents. Hence the lowest temperature in the entire troposphere is found directly above the equation (at 16 km.) and not over the pole (about 8 km)

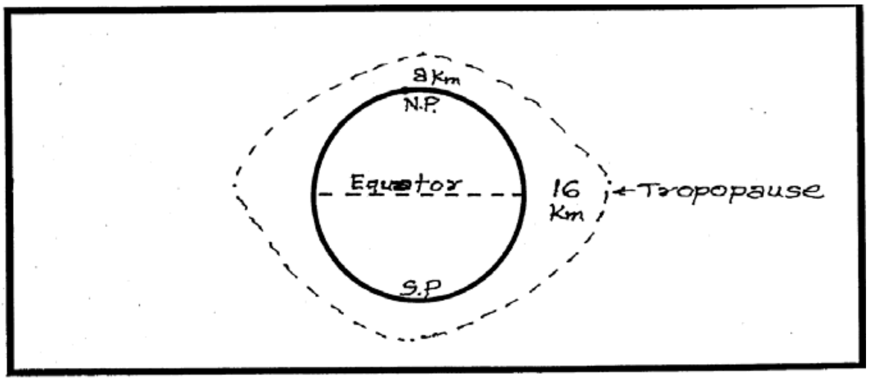



**Fig. 5**

**2) Stratosphere :**

This zone extends from Tropopause to stratopause - upper limit of stratosphere, at the height of about 50 kms. Hence thickness of stratosphere is less over equator (16 km to 50 km) and more over the pole (8 km to 50 kms)

Temperature remains constant with increase in height in lower part of the stratosphere. But it increases with increase in height in remaining part of stratosphere. This layer of the atmosphere is very important in the global problem of **Global Warming**; as it contains concentration of Ozone ($O_3$) in the lower part of the stratosphere upto the height of 30 kms.

Ozone ($O_3$) provides protection to the different forms of life on the Earth. Ozone obstructs and controls the excessive U.V. radiation coming from the sun.

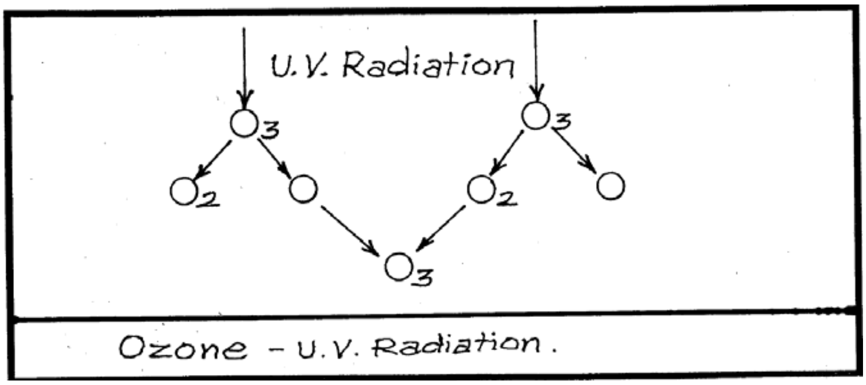



**Fig. 6**

Ozone splits up into $O_2$ and O when U.V. radiation falls on it. $O_2$ and O join together to form Ozone. Much of the U.V. radiation is utilized in this process and hence the amount of U.V. radiation reaching earth's surface is reduced. This had helped to maintain balance of temperature on the Earth for many thousand years.

Due to advancement in science and technology new products and chemicals were invented. CFC or Chloro - Fluoro - Carbon. This synthetic chemical was widely used as fluids in air conditioners and refrigerators, as propellant in spray. When these products are scrapped, CFC is released in the atmosphere. It reaches upto stratosphere, where it destroys Ozone.

The depletion of Ozone means lesser obstruction to the incoming U.V. radiation. Hence the amount of U.V. radiation reaching Earth's surface has increased more in the recent years. It is also responsible for increase in the global temperature, disturbance in the balance of temperature, melting of glaciers and rise in sea level, skin cancer, disturbance in ecosystem etc.

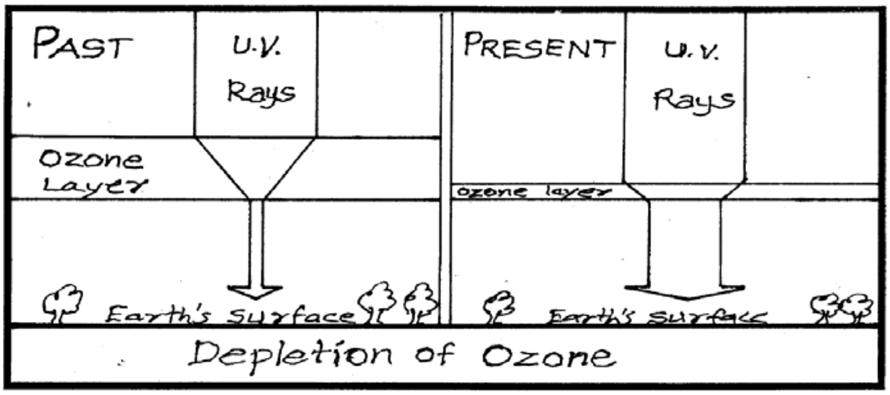



**Fig. 7**

**3) Mesosphere / Ozonosphere :**

This layer of atmosphere is found between strato pause (50 km) to Mesopause (80 kms) above the Earth's surface. Temperature decreases with increase in height in this layer. It is about $0^0$C at the stratopause to $90^0$C at the Mesopause.

The composition of air remains constant upto 80 kms i.e. upto Mesopause and hence the part of atmosphere upto the height of 80 kms is known as Homosphere.

It includes Troposphere, stratosphere and Mesosphere.

**Thermosphere :**

The part of atmosphere beyond Mesopause (80 kms.) is termed as Thermosphere. It is also a part of Heterosphere which is beyond 80 kms. It is termed as Heterosphere because composition of atmosphere is not same. It is different at various levels.

Temperature increases with increase in height. It is predicted that temperature at upper limit may be more than $1000^0$C still as the density of atmosphere is very very less and so this high temperature ($>1000^0$C) is not able to harm us.

Thermosphere is further subdivided into two layers.

1) Ionosphere - 80 to 400 km
2) Exosphere - 400 to 1000 km

**1) Ionosphere :**

Ionization is a process by which atoms are changed to ions through the removal or addition of electrons, giving them an electrical charge. Ionosphere consists of following ionized layers.

| Layer | Height (Km.) |
|---|---|
| D | 60 - 90 |
| E | 90 - 130 |
| $E_2$ | 150 |
| $F_1$ | 150 - 380 |
| $F_2$ | 150 - 380 |
| G | 400 |

**D - Layer (60 - 90 km) :**

Low - frequency radio waves are reflected back to earth by this layer, hence these can spread at a longer distances.

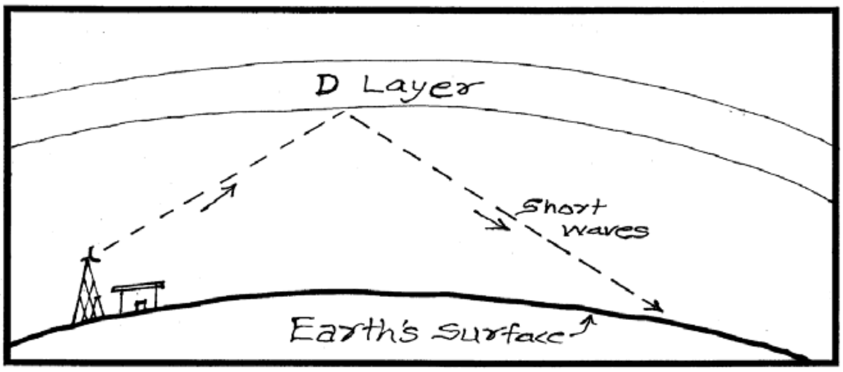



**Fig. 8**

It absorbs medium and high frequency waves.

**E - Layer (90 - 130 km)**

It is also known as the Kennelly - Heaviside layer. Medium and high frequency radio waves are reflected from this layer. As function of this layer is related to sun, it disappears after sunset.

**$E_2$ Layer (150 km) :**

This layer is produced by ultraviolet photons acting upon oxygen molecules. It vanishes at sunset.

**$F_1$ Layer (150 - 380 km)**

There are two layers in this layer - $F_1$ & $F_2$. These two layers together are known as 'Appleton layer'. This layer is important for long distance radio communication.

**G Layer :**

Due to the interaction of ultraviolet photons with nitrogen atoms free electrons are produced in this layer.

**2) Exosphere :**

This is the outermost limit of the atmosphere. It extends from 400 to 1000 km. Hydrogen & Helium gases are found in this region. Density of atmosphere is extremely low.

**Composition of Atmosphere :**

Atmosphere is the gaseous envelope that corers the Earth. The term Atmos + sphere means vapour + sphere. When this term was coined, at that time scientists were not aware about different type of gases. They were aware only about the water vapour. They could understand that gases are different from the water vapour. They thought that probably these (Gases) are the vapours of some substance and hence the name Atmosphere was given to the gaseous envelop that covers the Earth.

Atmosphere contains different gases like Oxygen, Nitrogen, Carbon dioxide, Argon, Neon, Helium, Ozone, Hydrogen, Krypton, Xenon and Methane, along with water vapour and solid and liquid particles, which are of great significance. Composition of dry air in Homosphere (from Earth's surface upto 80 km) is as follows.

| Gas | % by Volume |
|---|---|
| Nitrogen ($N_2$) | 78.08 |
| Oxygen ($O_2$) | 20.94 |
| Argon (Ar) | 0.93 |
| Carbon dioxide ($CO_2$) | 0.03 |
| Neon (Ne) | 0.0018 |
| Helium (He) | 0.00005 |
| Ozone ($O_3$) | 0.00006 |
| Hydrogen ($H_2$) | 0.00005 |
| Krypton (Kr) | Trace |
| Xenon ($X_2$) | Trace |
| Methane (Me) | Trace |

Among these gases Argon, Neon, Helium, Krypton and Xenon are termed as inert gases because they never found in any Chemical compounds. They remain isolated.

Detail information about the different gases is as follows.

**1) Nitrogen - 78% :**

Atmosphere contains 78% of Nitrogen. It is main constituent of many organic compounds. It serves as diluent & helps to regulate combustion by diluting oxygen. Plants, crops also require nitrogen but they are not able to take it directly from the atmosphere in the gaseous form. Plants can get it as nitrate, which is soluble in water, hence plants are able to take it through roots.

Nitrifying bacteria form colonies on the roots of the leguminous plants like groundnut. These bacteria have wonderful capacity to convert atmospheric nitrogen into nitrates.

Nitrate can be prepared in the fertilizer factory; by complicated process.

During storms & lightening intense heat is generated which helps to convert nitrogen from gaseous to nitrate form, which is dissolved in rain water.

**2) Oxygen :**

All forms of life on earth depend on Oxygen. Oxygen is capable of combining with different elements to form various compounds. Oxygen is also supports burning or combustion process. Rusting of iron objects is combining iron with Oxygen to form ferrous oxide.

**3) Carbon dioxide :**

Even though the proportion of $CO_2$ in the atmosphere is only 0.03% still it plays very important role in climate change. Carbon dioxide is exhaled by animals including man. It also enters into atmosphere by burning of fossil fuels like coal, oil & natural gas.

Carbon dioxide is absorbed by the plants to prepare their food in the process of photosynthesis. It is also absorbed by the oceans.

Carbon - dioxide is a green house gas, which means it is one of the gas which absorbs heat. Carbon dioxide is concentrated near the surface of the earth, where it is generated. It allows shortwave radiation of sun (insolation) to reach earth's surface but absorbs longwave radiation emitted by the earth's surface and redirects it to the earth.

Man has disturbed the balance of $CO_2$ in the atmosphere.

Green plants absorb $CO_2$ in large quantity & thus help to reduce level of $CO_2$ in the atmosphere. The rate of deforestation has increased in last century, hence Capacity of environment to absorb $CO_2$ reduced. At the same time due to development in science and technology, increasing use of fossil fuels, increase in population has contributed to increase in the proportion of $CO_2$ in the atmosphere. This has resulted in Global warming, which is a serious problem for environment & the existence of man on the Earth.

**4) Ozone :**

Ozone ($O_3$) is concentrated at the height between 20 to 30 km. in the atmosphere. Ozone absorbs ultraviolet radiation coming from sun-insolation. Hence the amount of U.V. radiation reaching earth's surface is reduced. U.V. radiation is useful to man & environment in small quanty but is harmful in large quantity. It can cause skin cancer & can contribute to Global Warming.

CFC is a synthetic chemical gas. One molecule of it can destry more than 1000 molecules of Ozone. Hence there is an urgent need to stop / reduce the use of such hazardous chemicals & protect our protective layer of Ozone.

**5) Water Vapour :**

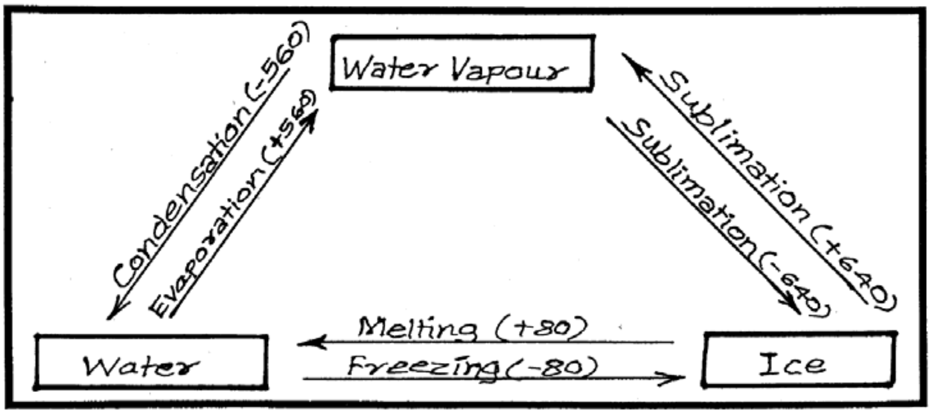
Water is called as Jeevan means life. It is essential for plants, man & other organisms in the environment.

Water vapour is invisible and its content in air is about 0.02% in cold dry climate to 4% in the humid climate.

Water is really magical substance on the Earth. It can exist in all three forms. Solid - Ice & snow, Liquid - water and Gas - water vapour. It is also considered as one of the Green house gases & greatest heat absorber. About six times more effective than $CO_2$ & $O_3$.

Water vapour also helps in transportation of heat from one place to another by various means like wind, hydrological cycle etc.

Much of the transfer of heat is done through Latent Heat. This is required or released when water vapour is transformed from one stage to another.




(Numbers in the bracket indicate the amount of latent heat required or given out.)

**Fig. 9**

Water vapour enteres into atmosphere through evaporation from the surface of the earth and hence about 90% of water vapour is found upto the height of about 6 km. Less than one percent water vapour is found beyond 10 kms.

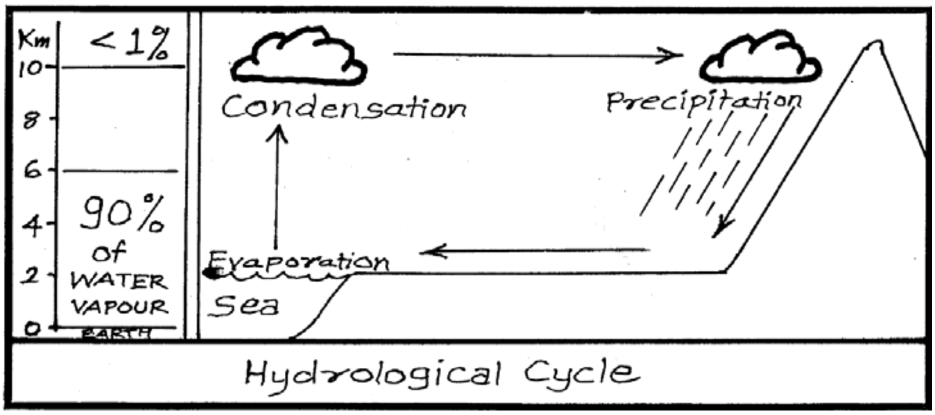



**Fig. 10**

In the Hydrological cycle when water is converted into vapour form in the process of evaporation.

1) Dirty, polluted water is purified.
2) Water vapour having less density moves in the upward direction thus it lifts millions of tones of water against the force of Gravity upto great height.
3) About 560 calories of heat is required for evaporation, which means this heat is added to water vapour and is transferred to far off places and released at the time of condensation. Hence water vapour plays a crucial role in the transfer of heat in the atmosphere.

**6) Dust Particles (Aerosols) :**

Dust particles means all types of microscopic particles in the atmosphere. These are also termed as (Aerosols)

Dust particles enter into atmosphere through various natural and man-made sources.

**Natural Sources :**
- Sea salt from breaking of waves
- Pollen grains of plants.
- Sand particles from deserts
- Dust particles from soil
- Volcanic eruptions
- Microscopic organisms
- Smoke & soot from fire

**Man made sources :**
- Cooking
- Economic activities
- Construction
- Farming
- Transportation
- Manufacturing
- Waste material

These microscopic dust particles or Aerosols play a wonderful role in the atmosphere and our life.

**1) Scattering :**

Insolation coming to the earth's surface is scattered by the dust particles if the diameter of particle is smaller than the wavelength of the incoming wave. In such situation the wave splits and it is termed as scattering. The day light which we get inside our room is due to scattering of sun radiation outside our home. (There is no scattering on Moon due to lack of atmosphere.)

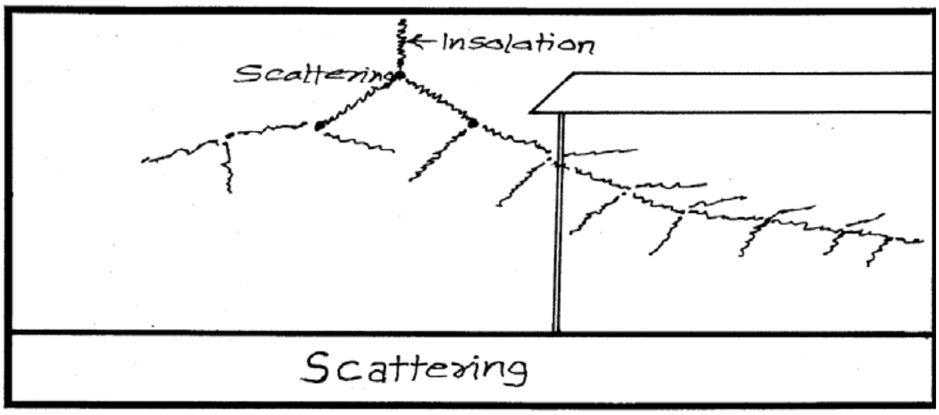



**Fig. 11**

Solar radiation or white light is composed of seven colours VIBGYOR - Violet Colour has shorter wavelength (0.4 microns) than Red colour. (0.7 microns) and hence sky appears blue due to scattering of violet colour in the sky.

**2) Condensation :**

The conversion of water vapour into water droplet is termed as condensation. Microscopic salt particles act as Hygroscopic particles and absorb water vapour thus they initiate process of cloud / raindrop formation.

**3) Forms of condensation :**

Fog, mist, clouds etc. are closely associated with the dust particles.

**4) Smog :**

Combination of smoke & fog is termed as smog. It is very dangerous for health - asthama patients & transporation - (accidents)

**5) Dawn & twilight :**

Colours in the sky are also related to dust particles.

## 1.4 WEATHER ELEMENTS AND CLIMATIC CONTROLS

**Weather and Climate :**

These terms are used in the study of climatology and Meteorology. Both of these terms are related to variations in the atmosphere.

**Weather :** It refers to the atmospheric condition over a smaller area and for a shorter period of time. e.g. We say today's weather; Rainy day, cold weather, warm weather etc.

Weather is variable in nature depending on the atmospheric condition. e.g. Rain in the morning & bring sunshine in the afternoon.

**Climate :** Weather and climate are decided on the basis of objective criteria, accurate measurements of elements of weather and climate

1) Temperature
2) Air pressure
3) Wind
4) Humidity
5) Clouds precipitation
6) Sunshine

There are separate instrument to record accurate variations in the these elements of weather and climate. Weather of a place is decided on the basis of daily reading of weather elements.

Climate is considered as average weather. It means it is the average of all readings of weather elements over a minimum period of 35 to 100 years. i.e. 35 years × 365 days × 2 readings per day (8.30 a.m. & 5.30 p.m.) = Total 25,550 readings per element.

So climate is the average atmospheric condition for a minimum period of 35 years. Hence climate is more stable than the weather. For many years climate of different areas was constant - i.e. not much variation. But in recent years it is disturbed due to human activities which we refer as - climate change.

Weather and climate have impact on our daily needs & entire life - our food, our clothing our homes, our activities etc. Transportation, agriculture are totally dependent on it.

They are also related to the growth of viruses and spread of diseases. In the past it was very difficult to predict about the weather conditions but due to development in science and technology today we have satellites, and other modern accurate instruments, which contribute in the accurate forecasting of weather conditions.

**Elements of weather and climate :**

Following major elements of weather and climate are used for the storage of data, preparation of weather charts / maps and analysis of data for research.

1) Temperature
2) Pressure
3) Wind
4) Humidity
5) Precipitation
6) Clouds
7) Sunshine

**Instruments used for the measurement of weather elements :**

| |
|---|
| Please copy text and diagrams from the following study material of IDOL - December 2015 |
| No. 247 - Physical Geography |
| F.Y.B.A. - Geography Paper - I |
| Page No. 180 to 187 |

**1) Temperature :**

Earth is heated due to insolation (Incoming Solar Radiation) Earth's axis is titled by 23½ to the vertical plane and Earth rotates around its own axis (day & night) At the same time Earth revolves around sun (seasons). Hence we get lot of variation w.r.t. temperature in different parts of the world, and in different seasons.

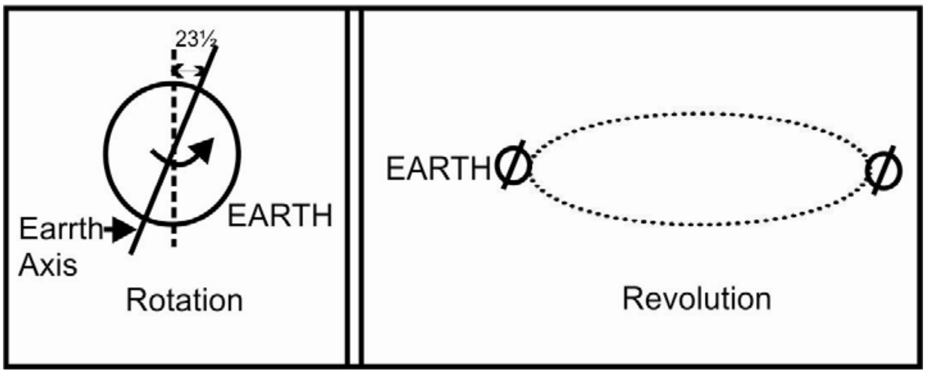



**Fig. 1**

Temperature is very crucial factor of weather & climate as it is associated with other elements & influence them. e.g.

1) **Temperature & pressure have inverse relationship :** Areas of high temperature have low atmospheric pressure.

2) **Temperature & wind :** Low pressure area develops at the region of high temperature surrounding area moves to this low pressure area as wind.

**3) Temperature and Humidity :** Warm air is capable of absorbing more water vapour and cold air promotes condensation.

Hence in humid areas like Equatorial region, evaporation is more due to high temperature so condensation and precipitation are also on a larger scale. Hence the Equatorial regions receive rainfall everyday. (It is said that there are no seasons in this region.)

In desert areas temperature is more but due to lack of water, humidity is low & so even condensation & precipitation are very rare. Condensation occurs on a smaller scale in the form of dew in the morning.

Temperature decreases with in distance from the equator. Temperature has great influence on our food, clothing, settlements, agriculture & other activities.

**2) Atmospheric Pressure :**

Atmospheric pressure means weight of the air over that particular place. This weight is maximum at sea level - 1013 mb. As we go at higher elevation air pressure decreases.

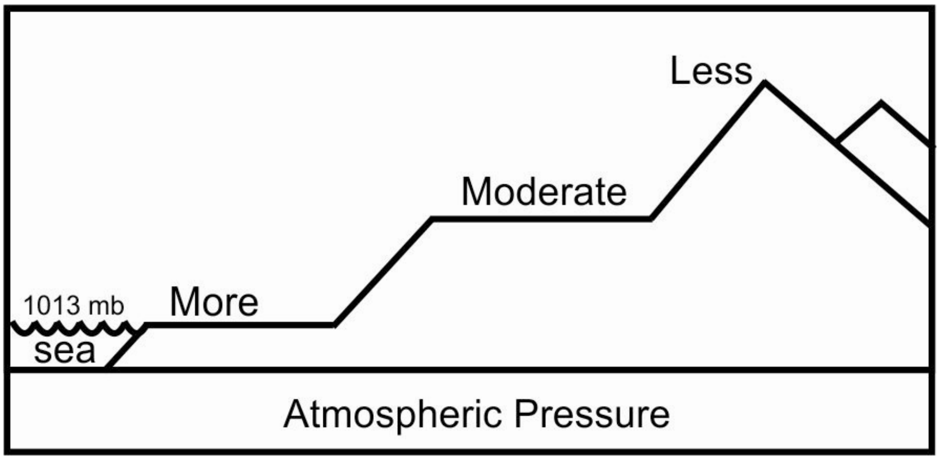



**Fig. 2**

**3) Wind :**

Air which moves from one place to another is termed as wind. Wind moves from high pressure area to low pressure area. In fact it is a mechanism to maintain balance in the atmospheric pressure.

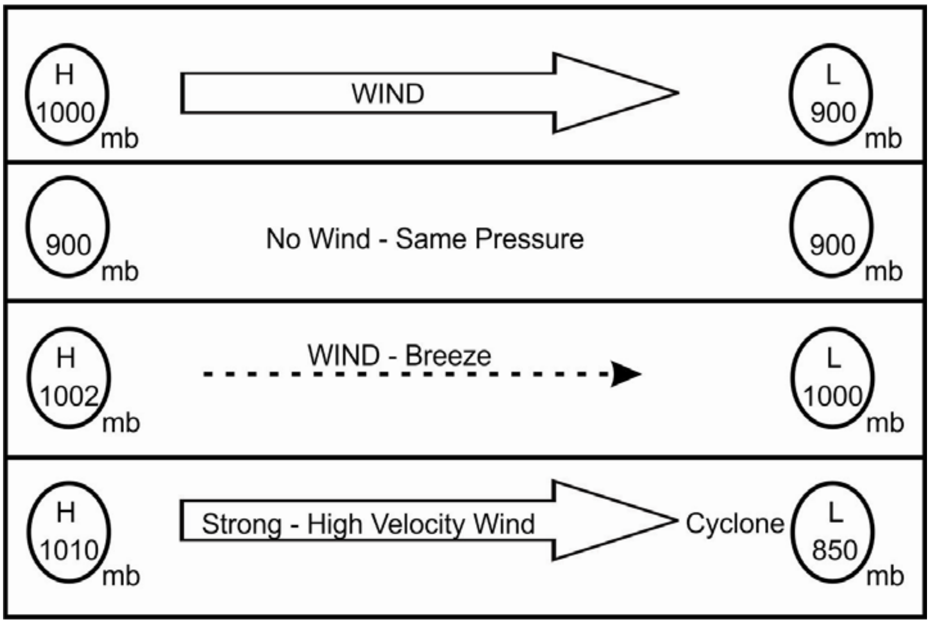



**Fig. 3**

Wind stops blowing when there is no pressure difference between two places.

Wind speed is very low-wind breeze if the difference in pressure between two places is very less.

Strong winds develop at the time of cyclones due to very high difference in pressure between two places.

Wind helps in the pollination of flowers & fruits. It helps to remove heat. Water transport was totally dependent on wind in the past. Wind is also used for the generation of electricity.

**Wind Vane** or **Weather Cock** is used to indicate direction from which wind is coming.

**Anemometer** is an instrument used for the measurement of wind speed.

Admiral Beaufort designed scale for the measurement of wind speed. It is known as Beaufort wind scale.

**4) Humidity :**

Humidity indicates proportion of water vapour present in the air.
Humid air has more water vapour & Dry air has less water vapour.
There are different types of measurement of Humidity.

**1) Absolute Humidity :**

It is the actual amount of water vapour present in the air. It is expressed in grams per cubic metre.

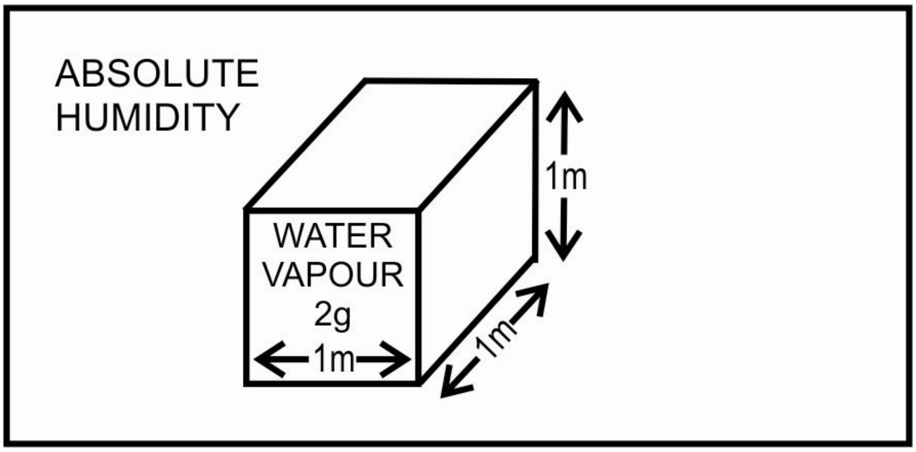



**Fig. 4**

**2) Relative Humidity :**

It is the ratio between the actual amount of water vapour present in the air to the ability of air to hold water vapour at the given temperature. It is expressed in percentage.

$$R.H. = \frac{A.H.}{S.H.} \times 100$$

R.H. = Relative Humidity
A.H. = Actual Humidity
S.H. = Saturation Humidity

R.H. = 20% - Dry air
R.H. = 80% Humid air
R.H. = 100% - saturated air

Humidity is more at the sea, coastal areas and at the equator (due to evaporation) & in Humid regions.

Humidity is less in dry deserts & interior parts of the continents. Humidity is measured with the help of wet and dry bulb thermometers.

Both thermometers are the normal thermometers are the normal thermometers but the bulb of the wet bulb thermometer is covered by the wet wick. The other end of wick is in the small reservoir of distilled water. Water rises upward upto the bulb due to the capillary action.

When water evaporates from the wick of wet bulb thermometer, it produces cooling effect and so wet bulb thermometer always records lower temperature than the dry bulb thermometer. With the help of Relative Humidity table / chart and the difference in dry and wet bulb thermometers we can decide Relative Humidity.

Dry Air - Rate of evaporation is faster - cooling more. Difference in temperatures of wet & dry bulb thermometers is more. (R.H. = 20%).

Humid Air - Rate of evaporation is slow - cooling less - Difference in temperature of wet & dry bulb thermometers is less (R.H. = 80%)

Saturated air - Evaporation stops. No cooling. Both thermometers indicate same reading (R.H. = 100%)

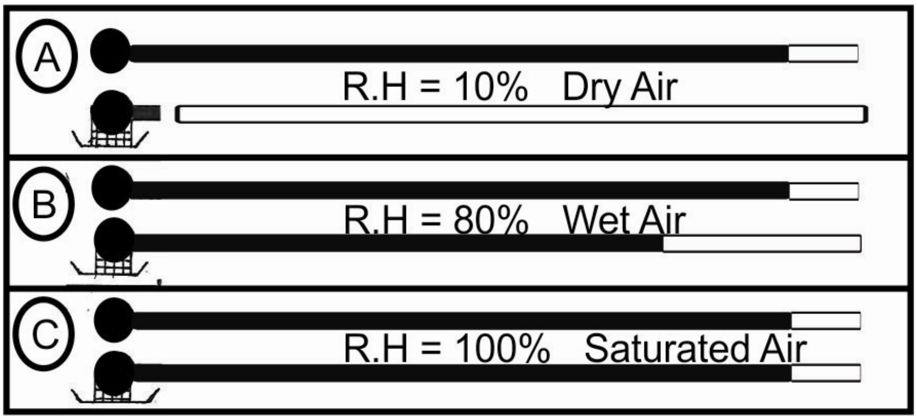



**Fig. 5**

Humidity is closely associated with our comfort. Humidity is important in some industries like cotton textile industry. All forms of precipitation, rainfall, condensation are closely associated with Humidity.

Humidity helps weather scientists to forecast weather condition.

**5) Precipitation :**

Major types of precipitation are as follows :

1) Drizzle - Liquid - droplet size 1mm.
2) Rainfall - Liquid - droplet size 5 mm
3) Sleet - Liquid + solid - combination of rainfall and snowfall
4) Snowfall - solid
5) Hail - Solid

Rain gauge is used for the measurement. Precipitation is closely associated with our dress, food, shelter and economic activities.

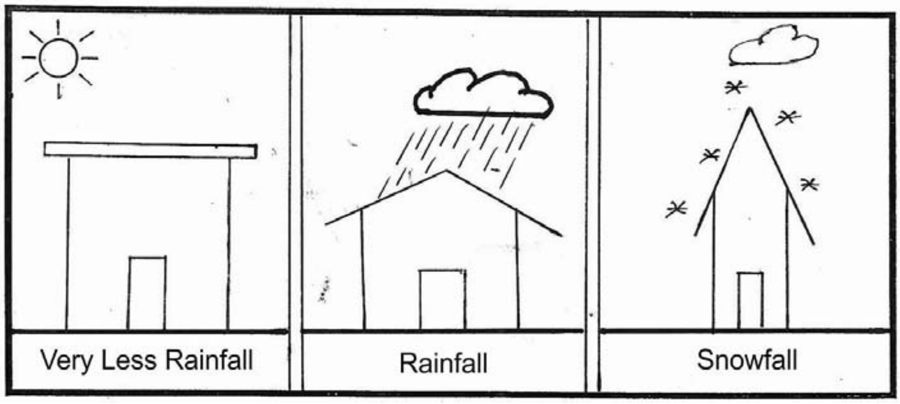



**Fig. 6**

**6) Clouds :**

Clouds are composed of tiny droplets of water or ice crystals. Clouds are classified on the basis of their shapes & location. Two basic shapes are

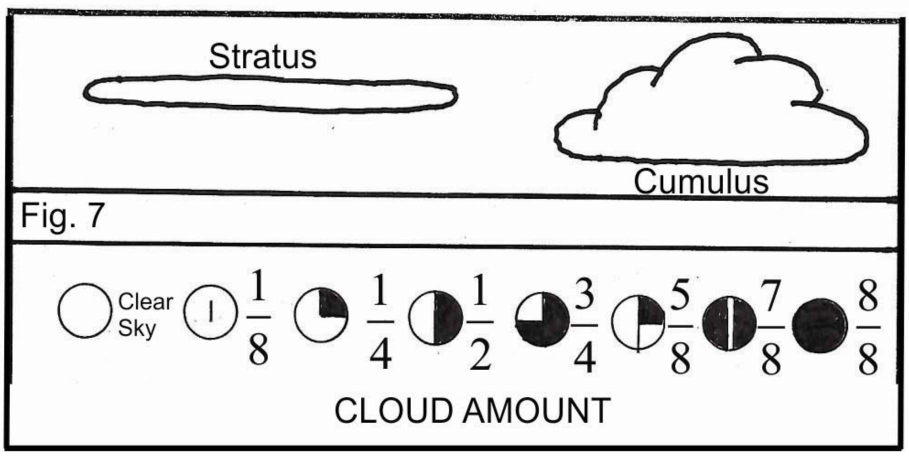



**Fig. 7**

On the basis of height.

a) High clouds - 6 km. - 12 km.
   1) Cirrus
   2) Cirrostratus
   3) Cirrocumulus

b) Middle clouds - 2 km - 6 km
   4) Alto stratus
   5) Alto cumulus
   (Alto means middle)

c) Low clouds - below 2 km
   6) Stratus
   7) Cumulus
   8) Strato cumulus
   9) Nimbo stratus
   10) Cumulo nimbus
   (Nimbus clouds are associated with rainfall)

Cumulonimbus cloud represents Thunderstorm and produces hail stones. This cloud has great vertical extent.

Cumulus and altocumulus clouds represent fair weather condition. The amount of cloud cover in the sky is expressed in eights or oktas, on the weather maps prepared by (IMD) Indian Meteorological Department - Indian Daily Weather Report (IDWR). An imaginary line drawn on weather map to represent having equal degree of cloudiness is known as isonephs.

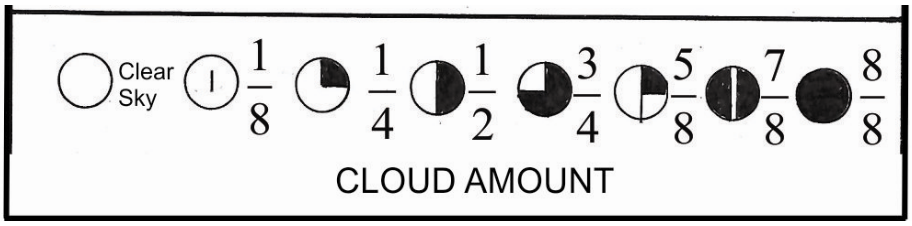



**Fig. 8**

**7) Sunshine :**

Intensity and duration of sunshine is measured at the Meteorological station with the help of Campbell - stokes sunshine recorder or modern sunshine sensors. The amount of sunshine received at a particular place is determined by its latitudinal location, season, Revolution and Rotation of the earth. People in the temperate region prefer sunshine as they get less amount of sunshine. They go to Meteterranean region for sun bath.

People in the tropics are not much interested in sunshine as they get it in ample amount. Sunshine is very useful for plants - Primary producers in the food chain- prepare their food in the pressure of sunshine - photosynthesis.

Solar radiation helps in various processes like evaporation in weather & climate.

Some industries like salt making, drying etc. are dependent on solar radiation.

Colour of our skin is also related to the sunshine received in that region - Nigro - Black - more sunshine.

Solar radiation can be used for the production of electricityusing solar panels.

**Climatic Controls :**

We have studied weather elements before understanding climatic controls, Let us try to understand difference between elements and controls.

Elements of weather and climate are the essential elements without which we will not be able to understand weather / climate properly climatic controls affect weather & climate. They are responsible for changes in climate. These are additional factors but not essential. (e.g. water is essential element for our survival. Our life depends on water.

Wine is not essential element for our survival but wine can control behaviour of a person.

**Climatic controls :**

1) Latitude
2) Altitude
3) Distance from sea
4) Ocean currents
5) Wind and air mass
6) Mountain barrier / slope
7) Nature of ground surface - soil & vegetation
8) Atmospheric disturbances - storm

**1) Latitude :**

Solar rays are vertical in the tropical belt. These vertical rays travel through shorter distance of the Atmosphere, and are concentrated over a smaller area and so vertical rays produce more heat.

Solar rays are oblique in Temperature belts and polar regions. Atmosphere contens microscopic particles - Aerosols. These are concentrated more in the lower layer of the atmosphere. These aerosols offer resistance to the incoming solar radiation by reflection, absorption, diffusion & scattering. The resistance offered by these processes is about 12 time more in the case of oblique rays than the resistance offered to vertical rays.

Hence the amount of solar radiation reaching Temperate & polar region is reduced considerably.

Oblique rays spread over larger area and hence heat gained per unit area is less in the case of oblique rays than the vertical rays.

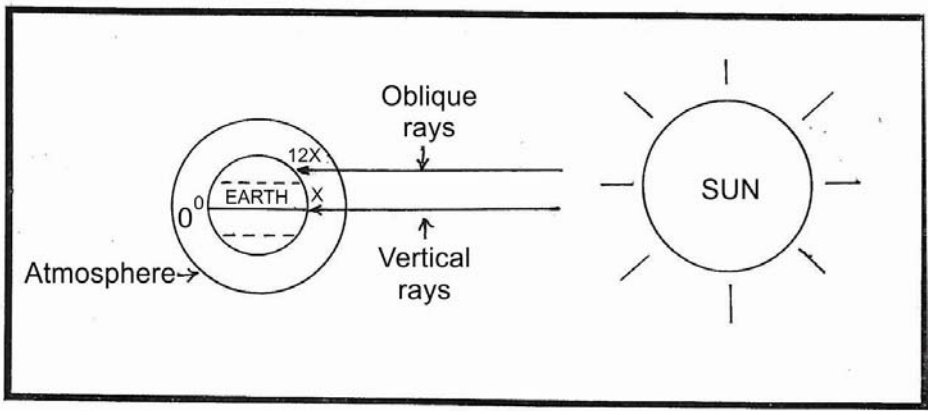



**Fig. 9**

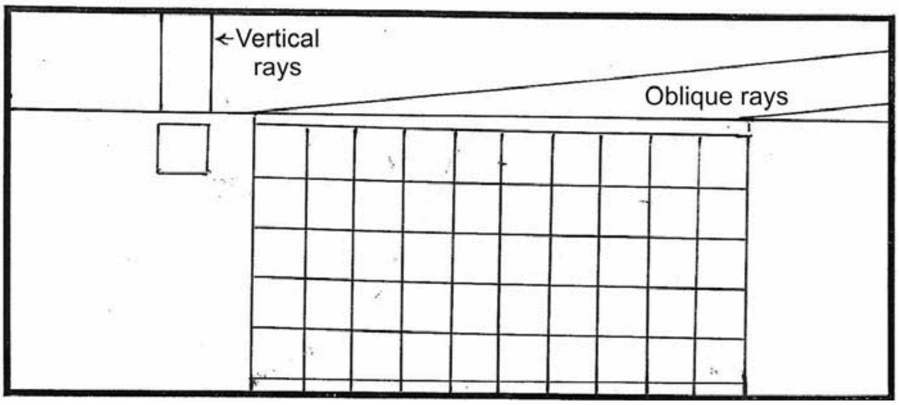



**Fig. 10**

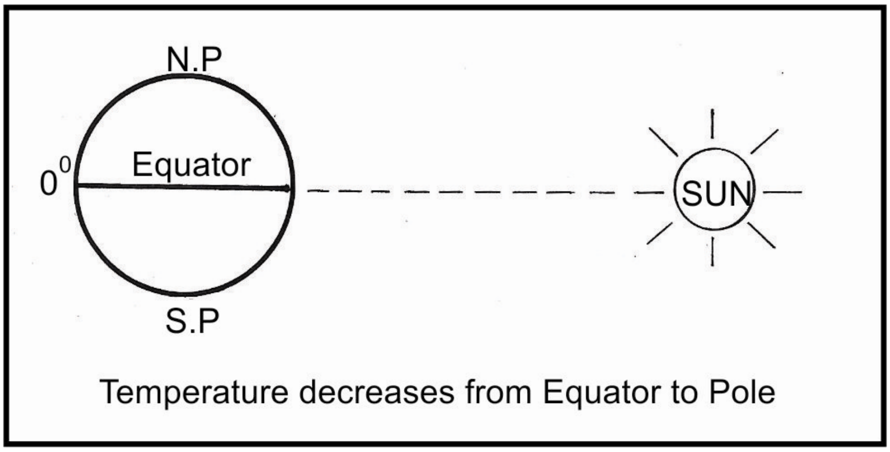



**Fig. 11**

**2) Altitude :**

Incoming Solar radiation - Insolation reaches Earth's surface without much obstruction. Earth's surface is heated. It emits heat in the form of longwave radiation, which is absorbed by the green house gases like carbon dioxide, water vapour etc. which are in the lower layer of the atmosphere, near to the earth's surface. Hence atmosphere is heated from below from earth's surface. As we move to higher altitude temperature decreases. The normal rate of decrease in temperature is termed as N.L.R. - Normal Lapse Rate. Which is $6.5^0$C per km.

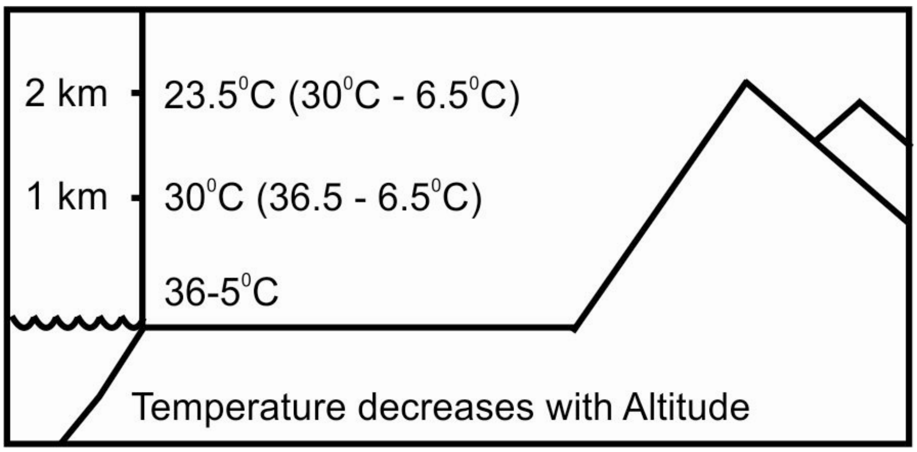



**Fig. 12**

**3) Distance from sea :**

The range of temperature is less near to the coastal areas, it is more away from the sea in the interior part of the continent. This phenomenon is termed as continentality.

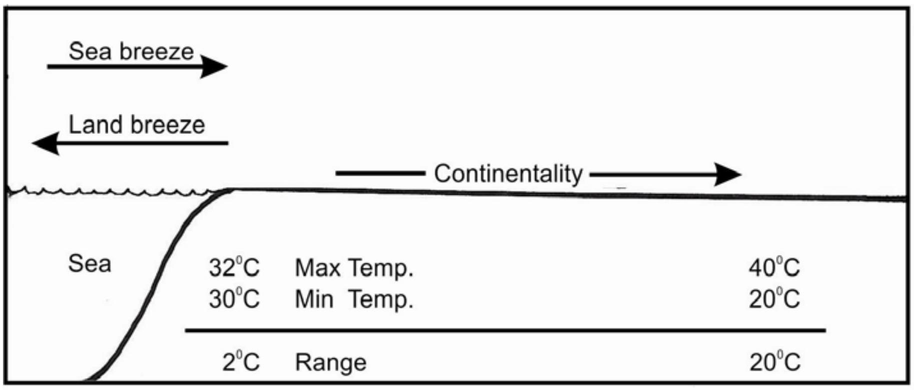



**Fig. 13**

The specific heat of water is five times more than the specific heat of land. Hence water requires more time for heating. Water evaporates & so heat is lost to atmosphere. Water is transparent and hence solar radiation penetrates deep in the water. Heat spreads over larger mass of water so the heat gained by per unit of water is less water is mobile due to tides, waves & currents. Hence water is heated slowly but water retains its heat for the longer period of time.

On the other hand land is not transparent, it is not mobile & so as solar radiation is able to heat upper surface of land much quickly.

During day time temperature of land is more than the water of sea. During night time temperature of water is more than the temperature of land.

Land breeze and sea breeze develop in the coastal areas. These winds exchance heat and hence the range of temperature is less in the costal area. As there is no moderating influence of water / sea at the interior part of the continent. Interior part of the continent have higher or more range of temperature.

This phenomenon is termed as continentality.

**4) Ocean currents :**

Ocean currents are of different types. Cols ocean currents like Labrador reduce temperature of the adjoining areas. Newfoundland and Grand Bank. This current brings down icebergs along with it. These icebergs cause hinderances in navigation. Dense fog is produced near Newfoundland as this cold Labrador current meets Warm Gulf stream current.

Fog is also formed to the east coast of Japan due to convergence of Oyashio - cold current and Kuroshio - Warm current. This fog is dangerious for navigation.

Due to the impact of warm ocean current - Gulf stream the coastal areas and ports of western Europe remain ice-free throughout the year. But the ports situated in the same latitude, north-east coast of Canada re frozen for many months due to cold Labrador current.

**5) Wind and air mass :**

Winds are classified as

a) Global or Planetary
b) Seasonal
c) Local

**a) Global or Planetary wind :**

**1) Trade winds :**

- These winds provide rain to the eastern margin of the continents.
- These winds are unable to provide rain to the Western margins of the continents. Hence western of the continents. Hence deserts are found at Western margin of continents. These are known as Trade Wind deserts.
- Trade winds are associated with cyclone and depressions.

**2) Westerlies :**

- Westerlies are associated with the changing nature and accompanying changing weather.
- These winds give rainfall almost throughout the year in Western Europe
- Westerlies play an important role in the balance of heat at global level by carrying warm equatorial water and air to the temperate region.

**b) Seasonal or Periodic wind :**

Monsoon winds give rainfall in the areas of Monsoon region. These winds have great influence on the weather & climate of this region.

**c) Local winds :**

- Land & sea breezes exchange heat between land and sea / water. Hence coastal areas have low range of temperature.
- ‘Loo’ is hot and dry local wind experienced in the northern part of India during summer, often cause heat waves.
- Hot local winds increase temperature

  Chinook - N. America
  Fohn - Europe

**Air Masses :**

Air masses are huge mass of air having uniform characteristics like temperature, humidity etc. These characteristics are decided by the region in which air masses originate. e.g. Air masses originated in the polar region are cold, having less temperature. When such air mass moves over area more temperature, it reduces temperature of that area.

On the other hand Warm airmass increases temperature of the cool region.

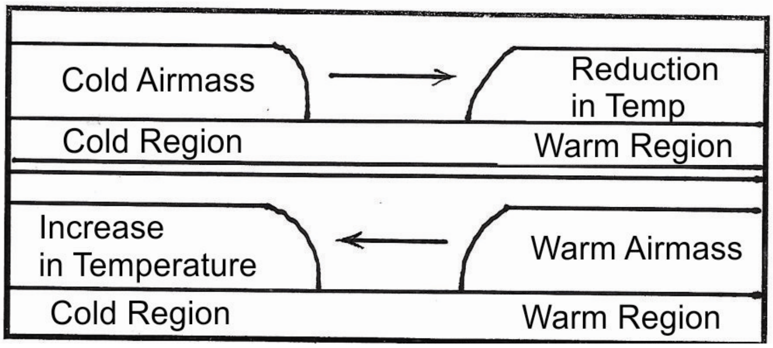



**Fig. 14**

**6) Mountain Barrier / slope :**

Mountain barriers have great impact on the weather & climate of the region. e.g. Western Ghat - Sahyadri hill range parallel is along the west coast of India / Maharashtra. Hence the western part of this mountain barrier - Konkan region receives heavy rainfall during monsoon season bet the eastern part of this mountain barrier Sangli, Satara - is in the rainshadow zone where amount of rainfall is very less.

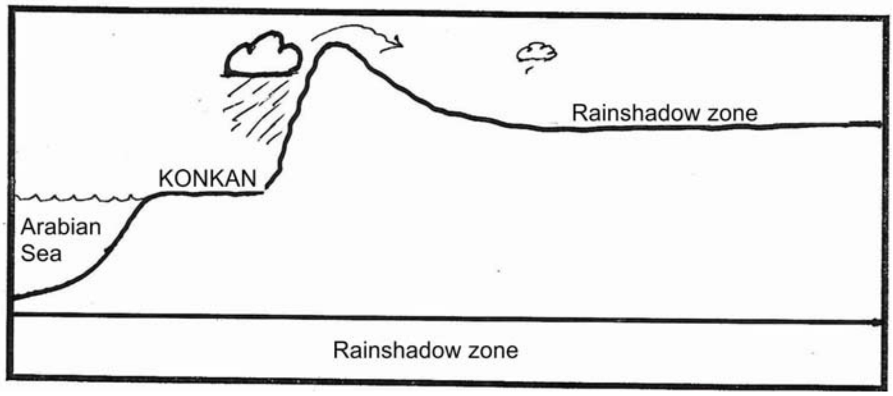



**Fig. 15**

Himalaya also acts as mountain barrier for Monsoon winds. These winds are obstructed by Himalayan Hill ranges & give more rainfall to India. Agriculture in India is totally supported by the water supply received through monsoon.

Himalayan hill ranges also help India by obstructing cold winds coming from the north.

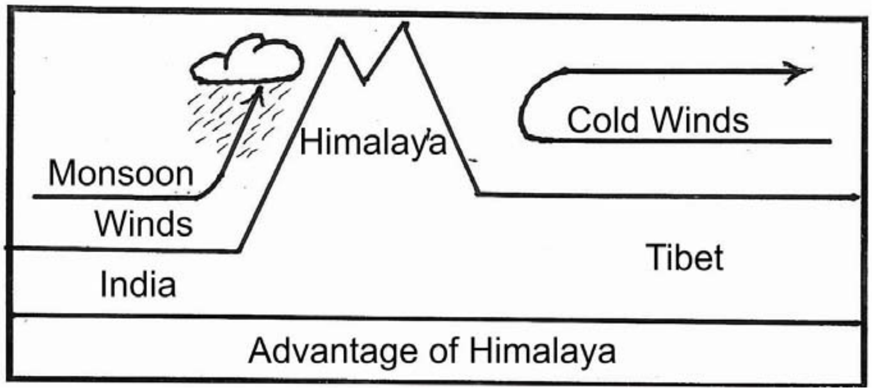



**Fig. 16**

Aspect effect - Effect of slopes South facing mountain slopes in the temperate regions of Northern Hemisphere receive more sunshine than the north facing slopes.

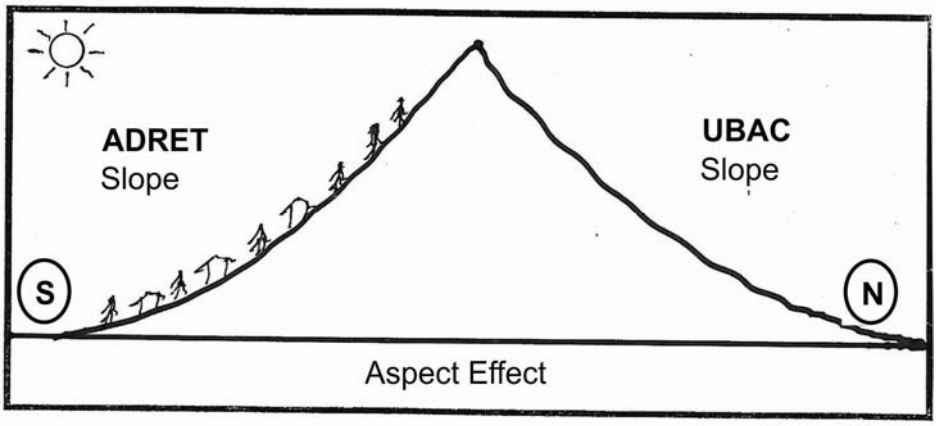



**Fig. 17**

The sunny - south facing slopes are warm and hence more vegetation and settlements are found on these slopes. These slopes are known as Adret slope.

The north facing slopes which do not receive much sunshine are termed as Ubac Slope.

It is termed as aspect effect.

**7) Nature of ground surface - soil & vegetation :**

A part of solar radiation (Insolation) is reflected back without using it. It is termed as Albedo.

Albedo depends upon the nature of ground surface. e.g.

Abedo is about 90% for the ice or snow covered surface, but it is only about 8 - 14% for the black soil.

Albedo for different types of surfaces is as follows.

| Surface | Albedo % | | Surface | Albedo % |
|---|---|---|---|---|
| Forest | 5 – 10 | | Snow | 90 |
| Black soil | 9 – 15 | | Sand | 30 |
| Wet ground | 10 | | Thick cloud | 80 |
| Dry ground | 15 – 25 | | Thin cloud | 50 |
| grass | 15 – 40 | | Water | 10 |
| Albedo of different type of surfaces. | | | | |

Due to dense cover of vegetation albedo of Forest is only 5 - 10% which means about 90% of the insolation is utilised by the forest.

**8) Atmospheric disturbances - cyclones :**

High velocity winds with heavy rainfall affect human life and weather / climate of that region.

❖❖❖❖

# 2

# INSOLATION AND TEMPERATURE

**Unit Structure**



## 2.0 OBJECTIVES:

By the end of the module, the learner will be able to -

- Explain the concepts of Insolation and temperature.
- Explain the factors affecting the distribution of insolation and temperature.
- Explain the horizontal and vertical distribution of insolation and temperature.
- Differentiate between insolation and temperature.

## 2.1 INTRODUCTION:

Insolation and temperature are the two important components of the study of climatic phenomena. All climatic phenomena include, composition and structure of the atmosphere; atmospheric pressure and general atmospheric circulation; formation of the local and seasonal winds; spatio-temporal patterns of atmospheric humidity, condensation, and precipitation; formation of air masses, frontogenesis, cyclones, & anticyclones; and climate change and global climatic problems are directly or indirectly related with the distributional patterns of insolation and temperature. In this chapter, the author has attempted to analyze the insolation and temperature and its distributional pattern with the view to create a base for the analysis of climatic phenomena. Some parts of the climatic phenomena can be studied in the fourth coming chapters.

## 2.2 INSOLATION AND HEAT BALANCE OF THE EARTH:

The insolation and heat balance of the earth and atmosphere are directly interrelated with each other. The earth receives energy from solar radiation, gravity,and endogenetic forces whereas the atmosphere receives energy from the sun and theearth. The distribution of solar energy on the surface of the earth varies with the location and the convectional and advocational forces play a significant role in the heat balance on the surface of the earth and the atmosphere.

The solar radiation, gravitational energy, and endogenetic forces coming fromwithin the earth are the three basic sources of energy to the Earth and the biosphere but solar radiation is the most significant source of terrestrial heat energy. The formation of various relief features is a result of endogenetic forces, the gravitationalforce controls the downslope movement of water and other related material whereas Solar Energy controls all the climatic and environmental phenomena on the surface of the earth (Singh, 2005).

### A. CONCEPT OF INSOLATION:

All the exogenetic forces on the surface of the earth are driven by solar energy. The energy which is received from the Sun is called solar energy. There are various definitions of solar energy given by various authors. Some of the important definitions of solar energy are given below.

1. According to G. T Trewartha, the radiant energy received from the Sun, transmitted in a form analogous to short waves, and traveling at a speed of 300000 km per second is called solar radiation for insolation (Singh, 2005).

2. Insolation is the total amount of solar energy received at a particular location during a specified time, often in units of kWh/(m2 day) (University of Calgary, 2020).

3. Insolation refers to the quantity of solar radiation energy received on a surface during an amount of time, expressed in kWh/ $m^2$ (S.G.Bowden, 2019).

4. According to Critchfield, the radiant energy from the sun that strikes the earth is called insolation.

5. Kendrew defines the sun as constantly radiating into space, the complex of energy which is called insolation.

6. The solar energy received at the surface of the earth or the atmosphere is called insolation.

7. In short, the energy radiated from the photosphere of the sun and after travelingthe distance of 152 billion km received at the Earth's surface or atmosphere which controls the atmospheric and environmental components is called insolation. The earth receives only ½ billionth part of the radiated energy from the surface of the sun i.e., the photosphere and it is equivalent to 23 trillion horsepower.

## B. THE DISTRIBUTION OF INSOLATION:

The amount of solar radiation or the Solar Energy received on a unit area of the surface facing the sun at an average distance between the sun and the earth is more or less constant and is called a solar constant. On average, the Earth's surface receives the radiation of 2-gram calories per square centimeter per minute. But the amount of insolation received at the Earth's surface decreases from the equator towards the poles. Also, there is spatial and temporal variation in the distribution ofinstallation on the surface of the earth and atmosphere. The relative position of the earth changes with summer and Winter solstice it is the reason that there is seasonal variation in the distribution of insolation. Three zones may be demarcated regardingthe distribution of Solar energy on the surface of the earth as detailed below.

### 1) LOW LATITUDE ZONE/ TROPICAL ZONE

The zone which extends between the Tropic of Cancer and Capricorn is included in the low latitude zone. It is also called the tropical zone because all the places in the region receive the maximum and minimum energy twice a year.

### 2) MIDDLE LATITUDE ZONES

The zone extending between 23 $½^{O}$ and 66 $½^{O}$ latitudes in both the hemisphere is called the mid-latitude zone. The northern hemisphere receives the maximum energy during the summer solstice and minimum energy during the wintersolstice. The situation is reversed in the southern hemisphere. All the places or receive energy throughout the year but the seasonal variation increases with increasing latitudes.

### 3) HIGH LATITUDE ZONES

The region extending beyond 66 ½$^{O}$ north and south latitude is called the high latitude region. It is also called the polar region. Every place receives the maximum and minimum insolation once a year but there are some places where insolation is absent for some days. The number of absent days of solar insolation increasestowards the pole.

## C. FACTORS AFFECTING THE DISTRIBUTION OF INSOLATION:

Various components affect the spatial and temporal distribution of insolationon the surface of the earth. The amount of solar energy received at the surface of theearth is decreasing from the equator towards the pole in both the hemispheres. Also, there is a seasonal variation in the distribution of solar energy on the surface of the earth and atmosphere. The variation is a result of the angle of the sun's rays, length of the day, changing distance between the Earth and the Sun, sunspots, atmospheric effects, etc. In the upcoming paragraphs, the author has attempted to analyze the factors affecting the distribution of insolation.

### 1. The angle of the sun rays

The amount of insolation to be received at a place is controlled by the angle between the rays of the sun and the tangent to the surface of the earth at a given place.The sun rays are vertical at the equator and become more oblique towards poles in both the hemisphere and it affects the proportion of insolation received at the unit area. The given below explanation and the diagrams are worth explaining the relationship between the angle of sun rays and the amount of insolation received at Earth's surface.

Vertical rays are spread over the minimum area of the Earth’s surface and heat the minimum possible area and the insolation received per unit area increases. Whereas oblique rays spread over a larger area of the Earth’s surface andhence the amount of energy received decreases for the unit area. Figure 2.1 provides an idea about how the angle of sun rays is affecting the reception of insolation per unit area.

Another aspect of vertical and oblique sun rays is vertical sun rays travel for shorter distances through the atmosphere as compared to oblique sunrays. It affects the loss of insolation through atmospheric effects such as reflection, scattering, and absorption. In short, the sun rays traveling for larger distances through the atmosphere lose more insolation through atmospheric effects and vice versa (Figure2.2).

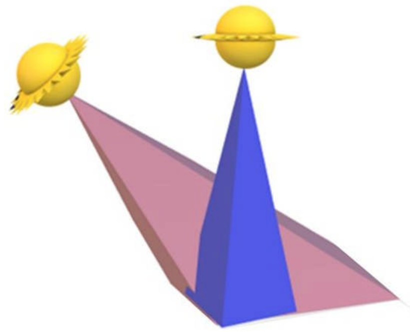


**Figure 2.1**

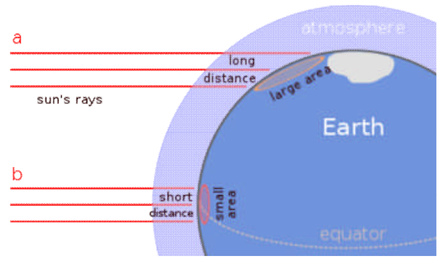



**Figure 2.2**

## 2. The length of a day

The earth is tilted by 23 ½$^{O}$ towards the north and the earth revolves around the sun in an elliptical manner. These two components are responsible for the formation of the seasons and the resulting variation in the length of day throughout the year. The length of a day varies from latitudes, seasons, locations, physiographic conditions, etc. There is a positive correlation between the length of a day and the amount of insolation received at a place. e.g., During the summer solstice, the lengthof a day is larger in the northern hemisphere and it is a reason that the northern hemisphere receives a higher amount of insolation during summer solstice than the winter. Whereas the situation is reversed in the southern hemisphere. It means the larger the length of a day higher the amount of insolation received per unit area and vice versa. The length of a day directly affects the proportion of insolation receivedper unit area at any place. Of course, it does not apply to the polar areas because though the polar area has a length of the day of more than 24 hours the amount of insolation received per unit area is very less due to the higher obliqueness of sunrays.

## 3. The distance between the Earth and the Sun

Due to the elliptical revolution of the earth around the sun, the distance between the earth and the sun is changing during the year. The average distance between the earth and the sun is 93 million miles (149 million kilometres). At the time of perihelion, the Earth is nearest to the sun on January 3, and the distance between the Earth and Sun is 147 million kilometres. On July 4, i.e., at the time of aphelion, the earth is at the farthest distance from the sun and the distance is 152 million kilometres. The distance between the earth and the sun affects the amount of insolation received per unit area on the surface of the earth. As per the rule at the time of the perihelion earthshould receive the maximum energy and at the time of aphelion, the earth should receive the minimum energy. But due to the presence of prevailing conditions of winter and summer this change has not being extremely experienced. Figure 2.3 gives information about the changing distance between the Earth and the Sun.

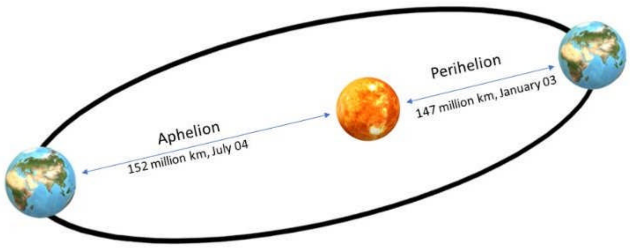



Figure 2.3

**4. Sunspots**

The dark areas within the photosphere of the sun and surrounded by the chromosphere are called sunspots. Parts are the result of periodic disturbances and explosions in the solar surface. The number of sunspots varies from year to year. Studies reveal that variation in the number of sunspots is cyclic in nature and each cycle is completed in 11 years. It seems that there is a positive correlation between the number of sunspots and the amount of insolation radiated from the Photosphere. in short at the time of the increased number of sunspots the earth receives maximum insolation and vice versa (Figure 2.4).

Figure 2.4

**5. The atmospheric effects**

The electromagnetic radiation transmitted from the Photosphere of the Sun and received at the surface of the Earth is traveling an average distance of 149 millionkilometres. When it reaches the earth's atmosphere the energy is diluted by the atmospheric processes which include reflection, scattering, absorption, etc.

**Reflection:**

If we consider the incoming shortwave radiation as hundred percent, out of that on average 27 % of incoming shortwave radiation is reflected by the clouds, 2% by the Earth's surface, and 6% by the scattering. On average 35% of the incoming solar radiation is reflected and it is called albedo. Also, the rates of reflection, scattering, and reflection vary from place to place.

**Scattering:**

Various dust particles and water vapor present in the atmosphere are responsible for the scattering of incoming solar radiation. Approximately 23% of incoming shortwave radiation is scattered in the atmosphere and out of which 6% isreflected and 17% is absorbed in the Earth's surface.

**Absorption:**

The atmosphere directly absorbs 14% of incoming shortwave solar radiation.Also, the rate of absorption varies from place to place and season to season. Figure 2.5 provides detailed information about the atmospheric effects and the amount of insolation received at Earth's surface.

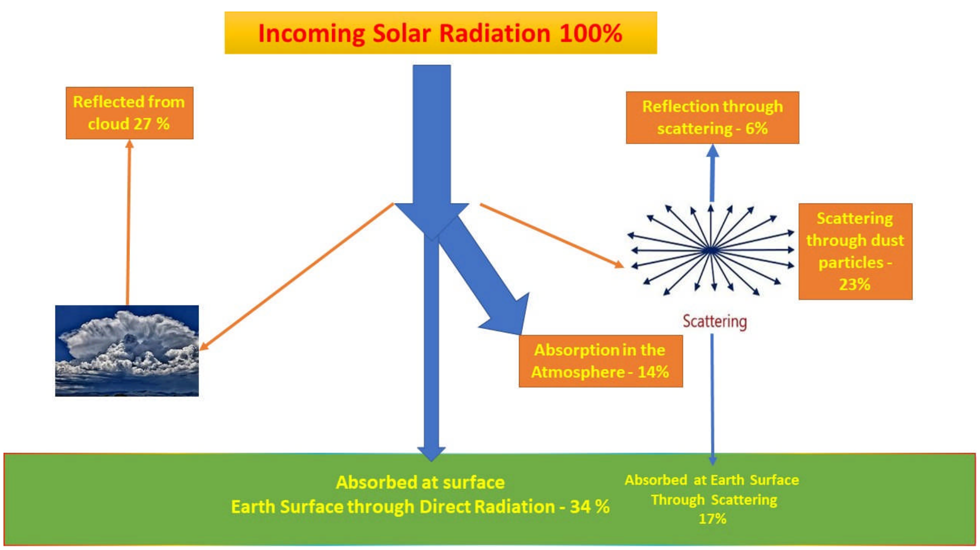



Figure 2.5

## D. HEAT BALANCE

The total solar radiation reaching a horizontal surface on the ground is called Global radiation. It comprises the direct shortwave radiation from the sun and diffuseradiation scattered by the atmosphere. The earth receives energy from the sun through incoming short-wave radiation and received energy sent back to the atmosphere andspace through long-wave terrestrial radiation. Always there is variation between theamount of incoming shortwave radiation received at a place and the energy sent back through terrestrial radiation. The various atmospheric processes try to balance between the gain and loss of energy. The heat budget of the earth and the atmosphere displaying statement of receipt of solar radiation by the atmosphere and the earth surface and the loss of energy by the earth and the atmosphere known as terrestrial radiation is also called energy balance of the earth and the atmosphere or global radiation balance.

The average temperature of the earth remains more or less constant because the incoming solar radiation and the outgoing Terrestrial radiation are almost constant. It has already been mentioned that Earth receives a mere ½ billionth parts of solar radiation. Even this small proportion of adsorption, reflection, and scattering by the earth's atmosphere and its surface. It is estimated that only half of the solar insolation received at the top of the atmosphere reaches the earth's surface. George Kundal, Moller, Howard Critchfield, Strahler, and Trewartha attempted to analyse the heat balance of the earth and atmosphere. In the forthcoming paragraphs, the author has attempted to analyse the heat balance of the earth and atmosphere given by Trewartha.

**Incoming Shortwave Radiation:**

The earth receives most of its energy from the sun through shortwave solar radiation. The amount of insolation received at the earth's surface is ½ billionth part of the radiated energy from the photosphere of the Sun. Though the amount received at the earth's surface is very less as compared to radiated energy from the photosphere of the sun, the earth receives 23 trillion HP solar energy. If we consider the shortwave radiation received at the outer surface of the atmosphere is 100%, 23% incoming shortwave radiation scattered, out of which 6% sent back to space and 17% sent to the Earth surface. 27% of the incoming shortwave radiation is reflected by the clouds and 2% is reflected by the Earth's surface directly at the time of receiving. In this way, the amount of total reflected shortwave radiation is 35% and it is called an albedo. 14% of incoming shortwave radiation is absorbed in the atmosphere and 34% of the incoming shortwave radiation is absorbed in the earth's surface directly whereas 17% of the incoming shortwave radiation is observed at the Earth's surface through scattering. Table 2.1 and Figure 2.6 provide detailed information about the incoming solar radiation and the processes of absorption and scattering and reflection.

**Table: 2.1 Incoming shortwave solar radiation (after Trewartha)**

| Sr. No. | Component | Amount of Solar Radiation | Total |
|---|---|---|---|
| ***Total energy reaching the top of the atmosphere*** | | | **100 %** |
| **1** | **The amount of solar radiation lost during its passage through theatmosphere** | | **35 %** |
| | Reflected by the clouds | 27 % | |
| | Reflected ok by the earth’s surface | 2 % | |
| | Reflected through the scattering | 6 % | |
| **2** | **The amount of solar radiation absorbed in the atmosphere during itspassage through the atmosphere** | | **14 %** |
| **3** | **The amount of solar radiation absorbed at the earth surface** | | **51 %** |
| | The incoming shortwave radiation received by directradiation | 34 % | |
| | The incoming shortwave radiation received through thescattering | 17 % | |
| | | **Grand Total** | **100 %** |
| | | **Balance** | **0%** |

**Incoming Shortwave Radiation**

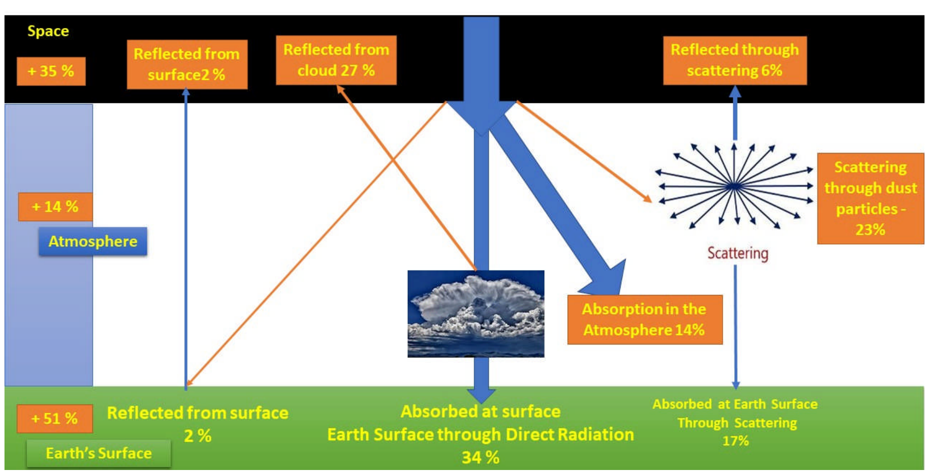



Figure 2.6

**Outgoing Terrestrial Radiation:**

The solar radiation received at the earth's surface is converted from shortwave to longwave radiation. The amount of energy received at the Earth's surface is 100% sent back to space through the process of radiation, evaporation, evapotranspiration, convection, turbulence, etc. The amount of energy lost through the process of radiation, convection, and evaporation through longwave terrestrial radiation is 23%, 9 %, and 19 % respectively. Initially, the energy is transferred from the earth's surface to the atmosphere and then to space. Table 2.2 and figure 2.7 give an insightinto the loss of energy through long without restaurant radiation.

**Table: 2.2 Outgoing Terrestrial radiation (after Trewartha)**

| Sr. No. | Component | Terrestrial radiation | Total |
|---|---|---|---|
| **A: Heat Budget of the Earth's Surface** | | | |
| **1** | **The amount of energy received at the earth's surface** | | **51 %** |
| | Terrestrial radiation lost through radiation | 23 % | |
| | Terrestrial radiation lost through convection and Turbulence | 9 % | |
| | Terrestrial radiation lost through evaporation | 19 % | |
| | **The amount of terrestrial radiation lost from the earth's surface to theatmosphere** | | **51 %** |
| | **The energy at the balance at the Earth's Surface** | | **0 %** |
| **B: Heat Budget of the Atmosphere** | | | |
| 1 | The amount of solar radiation absorbed in the atmosphere during itspassage through the atmosphere | | 14 % |
| 2 | The amount of outgoing terrestrial radiation absorbed in theatmosphere during its passage through the atmosphere to space | | 34 % |
| | **The amount of energy credited to the atmosphere throughshortwave and longwave radiation** | | **48 %** |
| | **The amount of energy sent to space through long-wave terrestrialradiation** | | **48 %** |
| | **The energy at the balance in the Atmosphere** | | **0 %** |

| | **B: Overall Heat Budget** | |
|---|---|---|
| A | The energy reflected through atmospheric effects | 35% |
| B | The amount of energy sent to space through long-wave terrestrialradiation | 48 % |
| C | The amount of outgoing terrestrial radiation directly sent to space | 17 % |
| | **The Loss of Energy** | 100% |
| | **The energy received through shortwave radiation** | 100% |
| | **Net Balance** | 0 % |

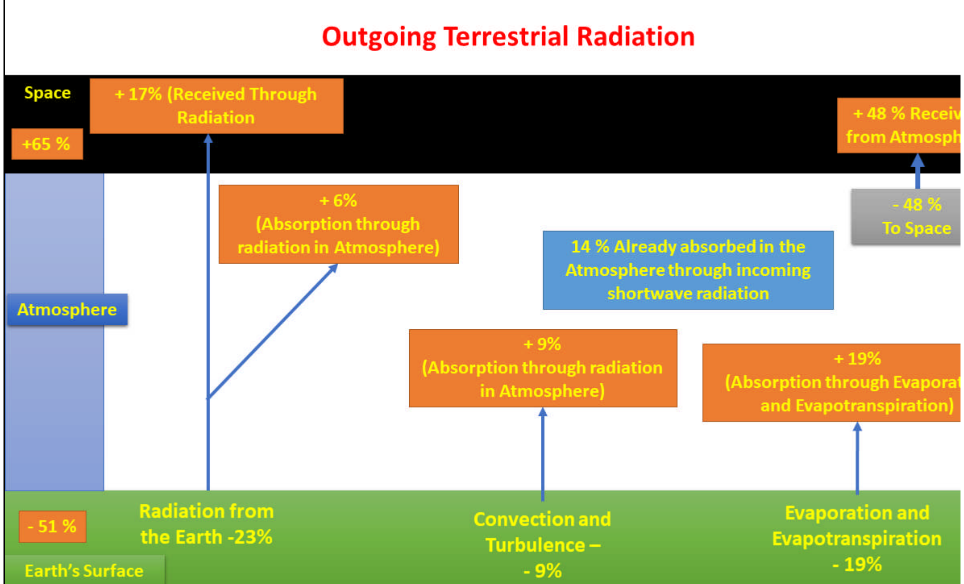



Figure 2.7

Hypothetically the net energy balance between incoming shortwave radiationand outgoing terrestrial radiation is 0%. But the same principle does not apply to allthe places on the earth's surface. There are some places on the surface of the earth which have an energy surplus and some places have an energy deficit. The advection movement of the air plays a significant role in the horizontal balancing of heat.

## 2.3 ATMOSPHERIC TEMPERATURE:

The earth receives energy from the sun, gravitational force, and endogenetic sources, but the sun is the major source of energy for the earth and various geo-bio- chemical processes on the earth's surface. 'Atmospheric temperature is a function ofthe modification of solar radiant energy by air, clouds, land, sea and other water surfaces' (Macdonald, 2007).

The atmospheric temperature depends upon the rate of heating and cooling ofthe atmosphere. The heating and cooling of the atmosphere are accomplished through direct solar radiation and the transfer of energy from the earth through the processes of conduction, convection, and radiation. Generally, heat and temperature are taken synonymously by common people but they are different. Heat is a form of energy whereas temperature is the measurement of the degree of hotness or coldness of anysubstance. Simply we can say the measurement of atmospheric heat energy in terms of Celsius, Fahrenheit, and Kelvin is called atmospheric temperature. The atmospheric temperature is a result of the amount of insolation received at Earth's surface and its conversion from shortwave to longwave radiation. Always there is a positive correlation between the amount of insolation received at a place and the temperature of that place. The Solar Energy received by the earth's surface is converted into heat energy in the form of sensible heat and is temporarily stored.

The atmosphere receives heat energy through incoming solar radiation and outgoing terrestrial radiation. 14 % of the incoming solar radiation is absorbed in the atmosphere by the greenhouse gases, dust particles, and water vapour present in the atmosphere. Also, the atmosphere is heated through the processes of ground radiation, conduction, convection, turbulence, evaporation, and adiabatic processes. The air is a poor conductor for heat transfer. Hence, the atmosphere gets more heated through ground radiation, evaporation, convection, and adiabatic heating.

In the forthcoming paragraphs we are going to analyse fundamental concepts related to atmospheric temperature, horizontal and vertical distribution of atmospheric temperature, and inversion of the temperature, also we will try to correlate various atmospheric activities with the distribution of temperature in short.

*Did you Know*

*Temperatures is Measured in degree Celsius, degree Fahrenheit and degreeKelvin. Following equations are used to convert the*

1. *Celsius to Fahrenheit*
2. $$°F = 1.8 \times °C + 32°F$$
   $$°C \quad \frac{\phantom{xx}}{1.8}$$
3. *Celsius to Kelvin*
4. $$° \quad = °C + 273.75$$

## A. CONCEPTS RELATED TO ATMOSPHERIC TEMPERATURE

### a) MAXIMUM TEMPERATURE:

The highest temperature recorded during the 24 hours is called the daily maximum temperature. Generally, the maximum temperature is recorded between 2 to 4 p.m. The highest maximum temperature is recorded during the summer season in a year. The official highest recorded temperature is now 56.7°C (134°F), which was measured on 10 July 1913 at Greenland Ranch, Death Valley, California, USA.

### b) MINIMUM TEMPERATURE:

The lowest temperature recorded within 24 hours is called minimum daily temperature. The minimum temperature is very from day to day and season 2 season. Generally, the winter season records the lowest minimum temperature in a year. The lowest daily minimum temperature is recorded between 4 to 6 a.m. According to Wikipedia, the lowest natural temperature ever directly recorded at ground level on Earth is −89.2 °C (−128.6 °F; 184.0 K) at the Soviet Vostok Station in Antarctica on 21 July 1983 by ground measurements.

### c) LAG OF TEMPERATURE:

There is no coincidence between the time of maximum and minimum amount of insolation received from the sun and maximum and minimum temperatures of the air. This is called the lag of temperatures. For example, the highest amount of insolation is being received around noon where has the maximum temperature is recorded between 2 to 4 p.m. In other words, the time required to convert the insolation into temperature is called the lag of temperature.

### d) MEAN TEMPERATURES:

The average of the maximum and minimum temperature within 24 hours is called mean daily temperature. Similarly, the average of daily maximum and minimum temperature is called mean monthly temperature, and an average of the monthly maximum and minimum temperature is called mean annual temperature.

### e) RANGE OF TEMPERATURES:

The difference between the highest and the lowest temperature per unit time at the local, regional, or global level is called the range of temperature. The range of temperature can be calculated as a diurnal range of temperature, monthly range of temperature, and annual range of temperature. The range of temperature varies from place to place. For example, Nagpur has the highest range of temperature as compared to Mumbai.

## B. THE DISTRIBUTION OF ATMOSPHERIC TEMPERATURE:

The spatial and temporal distribution of temperature is very significant because the different types of weather, climate, vegetation zones, animal and human life, etc. basically depend on the distribution of temperature whether horizontal or vertical (Singh, 2005). The Global mean annual temperature was $13.73^{O}$ C in the 1800s which rose to $14.51^{O}$ C in the 2000's decade. There is spatial and temporal variation in the distribution of atmospheric temperature on the earth's surface. The variation in the atmospheric temperature is a result of various factors related to the earth and the sun. In the forthcoming paragraphs, the author has attempted to analyze the factors affecting the distribution of atmospheric temperature.

## C. FACTORS AFFECTING THE DISTRIBUTION OF TEMPERATURE:

The horizontal and vertical distribution of atmospheric temperature is controlled by the latitude, altitude, distance from the coast, nature of land and water, nature of the ground surface, prevailing winds, ocean currents, and cloud cover.

### a) LATITUDES:

The sun is the major source of energy for the Earth's surface and obviously, the distribution of temperature on the Earth's surface is directly controlled by the distribution of insolation on the earth's surface. The sun rays are more vertical at the equator and they are becoming more oblique towards the poles. It is the reason that the low latitude region receives more energy and the high latitude region receives less energy. Because of this, the low latitudes record the highest temperature, and high latitudes or record the lowest temperature. The temperature decreases from the equator towards the poles and the rate of decrease of temperature with increasing latitudes is varying from the equator towards the poles.

### b) ALTITUDE:

The atmosphere receives the energy from the incoming short-wave radiation as well as outgoing terrestrial radiation. But the atmosphere is more heated by the processes of conduction, convection, turbulence, evaporation, and the process of adiabatic heating. The process of heating the atmosphere through ground radiation is directly controlled by the density of the air. The density of the air decreases with increasing elevation it is the reason that the temperature also decreases with increasing elevation. Generally, the rate of decrease in temperature with increasing height is $6.5^{O}$ centigrade and it is called a normal lapse rate. For example, Kelshi and Mahabaleshwar are located on the same latitude but there is a difference between the temperature of both places. The temperature of Kelshi is greater than the temperature of Mahabaleshwar.

### c) DISTANCE FROM THE SEA:

The differential heating of land and water directly affects the temperature of theair. In the coastal areas, the land and sea breezes reduce the range of temperature inthe region. Opposite to this, the interior places located at the same latitude record a higher degree of range of temperature. For example, the range of temperature of Nagpur is much higher than the range of temperature in Mumbai.

### d) OCEAN CURRENTS:

Ocean currents influence the temperature of adjacent land areas considerably. The warm currents increase the temperature of the coastal areas on theway whereas the cold currents decrease the temperature of the coastal areas on the way. For example, the temperature of Western Europe is much higher than in Eastern Europe due to the entry of the north Atlantic warm current. Opposite to this the arrival of the Canary current decreases the temperature along the coast of Western Africa.

### e) PREVAILING WINDS:

The prevailing wind conditions directly influence the temperature and it assists in the redistribution of it. Cold summers and mild winters along the windward coastal locations are results of the moderation experience of the oceans. On the other hand, locations on the same latitude or leeward coastal location will have a more Continental temperature regime because the winds do not bring oceanic effect to it. Heatwaves in North India during the summer are an example of the influence of prevailing wind conditions.

### f) NATURE OF GROUND SLOPE:

The ground slope facing the sun is called the onward slope and the shadow region opposite to the onward slope is called the leeward slope. In the Northern hemisphere, the south-facing slope, and in the southern hemisphere north-facing slope is an onward slope and the onward slope receives more solar energy than the leeward slope. Hence the higher temperature is recorded on the onward slope than the leeward slope. For example, the onward slope of Almora City records higher temperature than the temperature on the leeward slope.

### g) NATURE OF LAND AND WATER:

The contrasting nature of land and water surfaces about the incoming shortwavesolar radiation largely affects the spatial and temporal distribution of temperature. This is why even after receiving an equal amount of insolation the land surfaces become warmer than the water bodies during the daytime whereas during the night water bodies are warmer than the land surfaces. The distributional pattern of land andwater bodies affects the distributional pattern of the atmospheric temperature on theearth's surface (Singh, 2005).

### h) NATURE OF GROUND SURFACE:

The nature of the ground surface in terms of colour, vegetation, land-use practices, land-cover, etc. affects the distribution of temperature on the surface of the earth. The snow-covered areas reflect most of the energy received from the sun and hence the net amount of energy received in the area is very low. Whereas the areas covered by wet soil absorb maximum insolation. This is the reason that snow-covered areas record the lowest temperature and the regions with wet soil or sandy surfaces record the highest temperature throughout the year. Generally, sandy surfaces record the highest temperature during the day and lowest during the night. Opposite to this, the wet soil records the lowest temperature during the day and the highest temperature during the night.

### i) CLOUD COVER:

The cloudiness affects the local, regional, and seasonal distribution of temperatures. According to Trewartha, 27 % of the incoming solar radiation is reflected by clouds. Also, clouds play a significant role in the counter radiation of theoutgoing terrestrial radiation. It creates a greenhouse effect and automatically increases the temperature of the area. This is the reason that during the cloudy condition, the atmospheric temperature increases whereas at the time of cloudless condition more terrestrial radiation passes to space through the atmosphere without any hurdle. For example, human beings experience uncomfortable due to increased temperature during cloudy conditions. On the other hand, during the winters, the skyis clear and cloudless, it is the reason that the atmospheric temperature is low.

## D. HORIZONTAL DISTRIBUTION OF THE TEMPERATURE:

The horizontal distribution of atmospheric temperatures can be analyzed according to latitudinal distribution, regional distribution, and seasonal distribution.

### LATITUDINAL DISTRIBUTION:

Temperature decreases from the equator towards the poles and thus low latitudes are characterized by the highest temperature and vice versa high latitudes record the lowest temperature. It is a result of the highest insolation received within the tropics and minimum insolation received in the polar areas. It is interesting to note that the highest temperature of the earth's surface is never recorded at the equator, instead, it is recorded near the tropics of Cancer and Capricorn during northern and southern summers respectively. This anomaly is being observed due tothe following reasons.

## ISOTHERMS & DISTRIBUTION OF TEMPERATURES

The horizontal distribution of temperature over the earth's land-sea surfaces is studied with the help of isotherms. Isotherms are the imaginary lines drawn on the maps joining places of equal temperature reduced to sea level. It is necessary to reduce the actual temperatures of all places at sea level before drawing isotherms. It is, thus, obvious that isotherms do not represent the real temperature of the places through which they pass rather they show the temperature of the places at seal level. This is why the isotherm maps are not useful for farmers because they need the real temperature of a particular place for growing crops. Normally, isotherms run east-west and are generally parallel to latitudes. This trend shows strong control of latitudes on the horizontal distribution of temperature. Generally, isotherms are straight but they bend at the junction of continents and oceans due to differential heating and cooling of land and water. Isothermal lines are more irregular in the northern hemisphere because of the large extent of continents but they are more regular in the southern hemisphere due to the over dominance of oceans. Isotherms are generally closelyspaced in the northern hemisphere but they are widely spaced in the southern hemisphere. The closely spaced isotherms denote a rapid rate of change of temperature and steep temperature gradient. On the other hand, widely spaced isotherms indicate the slow rate of temperature change and low-temperature gradient. On average, isotherms trending from land towards the ocean bend equatorward during summer and poleward during winter. On the other hand, isotherms trending from the oceans to the continents bend poleward during summer and equatorward during winter.

1. The relative position of the earth as compared to the sun changes throughout the year due to the revolution of the earth around the sun and the tilt of the earth by $23.5^{O}$ towards the north. It is a reason that within the equatorial zone demarcatedby 6°N and 6°S latitudes, the sun's rays are near vertical for only 30 days in a year, whereas the sun's rays are near vertical for 86 days in a year within the latitudinal zone of 17.50 and 23.5° in both the hemispheres and hence the zone near the tropics (23.5°) receives the highest amount of insolation resulting into highest temperature.

2. The tropics have almost clear skies for most of the year, it allows to reach more incoming solar radiation to the Earth’s surface and the energy absorbed at the earth's surface generates more outgoing terrestrial radiation which increases the temperature of the tropics.

3. In the equatorial belt more energy is spent on evaporation and convection and also the belt is covered by clouds throughout the year. It is a reason that the average temperature of the equatorial belt is less than in the tropics.

Besides the aforesaid unorthodoxy, mostly temperature decreases from the equator towards the poles. This change of temperature rather than a decrease of temperature poleward is called a temperature gradient or simply horizontal lapse rate. The rate of decrease of temperature (thermal gradient) between the tropics of Cancer and Capricorn is rather low and therefore temperature gradient is insignificant but temperature decreases more rapidly from the tropics poleward and hence temperature gradient becomes steep.

**Seasonal Horizontal Distribution of Temperature**

The isotherms during the months of January and July are taken as representatives for the study of horizontal distribution of temperature during winter and summer seasons respectively because they represent seasonal extremes. As stated earlier, the months of maximum (June, northern hemisphere) and minimum (December, northern hemisphere) insolation do not coincide with the months of hottest and coldest months (July and January in the northern hemisphere) respectively and hence the months of July (hottest in the northern hemisphere and coldest in the southern hemisphere) and January (coldest in the northern hemisphere and hottest in the southern hemisphere) are taken as representatives to describe the seasonal (and also annual) distribution of average temperature. Figs. 2.8 and 2.9 illustrate the distribution of average temperature in July (representing temperature during the summer season) and January (representing temperature during the winter season). The two isotherm maps reveal the following trends:

(1) The months of July and January are warmest and coldest in the northern hemisphere whereas the warmest and coldest months in the southern hemisphere are January and July respectively.

(2) Both the maps demonstrate latitudinal shifts of isotherms following the seasonal shifting of overhead sun but this shifting of isotherms is more pronounced on the continents.

(3) The maximum temperatures in January and July are always recorded on thecontinents. The minimum temperature in January is observed in Asia and North America.

(4) January isotherms suddenly bend poleward while passing through warm portions of the oceans and bend equatorward while passing through the cold portions of the oceans in January in the northern hemisphere while the trendis opposite in July. On the other hand, the isotherms are more or less regular and straight in the southern hemisphere because of the over-dominance of oceans.

(5) The temperature gradient is more pronounced during winter than summer.

(6) The January isotherms denote steep temperature gradients in the northern hemisphere as revealed by their closer spacings (Fig. 4.4) while relatively widely spaced isotherms in the southern hemisphere denote gentle (low) temperature gradient because of the dominance of the oceans. In the northern hemisphere, the eastern coasts register a steeper temperature

gradient (1.5°C per latitude) than the western coastal areas (0.5°C per latitude).

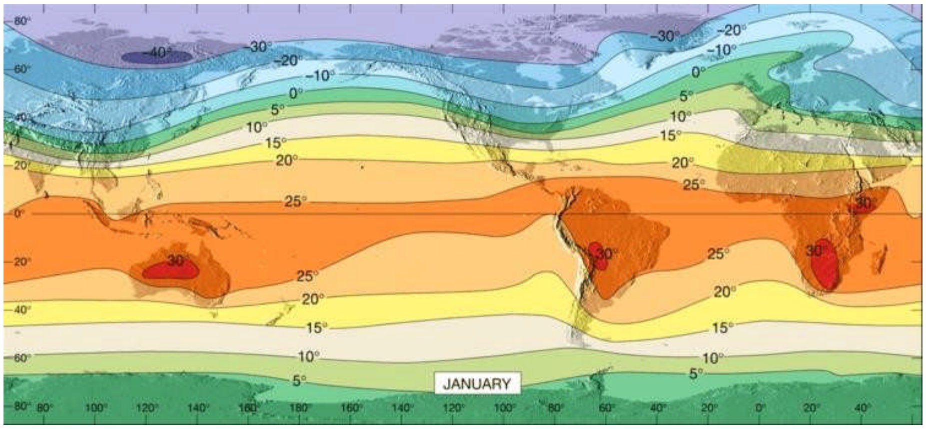



Fig. 2.8

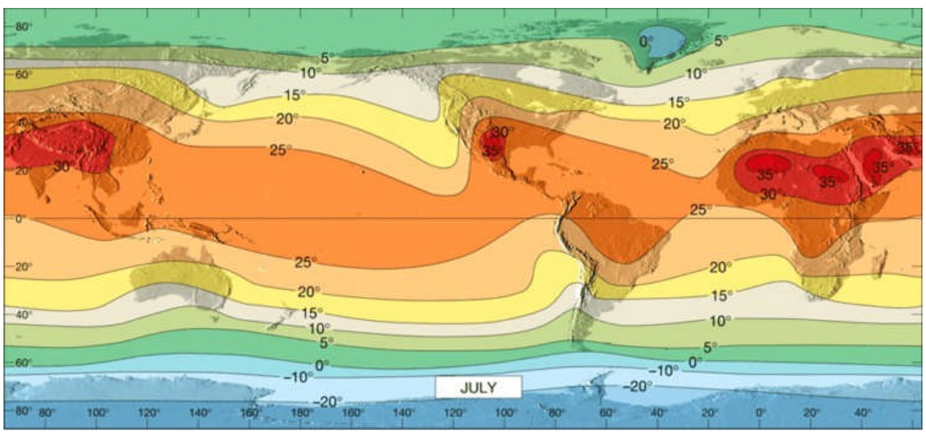


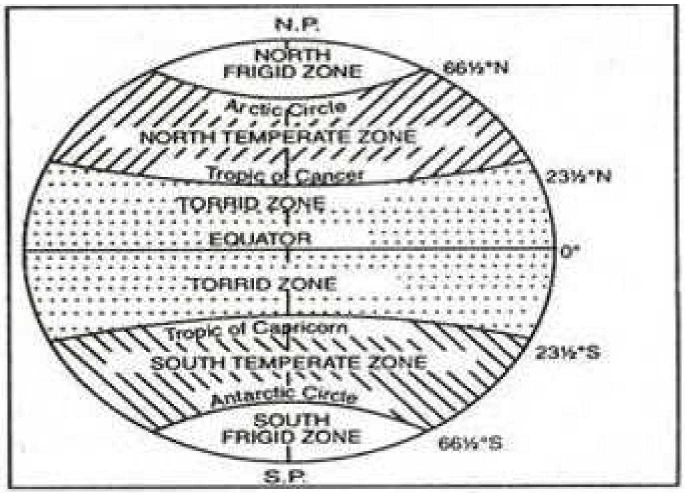

Fig. 2.9

**Regional Distribution**

When the horizontal distribution of temperature is explained concerning tropical, temperate, and frigid zones it is called regional distribution of temperature.A detailed analysis of the same has been given in the following paragraphs and depicted in Fig. 2.10.

**The tropical zone** extends between the tropics of Cancer (23.5°N) and Capricorn (23.5°S). The Sun's rays are more or less vertical on the equator throughout the year.The remaining areas are also characterized by vertical sun rays at least once every year. There is no winter around the equator because of high temperature prevailing throughout the year but as one approaches the tropics of Cancer and Capricorn summer and winter are observed and differentiated.

**The temperate zone** extends between 23.50 and 66.50 latitudes in both the hemispheres.




*Horizontal and Vertical Distribution of Temperature*

**Fig. 2.10**

## E. VERTICAL DISTRIBUTION OF THE TEMPERATURE

Like the latitudinal distribution of temperature, the atmospheric temperature changes with the changing elevation from MSL in the atmosphere. The rate and trend of change in the temperature in the atmosphere with increasing elevation are varied with the atmospheric structure. The vertical distribution of temperature can be well explained concerning the atmospheric structure. In the forthcoming paragraphs, an attempt has been made to analyse the vertical distribution of temperature.

**Vertical distribution of temperature in the troposphere:**

Generally, in the troposphere, atmospheric temperature decreases with increasing elevation at the rate of $6.5^{O}$ C per kilometre. The rate of decrease in temperature with increasing elevation is called the normal lapse rate. If the surface temperature is $30^{O}$ C it decreases to $-70^{O}$ C at the upper limit of the troposphere. The decrease in density of the air with increasing elevation from the MS, decreasing impact of outgoing terrestrial radiation, decrease in the proportion of greenhouse impact, etc. are some of the reasons which are responsible for the decrease in temperature in the troposphere with the elevation.

Sometimes temperature decreases due to the changes in the size of the upwardmoving air, this phenomenon is known as the adiabatic change of temperature. The adiabatic lapse rate can be expressed in terms of dry adiabatic and wet adiabatic lapse rate and it is $10^{O}$ and $5^{O}$ C per km respectively. The adiabatic change of temperature is mostly related to the Cumulonimbus clouds and it is restricted to the lower troposphere.

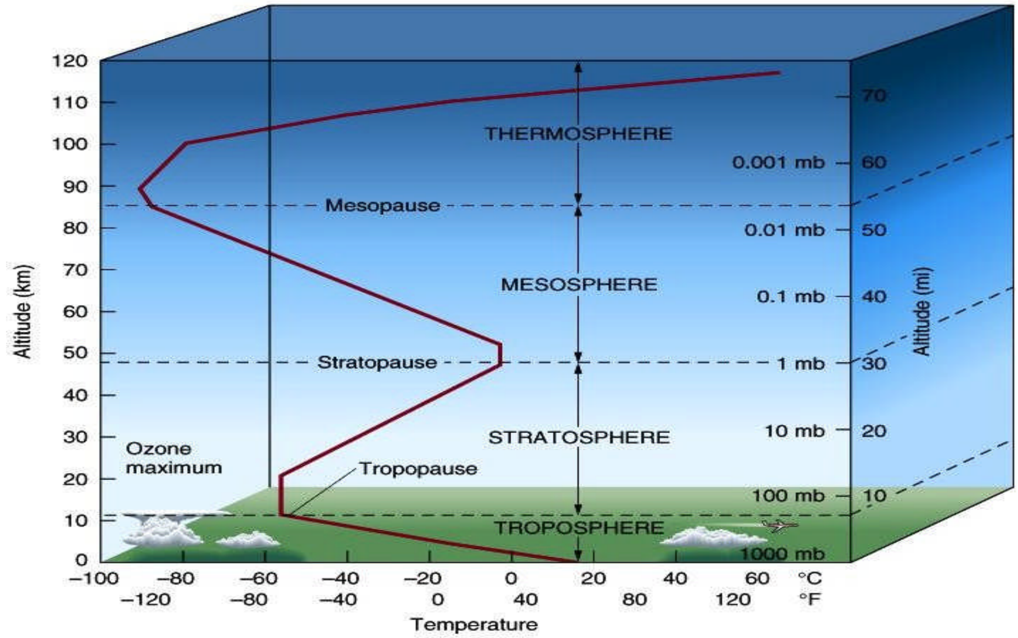



Fig. 2.11

**Vertical distribution of temperature in the Stratosphere:**

In the tropopause, the upper limit of the troposphere, the temperature remains stagnant. In the stratosphere, temperature increases with increasing elevation. Many geographers and metrologists have explained this positive change in the context of the presence of the ozone layer. At the Earth's surface, the proportion of ozone gas is negligible but it has more concentration in the stratosphere. The density of the ozone layer increases with increasing elevation in the stratosphere and the layer absorbs the incoming ultraviolet radiation. This is the reason that temperature increases with increasing elevation in the stratosphere. In the tropopause, the temperature is around – $70^{O}$ C and it reaches $0^{O}$ C at the upper limit of thestratosphere, i.e. stratopause.

**Vertical distribution of temperature in the Mesosphere:**

In the mesosphere, temperature decreases with increasing elevation from meansea level. The negative change of temperature in the mesosphere is mostly related to the decreasing density of the air in the mesosphere. No other shreds of evidence havebeen observed concerning the negative change of temperature in the mesosphere. The temperature reaches – $80^{O}$ C at the upper limit of the mesosphere which is around $0^{O}$C at the lower mesosphere.

**Vertical distribution of temperature in the Exosphere:**

Beyond mesopause temperature again increases with increasing elevation in the thermosphere. It is estimated that the temperature at its upper limit becomes $1700^{O}$ C. it may be pointed out that this temperature cannot be measured by an ordinarythermometer because the gases become very light due to the very low air density.

Based on the analysis the following conclusions can be drawn concerning the vertical distribution of the atmospheric temperature.

1) The temperature decreases with increasing elevation in the troposphereand mesosphere only.
2) The temperature increases with increasing elevation in the stratosphere and thermosphere.
3) The rate of change in temperature with increasing elevation is varied from place to place and structure of the atmosphere, But in general, temperature decreases with increasing elevation at the rate of $6.5^{O}$ C perkm in the troposphere and it is called the normal lapse rate.
4) In certain conditions temperature decreases due to a change in the size of the air mass as a result of the movement of the air in the upper atmosphere, it is called the adiabatic lapse rate. the adiabatic lapse rate can be explained in terms of dry adiabatic lapse rate and wet adiabatic lapse rate.

## F. INVERSION OF TEMPERATURE:

Though, the inversion of temperature is a part of the vertical distribution of the temperatures it has been explained separately with the view to elaborate the conceptin more detail.

### Conceptual Background:

As stated earlier in this module, the temperature decreases with increasing elevation at the rate of $6.5^{O}$ C per km in the troposphere. This is called the normal lapse rate. Sometimes due to certain reasons the temperature in the troposphere increases with increasing elevation, this is called the inversion of temperature. The inversion of temperature is also called a negative lapse rate. In any region, the negative lapse rate is observed because of various physical and metrological components. This may be well explained through the types of inversion of temperature.

### Types of Inversion of Temperature:

Inversion of temperature arises in numerous physical and atmospheric circumstances. Every so often it arises at the ground surface while rarely it happens at the highest elevation. Occasionally it is caused by static atmospheric conditions while irregularly, it occurs due to horizontal or vertical movement of the air. Thus temperature inversion is classified into the following types based on elevation from the earth surface at which it or cause and the types of air circulation.

### Surface Inversion:

When air is cooled by contact with a colder surface until it becomes cooler than the overlying atmosphere this is called a ground surface inversion. The ground surface inversion is also called radiation inversion. Mostly the lower atmosphere is heated and cooled under the influence of longwave terrestrial radiation. In short, thetemperature of the lower atmosphere is influenced by the temperature of the ground surface. The ground surface inversion is also called non-advection inversion. Duringthe winters, the proportion of incoming solar radiation is less than the outgoing terrestrial radiation. Long winter nights, cloudless and clear sky, presence of dry air near the ground surface, stable atmospheric conditions, snow-covered ground surface, etc. are some of the reasons for a ground surface inversion. Topography greatly affects the magnitude of ground inversions. If the land is rollingor hilly, the cold air formed on the higher land surfaces tends to drain into the hollows, producing a larger and thicker inversion above low ground and little or noneabove higher elevations.

**The Upper Air Inversion:**

The upper air inversion can be categorized into thermal and mechanical upper air inversion. **The thermal upper air inversion** is caused due to the presence of the Ozone layer in the stratosphere. The ozone layer absorbs the ultraviolet radiation received from the Sun and that is the reason that temperature increases with increasing elevation in the stratosphere. This happens in stable atmospheric conditions.

The **mechanical upper air inversion** is also called a subsidence inversion. A subsidence inversion develops when a widespread layer of air descends. The layeris compressed and heated by the resulting increase in atmospheric pressure, and, as a result, the lapse rate of temperature is reduced. If the air mass sinks low enough, the air at higher altitudes becomes warmer than at lower altitudes, producing a temperature inversion. Subsidence inversions are common over the northern continents in winter and over the subtropical oceans; these regions generally have subsiding air because they are located under large high-pressure centers.

**The Advection Inversion of Temperatures:**

Advectional inversion of temperature is also called dynamic inversion because it is always caused due to either horizontal or vertical movement of air. The strong wind movements and unstable atmospheric conditions are the prerequisites for the formation of advectional inversion of temperature. Advectional inversion of temperature can be divided into three subcategories, as explained in the following paragraphs.

**A frontal inversion** occurs when a cold air mass undercuts a warm air mass and lifts it aloft. This kind of inversion has a considerable slope, It is also called cyclonic inversion. This kind of inversion mostly occurs in mid-latitude regions where the polar easterlies and subtropical westerlies meet together. Frontal inversion habitually producers the lighter showers in the respective region.

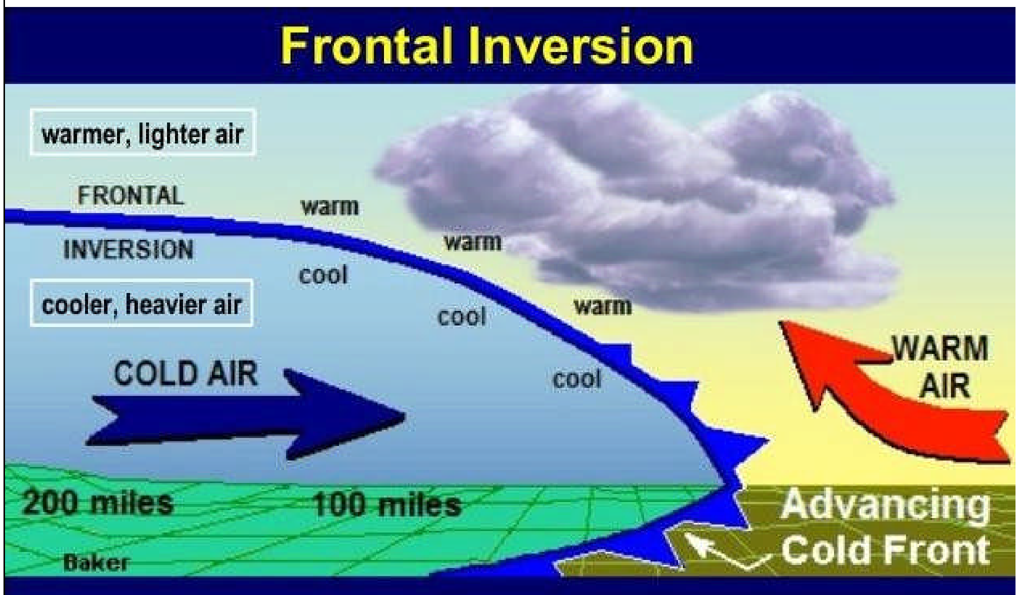



Fig. 2.12

**Surface inversion** may be produced due to the advectional movement of the air masses. It happens when the warm air mass moves through the cold surface and the warm air mass is cooled by the surface. The surface inversion is frequently produced along with the coastal areas.

**Valley inversions** generally occur in the valleys of the mountains due to radiation and vertical movement of the air. This is also called vertical advectional inversion of temperature. During the long winter nights, the mountain tops are cooled earlier than the valley bottoms. The cooled air is denser so it starts its journey along the valley slopes towards valley bottoms. After reaching the valley bottoms thecolder air pushes the warm air in an upward direction and valley inversion is formed.

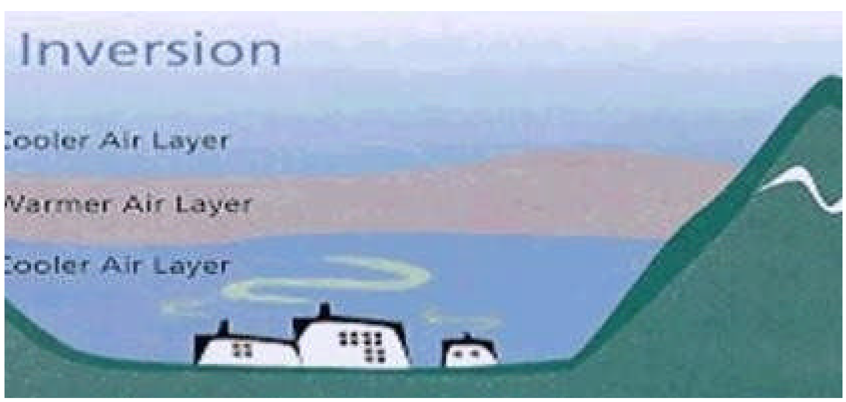



Fig. 2.13

**Significance of the inversion of temperature:**

Inversions play an important role in determining cloud forms, precipitation, and visibility. An inversion acts as a cap on the upward movement of air from the layers below. As a result, convection produced by the heating of the air from below is limited to levels below the inversion. Diffusion of dust, smoke, and other air pollutants is likewise limited. In regions where a pronounced low-level inversion is present, convective clouds cannot grow high enough to produce showers and, at the same time, visibility may be greatly reduced below the inversion, even in the absenceof clouds, by the accumulation of dust and smoke particles. Because air near the baseof an inversion tends to be cool, fog is frequently present there.

Inversions also affect diurnal variations in air temperature. The principal heating of air during the day is produced by its contact with a land surface that has been heated by the Sun's radiation. The heat from the ground is communicated to theair by conduction and convection. Since an inversion will usually control the upper level to which heat is carried by convection, only a shallow layer of air will be heatedif the inversion is low and large, and the temperature rise will be great.

## 2.4 PROCESSES OF HEAT ENERGY TRANSPORT

The energy received at the Earth's surface and in the atmosphere has spatial and temporal variation. Hypothetically some of the geographers have calculated heatbalance for the earth and atmosphere as 0%. The transfer of heat energy from one body to another and from one place to another is accomplished through conduction, convection, and radiation. Some of the areas on the earth's surface have surplus energy and some of the areas have an energy deficit. This imbalance of energy is balanced through the transfer of energy in the horizontal and vertical directions. In the forthcoming paragraphs, an attempt has been made to analyze the transfer of heatenergy into the atmosphere.

The transfer of heat energy can be well-explained through the analysis of heating and cooling of the earth and atmosphere through direct solar radiation long wave terrestrial radiation. A detailed analysis of incoming solar radiation and outgoing terrestrial radiation has been carried out under the heat balance. However, here the focus is given to analyse the processes of conduction, convection, and radiation.

**Conduction**

When two bodies at diverse temperatures come in contact with each other heatis transmitted from the one body of higher temperature to the body with lower temperature. This is known as conduction. The heat radiation received from the sun in the form of shortwave radiation directly reaches the Earth's surface and heats the earth's surface. The atmosphere in close contact with the heated earth's surface is heated through conduction. Air is a poor conductor hence the process of heat transfer through conduction is limited to the lower portion of the atmosphere.

**Convection**

The air heated by the incoming solar radiation expands and becomes lighter. As a result, the heated air rises upward direction. To keep the balance, the upper cold airdescends and gets heated up. Thus, convection currents are formed which transmit heat energy upwards. In this way, the upper layers of the atmosphere are also heatedby Convection.

**Radiation**

The movement of the heat energy without any medium of transfer is called radiation. The earth receives heat energy in the form of shortwave radiation from the Sun. After reaching the Earth's surface, the short-wave radiation is converted into longwave radiation. The longwave radiation radiates from the Earth's surface to the atmosphere and then space. While traveling through the atmosphere the radiated energy is absorbed by the atmosphere and the atmosphere gets heated. Sometimes atmosphere reradiates longwave radiation to the Earth's surface.

## 2.5 SUMMARY

In this module, we have discussed the fundamentals of insolation and temperature, factors affecting insolation and temperature, the distributional pattern of insolation and temperature, inversion of temperature, and transfer of heat energy.

## 2.6 CHECK YOUR PROGRESS/ EXERCISE

### 2.6.1 True or False

**2.6.1.1** According to Critchfield, the radiant energy from the sun that strikes the earth is called temperature.

**2.6.1.2** The earth receives only ½ billionth part of the radiated energy fromthe surface of the sun i.e., the photosphere and it is equivalent to 29trillion horsepower.

**2.6.1.3** The zone extending between 23 ½$^{O}$ and 66 ½$^{O}$ latitudes in both thehemisphere is called the high-latitude zone.

**2.6.1.4** The number of absent days of solar insolation increases towards thepole.

**2.6.1.5** Vertical rays are spread over the minimum area of the Earth’s surface and heat the minimum possible area and the insolation received per unit area increases.

**2.6.1.6** The length of a day directly affects the proportion of insolation received per unit area at any place.

**2.6.1.7** Due to the elliptical revolution of the earth around the sun, the distance between the earth and the sun is changing during the year.

### 2.6.2 Fill in the blanks

**2.6.2.1** According to ………., the radiant energy received from the Sun, transmitted in a form analogous to short waves, and traveling at a speed of 300000 km per second is called solar radiation for insolation.

**2.6.2.2** ……………. refers to the quantity of solar radiation energy received on a surface during an amount of time, expressed in kWh/m².

**2.6.2.3** defines the sun as constantly radiating into space, the complex of energy which is called insolation.

**2.6.2.4** The amount of solar radiation or the Solar Energy received on a unit area of the surface facing the sun at an average distance between the sun and the earth is more or less constant and is called a solar……………..

**2.6.2.5** The zone which extends between the …………… of Cancer and Capricorn is included in the low latitude zone.

**2.6.2.6** At the time of , the Earth is nearest to the sun on January 3, and the distance between the Earth and Sun is 147 million kilometres.

**2.6.2.7** Studies reveal that variation in the number of sunspots is cyclic in nature and each cycle is completed in ________years.

**2.6.2.8** On average % of the incoming solar radiation is reflected and it is called albedo.

**2.6.2.9** Approximately % of incoming shortwave radiation is scattered in the atmosphere.

### 2.6.3 Multiple Choice Questions

**2.6.3.1** is the total amount of solar energy received at a particular location during a specified time, often in units of kWh/(m2 day). (Insolation, Temperature, heat balance, inversionof temperature)

**2.6.3.2** The energy received at the surface of the earth or the atmosphere is called insolation. (Solar, heat, tidal, longwave)

**2.6.3.3** On average, the Earth's surface receives the radiation of ……….. - gram calories per square centimetre per minute. (2, 4,5, 3)

**2.6.3.4** The region extending beyond 66 ½$^{O}$ north and south latitude is called the latitude region. (high, mid, low, north)

**2.6.3.5** On July 4, i.e., at the time of aphelion, the earth is at the farthest distance from the sun and the distance is_______million kilometres. (152, 147, 148, 149)

**2.6.3.6** The atmosphere directly absorbs ________% of incoming shortwave solar radiation. (14, 18, 23, 17)

**2.6.3.7** 'Atmospheric is a function of the modification of solar radiant energy by air, clouds, land, sea and other water surfaces'(temperature, pressure, insolation, heat)

**2.6.3.8** The highest temperature recorded during the 24 hours is called thedaily temperature. (maximum, minimum, average, all of these)

**2.6.3.9** The difference between the highest and the lowest temperature perunit time at the local, regional, or global level is called the………… of temperature. (average, range, mean, median)

**2.6.3.10** Generally, in the troposphere, atmospheric temperature decreases with increasing elevation at the rate of ____$^{O}$ C per kilometre. (6.5, 7.5, 8.5, 9.5)

### 2.6.4 Answer the following questions

**2.6.4.1** Define insolation and explain the factors affecting the distributionof insolation on the earth's surface.

**2.6.4.2** Differentiate between insolation and temperature.

**2.6.4.3** With the help of a suitable diagram, explain the heat balance of the earth and atmosphere.

**2.6.4.4** Explain the factors affecting the distribution of temperature on theearth's surface.

**2.6.4.5** Define inversion of temperature and explain types of inversion oftemperature.

**2.6.4.6** "Distribution of the temperature varies from latitude and altitude",explain it with suitable examples.

**2.6.4.7** Explain the horizontal and vertical distribution of the temperature.

## 2.7 Answers to the Self-learning Questions

**2.7.1** True or False**2.7.1.1**True **2.7.1.2**False

**2.7.1.3** False

**2.7.1.4** True

**2.7.1.5** True

**2.7.1.6** True

**2.7.1.7** True

**2.7.2** Fill in the Blanks

**2.7.2.1** G. T Trewartha

**2.7.2.2** Insolation

**2.7.2.3** Kendrew

**2.7.2.4** Constant

**2.7.2.5** Tropics

**2.7.2.6** Perihelion

**2.7.2.7** 11

**2.7.2.8** 35

**2.7.2.9** 23

**2.7.3** MCQ

**2.7.3.1** Insolation

**2.7.3.2** Solar

**2.7.3.3** 2 grams

**2.7.3.4** High

**2.7.3.5** 152

**2.7.3.6**14

**2.7.3.7** temperature

**2.7.3.8** maximum

**2.7.3.9** range

**2.7.3.10** 6.5

## 2.8 Technical words and their meaning

**2.8.1 Albedo:** On average 35% of the incoming solar radiation is reflectedand it is called albedo.

**2.8.2 Lag of Temperature:** There is no coincidence between the time of maximum and minimum amount of insolation received from the sun and maximum and minimum temperatures of the air. This is called the lag of temperatures.

**2.8.3 Inversion of temperature:** Sometimes due to certain reasons the temperature in the troposphere increases with increasing elevation, this is called the inversion of temperature. The inversion of temperature is also called a negative lapse rate.

## 2.9 TASK

Measure the temperature of the air in your locality through Google WeatherApp and try to convert it

## 2.10 WORK CITED AND THE SOURCES FOR FURTHER STUDY

Bibliography

Macdonald, E. H. (2007). *Handbook of Gold Exploration and Evaluation,*. USA: Science Direct.

Retrieved from https://www.sciencedirect.com/topics/engineering/atmospheric-temperature

S.G.Bowden, C. a. (2019). *Measurement of Solar Radiation.* www.pveducation.org: “Photovoltaics

Education .

Singh, S. (2005). *Climatology.* Allahabad, Uttar Pradesh, India: Prayag Pustak Bhavan.University of Calgary. (2020). *Energy Education.* Calgary: https://energyeducation.ca.

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# 3

# ATMOSPHERIC PRESSURE

**Unit Structure**

**After going through this unit the students will be able to understand thefollowing features:**



## 3.1 OBJECTIVES

1. To give the knowledge of atmospheric pressure and causes of variations inatmospheric pressure to the students.
2. To explain the vertical and horizontal distribution of pressure.
3. To aware the students about the general pattern of atmospheric pressure.

4. To aware the students about the wind pattern
5. To explain in detail about the various types of winds to the students

## 3.2 INTRODUCTION

Air being a physical substance is an admixture of several gases present in the atmosphere and hence has its own weight. Thus, the air exerts pressure through its weight. Air pressure is defined as the force per unit area or total weight of mass of column of air above per unit area at sea level.

Air pressure is measured in terms of height of mercury in the glass tube in a mercurial barometer. The standard air pressure at sea level is 1013.25mb or 29.92 inches or 76 cm at a temperature of 15°C at the latitude of 45°. Air pressure is measured with the help of mercurial barometer, aneroid barometer, altimeter, barograph, microbarograph etc. The lines joining the places of equal pressure at sea level are called isobar. Air pressure decreases with increasing altitudes at the rate of o.1 inch or 3.4 mb per 600 feet but this rate is confined to the altitude of a few thousand feet only i.e. 1800 feet. The standard atmospheric air pressure varies both horizontally and vertically, seasonally and diurnally.

## 3.3 ATMOSPHERIC PRESSURE

The atmosphere is held on the earth by the gravitational pull of the earth. A column of air exerts weight in terms of pressure on the surface of the earth. The weight of a column of air contained in a unit area from the mean sea level to the top of the atmosphere is called the atmospheric pressure. Pressure is normally measured in millibars or pascals and spatial variations of pressure are depicted on maps by means of isobars, which are lines connecting places having the same barometric pressure. The actual pressure at a given place and at a given time fluctuates and it generally ranges between 950 and 1050 millibars. Air pressure is measured with the help of a mercury barometer or the aneroid barometer.

The gradual change of pressure between different areas is known as the barometric slope or pressure gradient. The closer the isobars are together, the greater the pressure gradient; for example, widely spaced isobars indicate a weak pressure gradient.

### 3.3.1 VERTICAL DISTRIBUTION OF AIR PRESSURE

The air pressure decreases with height. This fact is easily experienced by mountaineers. The mountaineers experience breathing and other troubles while they are scaling high peaks. Due to low pressure, blood oozes out of their nostrils and their lungs work feverishly. If the pressure is very low the mountaineers fall down and lose consciousness.

The study of air pressure at high levels was made with the help of balloons which are fitted with meteorological instruments. Man has also ascended in balloons. Adams and Stevens tried to reach a height of 21,945 meters in 1935. Major Simon created a world record by reaching a height of 30,937 meters in 1958. It is necessary for meteorologists to study the upper air of the atmosphere.

### 3.3.2 Vertical Distribution of Air Pressure

| Height (Meters) | Height (Feet) | Air Pressure (Inches) | Air Pressure (Mb) |
|---|---|---|---|
| 5486 | 18,000 | 14.94 | 5.56 |
| 5181 | 17,000 | 15.56 | |
| 4907 | 16,000 | 16.21 | |
| 4572 | 15,000 | 16.88 | |
| 4267 | 14,000 | 17.57 | |
| 3962 | 13,000 | 18.29 | |
| 3656 | 12,000 | 19.03 | |
| 3351 | 11,000 | 19.79 | |
| 3048 | 10,000 | 20.58 | 666.8 |
| 2743 | 9,000 | 21.38 | |
| 2438 | 8,000 | 22.22 | |
| 2133 | 7,000 | 23.09 | |
| 1828 | 6,000 | 23.98 | |
| 1524 | 5,000 | 24.89 | |
| 1219 | 4,000 | 25.84 | 875.1 |
| 914 | 3,000 | 26.81 | |
| 609 | 2,000 | 27.82 | |
| 304 | 1,000 | 28.85 | |
| Sea Level | Sea Level | 29.92 | 1013.2 |

Table: Vertical Distribution of Temperature
*Source: http;/ www.distance educationju.in*

### 3.3.3 Horizontal Distribution of Pressure and Pressure Belts

The horizontal distribution of air pressure on the globe is studied on the basis of isobars. Air pressure is generally divided into two types' viz. (i) high pressure also called as high or anticyclone, and (ii) low pressure, also called as low or cyclone or depression. The regularity of pressure belts is distributed due to unequal distribution of land and water. The pressure belts are discontinued in northern hemisphere and several centres of pressure belts are developed but they are more are less regular in southern hemisphere. If the air pressure would have been the functions of temperature alone there should have been regular increase of pressure from equator towards poles but this is not the case as there are sub polar low pressure belt.

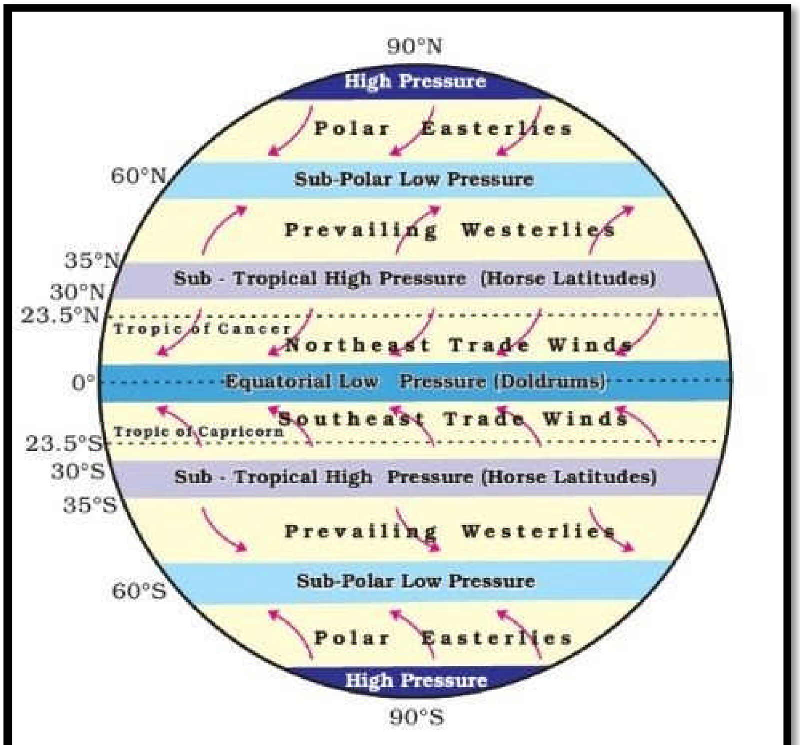
### 3.3.4 Latitudinal distribution of pressure

There is no definite trend of distribution of pressure from equator towards the poles. If the air pressure would have been the function of air temperature alone then there should have been regular increase of pressure pole ward because temperature regularly decreases from equator towards poles but this is not the case. There is low pressure near the equator due to high mean annual temperature but the existence of high pressure belts near the tropics of cancer and Capricorn cannot be explained on the basis of temperature because the tropics record very high temperature and hence there should have been low pressure if the temperature would have been the only control of air pressure. The air pressure should increase pole ward from the tropic of cancer and Capricorn because there is rapid rate of decrease of temperature pole ward but we find low pressure belt near 60° latitudes.

It is obvious that pressure belts are not only induced by thermal factor but they are also induced by dynamic factor.

On the basis of mode of genesis pressure belts are divided as:

1. Thermally induced pressure belts: -
   (i) Equatorial low pressure belt
   (ii) Polar high pressure belt
2. Dynamically induced pressure belts: -
   (i) Sub-tropical high pressure belt
   (ii) Sub-polar low pressure belt



*Major Pressure Belts and Wind System*

**Fig 3.1**
***Source- https://www.pmfias.com***

**(a) Equatorial low pressure belt**

The equatorial low pressure belt is located on the either side of the geographical equator in the zone extending between 5° North to 5° South latitude but this zone is not stationary because there is seasonal shift of this belt of this belt with the northward (summer solstice June 21st) and southward (winter solstice 22nd Dec) migration of sun.

This belt is thermally induced because the ground surface is intensely heated during the day due to almost vertical sun rays. Thus the warm air expands become light and consequently rise upward causing low pressure. This belt represents zone of convergence of northeast and southeast trade winds. There are light feeble and variable winds within the convergence belt because of frequent calm conditions this belt is called belt of calm or doldrums.

**(b) Sub-tropical high pressure belt or horse latitude**

This belt extends between 20°-25° latitude in both the hemisphere. This belt is not thermally induced, because besides due to three winter months, receives fairly high temperature throughout the year. Thus belt owes its origin to the rotation of earth and sinking and setting down of wind. Thus it is dynamically induced. The convergence of winds at higher altitude above this zone results in the subsidence of air from higher altitudes. Thus decent of winds in the contraction of their volume and ultimately causes high pressure that is why this zone is characterized by anti -cyclonic conditions which cause atmospheric stability and aridity. This is one of the reasons for the presence of hot deserts of the continents in a zone extending between 25°-35° latitude in both the hemispheres. This zone of high pressure is called horse latitude because of prevalence of frequent calms. This zone of high pressure is not continuous belt but is broken into number of high pressure centres and cells.

**(c) Sub-polar low pressure belt**

This belt is located between 60°-65° latitude in both hemispheres. This low pressure does not appear to be thermally induced because there is low temperature throughout the year and as such there should have been high pressure instead of low pressure belt. Thus this belt is dynamically induced. In fact, surface air spreads outwards from this zone due to rotation of earth and low pressure is created. Thus, due to verification of this belt there is low pressure instead of high pressure.

**(d) Polar high pressure belt**

High pressure persists at the poles throughout the year because of low temperature throughout the year. In fact, both the factors thermal and dynamic operate at the poles. There is thinning out of layers of air due to diurnal rotation of earth as the air spreads outwards due to this factor but this factor is over shadowed by the thermal factor and high pressure is produced due to very low temperature.

### 3.3.5 Isobaric horizontal distribution of air pressure

Isobars are the imaginary lines on a map joining places of equal pressure at sealevel.

The seasonal (annual) horizontal distribution of air pressure is represented and studied through isobars for the months of July and January in the northernhemisphere.

### 3.3.6 Meridional distribution of pressure

Meridional pressure distribution means average seasonal sea level pressure for all the longitudes. It may be mentioned that sea level pressure for all the longitudes for a latitude are averaged to show the meridional seasonal pressure profiles for the study of seasonal variations in pressure belts in summer and winter hemisphere.

### 3.3.7 Shifting of Pressure Belts

The surface pattern of air pressure seldom remains stationary in its latitudinal zone. There are daily, seasonal and annual changes in the air pressure because of northward and southward movement of the overhead sun, contrasting nature of the heating and cooling of land and water etc. The lowest pressure is developed between2 to 4 p.m. during the day due to maximum temperature while the highest pressure is recorded between 4-6 a.m. due to minimum temperature during night. Coastal lands record low pressure while adjoining oceanic area has high pressure during the day. This situation is reversed during the night.

### 3.3.8 The Horizontal Distribution of air pressure in January-

A study of the weather map of this month reveals the following facts-

(1) Equatorial Low Pressure belt situated in the south of the equator because the sun shifts south of equator this month. The main low pressure cells are situated in Australia, South America and Africa.

(2) In Southern hemisphere sub-tropical highs are clearly visible in oceans because itis the summer season and water is colder than the land. In Northern hemisphere high pressure cells are not properly developed in semi-tropical areas but appear as a long high pressure ridge.

(3) The low pressure trough in semi-tropical bet in southern hemisphere is deep and continuous but there are two low pressure cells in the sub-tropical areas of northern hemisphere which exist in the northern Atlantic and northern Pacific Ocean.

(4) In eastern central Asia there is a fully developed and broad based high pressure cells which has all the characteristics favourable for intense heating. No such cell with such a high pressure is found in Northern America.

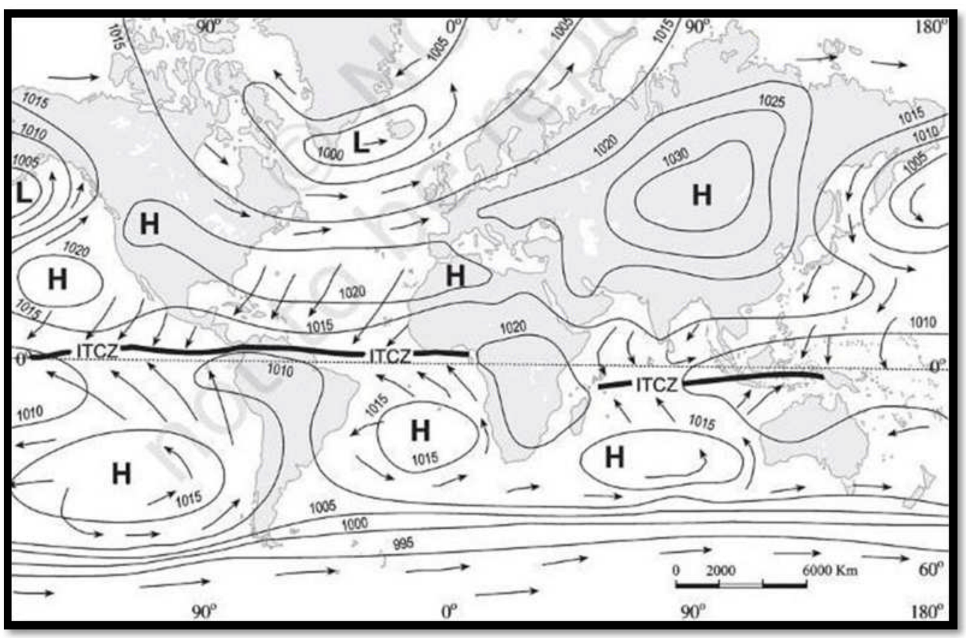



**Fig.: 3.2-Pressure belts in January**
***Source - https://www.pmfias.com***

### 3.3.9 Horizontal Distribution of air pressure in July

The following facts emerge out from a study of the world map depicting pressure in the month of July:

(1) The equatorial low pressure trough has shifted towards the north of equator in summer following the corresponding shift of the sun.

(2) The whole of the pressure system has shifted to the north following the shift of the sun.

(3) The sub polar high pressure system extends in the form of a long trough in southern hemisphere but the low pressure cells in northern hemisphere are very feeble.

(4) Centres of low pressure have developed in Asian continent and north-west North America. This disrupts the sub-tropical high pressure system.

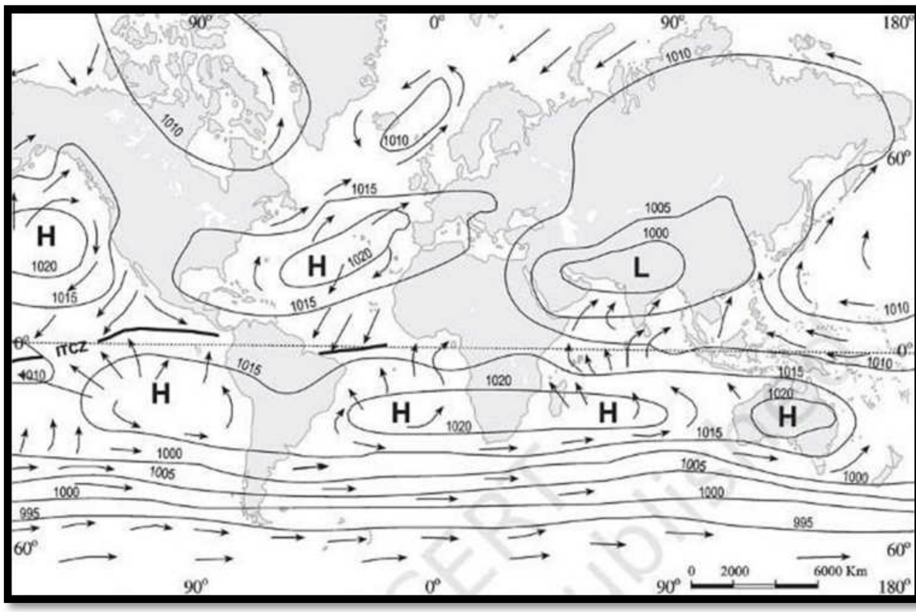



**Fig.: 3.3-Pressure belts in July**
***Source: https://www.pmfias.com***

## 3.4 GENERAL CIRCULATION OF THE ATMOSPHERE

As discussed earlier that wind is the result of pressure gradient which is largely caused by differential heating of the earth. Winds in the atmosphere are neither unidirectional nor have a same pattern as we go up in the atmosphere. In fact, winds may change their direction and intensity multiple times within same day. Largely, wind movement in the atmosphere may be classified into three broad categories:

1. Primary circulation
2. Secondary circulation
3. Tertiary circulation

### 3.4.1 Primary circulation

It includes planetary wind systems which are related to the general arrangement of pressure belts on the earth's surface. The pattern of the movement of the planetary winds is called the general circulation of the atmosphere. In fact, it is the primary circulation patterns which prepare the broad framework for the other circulation patterns.

### 3.4.2 Secondary circulation

It consists of cyclones and anti-cyclones, monsoon

### 3.4.3 Tertiary circulation

It includes all the local winds which are produced by local causes such as topographical features, sea influences etc. Their impact is visible only in a particular area.

## 3.5 Types of winds: Geostrophic, Gradient and local winds

Wind has been defined as air in horizontal motion. According to Byers, "the wind is simply air moving in motion usually measured only in its horizontal component." According to Trewartha, "wind is simply air moving in a direction which is essentially parallel with the earth's surface." In fact, wind is horizontal movement of air that is caused by differences in pressure.

### 3.5.1 Geostrophic wind

When a wind usually above a height of 600 metres, blows parallel to the isobars, it is called the geostrophic wind. Geostrophic wind has also been defined as the horizontal pressure force. When the wind motion is almost in a straight line without friction force acting on it, it is worked upon only by two forces: the Coriolis force and the gradient force. These forces are equal and are directed at right angles to the wind as shown in figure:

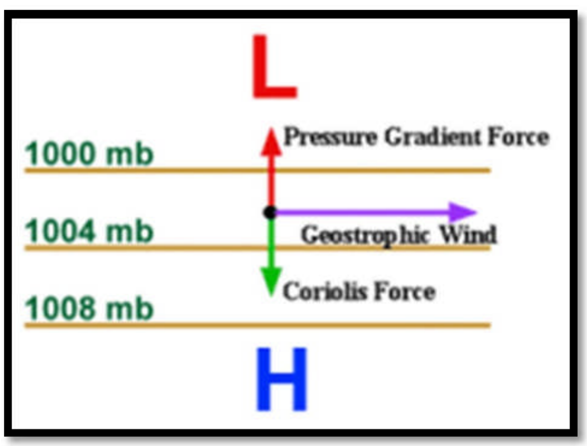



**Fig.:** 3.4-Geostrophic Wind
*Source: http://ww2010.atmos.uiuc.edu*

It may be pointed out that these forces are opposed to each other. Under the influence of pressure gradient force which always works to right angles to the isobars, the parcel of air begins to accelerate directly towards the area of low pressure. But no sooner than the wind begins to blow, the Coriolis force deflects it to the right in northern hemisphere and to the left in the southern hemisphere. Since the Coriolis force is proportional to wind speed, it intensifies with the acceleration. Ultimately, the wind is deflected to the extent that it starts blowing parallel to the isobars.

The pressure gradient force is directed towards the area of pressure and is opposed by the Coriolis force. This force is directed towards the area of high pressure. Fig- when two opposing forces are equal in magnitude, the wind will continue to flow parallel to the isobars. However, the wind speed remains constant.

In fact, the wind, instead of blowing parallel to the isobars, tends to adjust its speed and direction so as to reach a balance between the pressure gradient force and the Coriolis force. The state of equilibrium reached by the two opposing forces is called geographic balance. Thus geographic winds are those that are generated by this balance of the two opposing forces. A steep gradient force will create winds with high velocities and these in turn will generate an equally strong Coriolis force. It is the Dutch meteorologist, Buys Ballot, who in 1857 formulated this simple relationship between wind direction and pressure distribution. This is known as Buys Ballot's law which states: "in northern hemisphere, if you stand with your back to the wind, there will low pressure to your left and high pressure to your right. In southern hemisphere, the Coriolis deflection being to the left, the situation is reversed." In caseof air flow near the earth's surface, this law should be applied with some caution because of so many geographical factors which create local disturbances in the larger circulation.

**3.5.2 Gradient wind**

A wind moving along the isobars at such a velocity that the force due to pressure gradient is balanced by the deflective and centrifugal effects is called a gradient wind. In other words, gradient wind refers to the horizontal wind velocity in which balance is achieved between the Coriolis force, pressure force and centrifugal force as seen in figure. In figure three forces are affecting a moving parcel of air and resultant gradient wind around the high as well as low pressure centres in the northern hemisphere are shown.

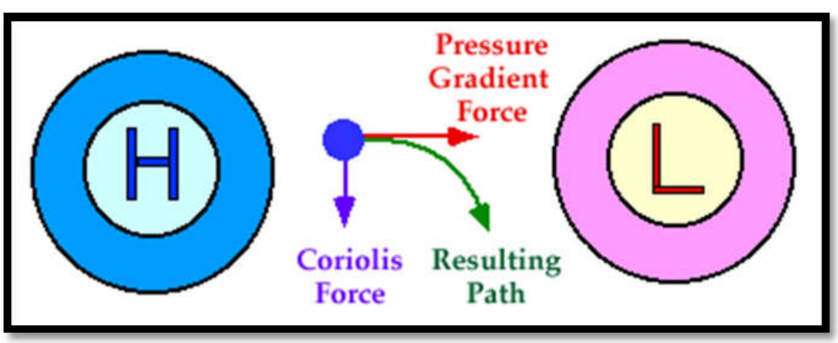
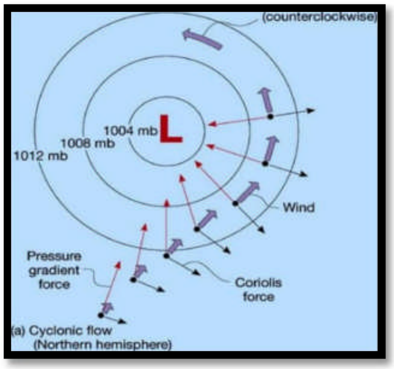



**Fig.: 3.5-Pressure Gradient Wind**
***Source - http://ww2010.atmos.uiuc.edu***



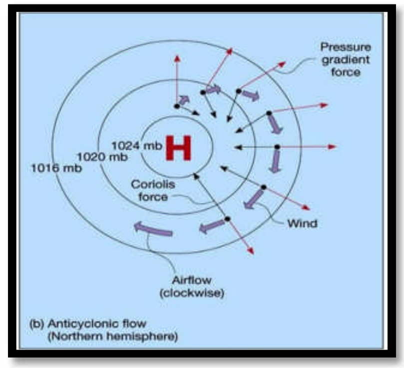




**Fig.:** 3.6-a **Fig.:** 3.6-b

**Fig:** 3.6 (a) shows that for geographic gradient flow around a centre of the high pressure, the pressure gradient force is directed outward and is balanced by inward directed Coriolis force. in the northern hemisphere where the Coriolis force deflects the wind motion to the right, resultant wind blows clockwise about a high. On the contrary, around a low pressure centre the inward directed pressure gradient force, that is balanced by the outward directed Coriolis force, results in anticlockwise flow in the northern hemisphere. **Fig:** 3.6 (b)

The gradient wind may be defined as the wind that corresponds to the balance between pressure force on the one hand, and the Coriolis force and centrifugal force on the other.

### 3.5.3 Primary wind/ Planetary Winds

Primary or planetary winds blow from high pressure belts to low pressure belts in the same direction throughout the year. They blow over vast area of continents and oceans. Trade winds, Westerlies and polar easterlies together form the planetary wind circulation (figure). These are described below:

The air at the Inter Tropical Convergence Zone (ITCZ) rises because of convection caused by high insolation and a low pressure is created. The winds from the tropics converge at this low pressure zone. The converged air rises along up. It reaches the top of the troposphere up to an altitude of 14 km. and moves towards the poles. This causes accumulation of air at about $30^0$ N and S. Part of the accumulated air sinks to the ground and forms a subtropical high. Another reason for sinking is the cooling of air when it reaches 300 N and S latitudes. Down below near the land surface the air flows towards the equator as the easterlies1 or tropical easterlies or trade winds. Because of Coriolis force, their direction becomes north-east and south- east in northern and southern hemisphere respectively. The easterlies from either side of the equator converge in the Inter Tropical Convergence Zone (ITCZ). Thus, winds originated at ITCZ come back in a circular fashion. Such a cell in the tropics is called Hadley Cell.

### 3.5.4 Prevailing Westerlies

In the middle latitudes ($30^0$-$60^0$) the circulation is that of sinking cold air that comes from the poles and the rising warm air that blows from the subtropical high pressure belt. These winds are deflected due to Coriolis force and become westerly in both the hemisphere. Deflected wind is called westerlies. These winds meet along the sub-polar low pressure belt to raise high in the troposphere. From here, air moves away in both directions – towards pole and equator. These winds start descending down above the sup-tropical high pressure belt and polar high pressure belt to form cells. These cells are called Ferrel cell and Polar cell respectively**.**

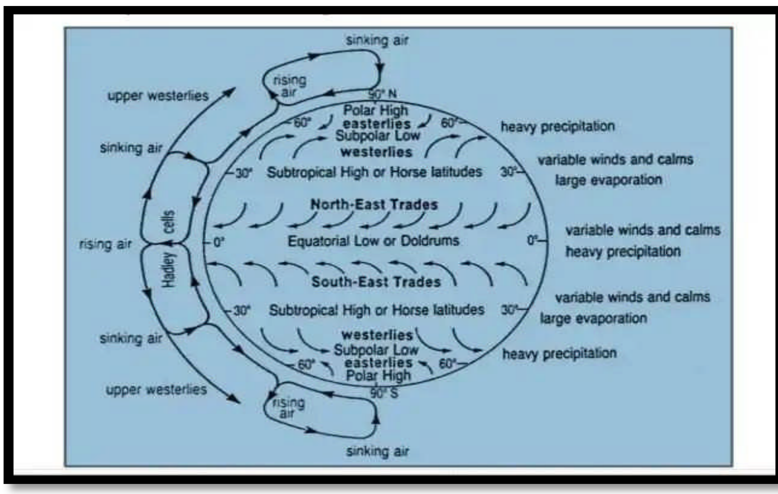



**Fig.:** 3 .7- Planetary winds
*Source: jotscroll.com*

The prevailing westerlies are relatively more variable than the trade winds both in direction and intensity. There are more frequent invasions of polar air masses along with the travelling cyclones and anti-cyclones. These moving cells of low and high pressures largely affect the movement of westerlies. The westerlies are strongerin the cold. In the southern hemisphere, westerlies are so powerful and persistent due to absence of land between 400-600 S that these are called 'roaring forties', 'furious fifties' and 'screaming sixties' along 400 S, 500 S and 600 S latitudes**.**

### 3.5.5. Polar Easterlies

Winds move away from polar high pressure to sub-polar low pressure along the surface of the earth in Polar cell. Their direction becomes easterlies due to Coriolis force. These are called polar easterlies. Winds coming from the sub-tropical and the polar high belts converge to produce cyclonic storms or low pressure conditions. This zone of convergence is also known as polar front (see fronts and cyclones).

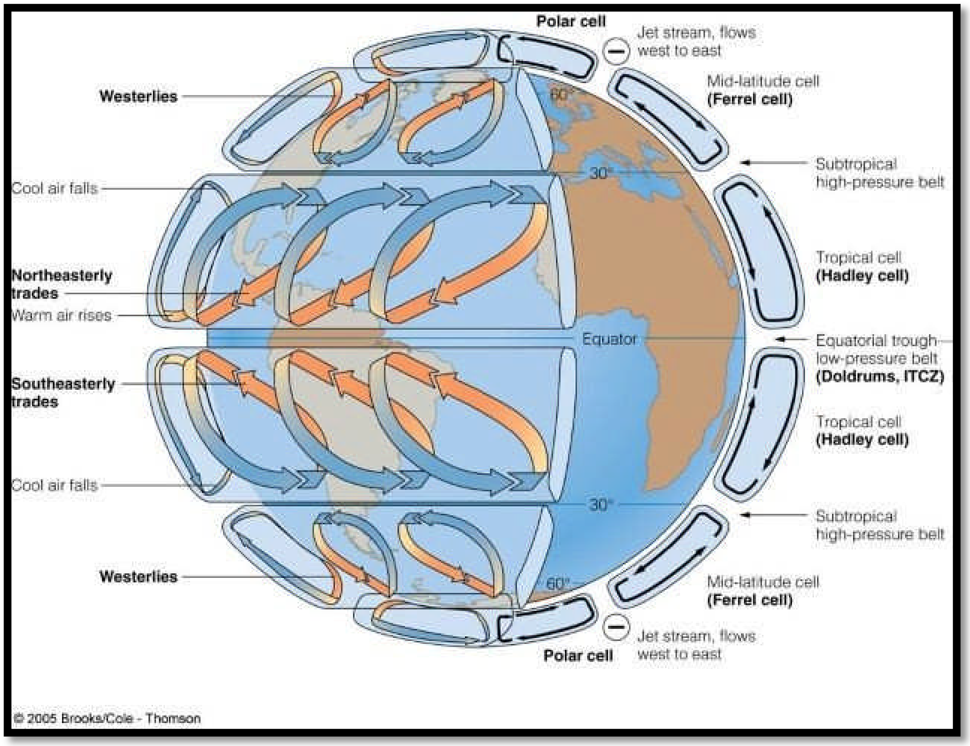



**Fig.: 3. 8**
***Source: Brooks Cole. Thomson***

## 3. 6 LOCAL WINDS

Besides major wind systems of the earth's surface, there are certain types of winds which are produced by purely local factors and therefore, are called local winds. These local winds play a significant role in the weather and climate of a particular locality. Following is a brief account of some of the well-known local winds which are found in different parts of the world.

### 3.6.1 The Land and sea Breezes

These winds are defined as the complete cycle of diurnal local winds occurring on sea coasts due to differences in the surface temperature of sea and adjacent land (figure 19). There is complete reversal of wind direction of these coastal winds. The land and sea breeze system is very shallow with average depth of 1-2km. Over lakes, the height of circulation is much less. Warm tropical areas, where intense solar heating persists throughout the year, experience stronger and regular breezes compare to higher latitudes. Details of land and sea breezes are given in **table 2:**

| Land Breeze | Sea Breeze |
|---|---|
| In the night, the land cools up faster than the surrounding sea. This creates relatively high pressureon land. | During the day the land heats up faster and becomes warmer than the sea. Theheated air rises giving rise to a low pressure area, whereas the sea is relatively cool and the pressure over sea is relatively high. |
| Pressure gradient is created from land to sea. | Pressure gradient is created from sea to land. |
| the wind blows from the land to the sea as the land breeze | the wind blows from the sea to the land as the sea breeze |
| Reaches at peak shortly before the sunrise | Reaches at maximum intensity in mid-afternoon |
| In morning, fishermen enter into sea with the help of land breeze and stays there till mid-afternoon. | Helpful for fishermen in returning fromsea after a good catch. |

**Table: 2-**land and sea breezes

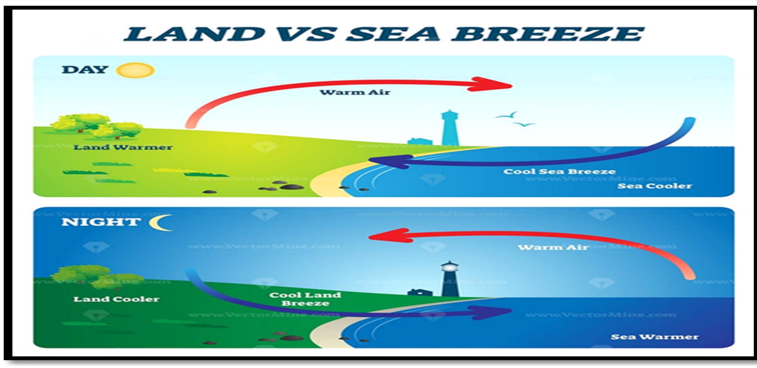




Fig.: **3.9 and 3.10**

***Source: https://www.britannica.com***


Fig.: 3.11

*Source: thecompetitionworld.com*

### 3.6.2 The Mountain and Valley Breezes

Another combination of local winds that undergoes a daily reversal consists of the mountain and valley breezes (figure). During the day the slopes get heated up more than the valleys. Hence, the pressure is low over the slopes while it is comparatively high in the valleys below. Air moves up from slope and to fill the resulting gap the air from the valley blows up the valley. This wind is known as the valley breeze or anabatic wind. The valley breeze is sometimes accompanied by the formation of cumulus cloud near mountain peaks to cause orographic rainfall.

During the night the slopes get cooled and the dense air descends into the valley as the mountain wind. The cool air, of the high plateaus and ice fields draining into the valley is called mountain breeze or katabatic wind.

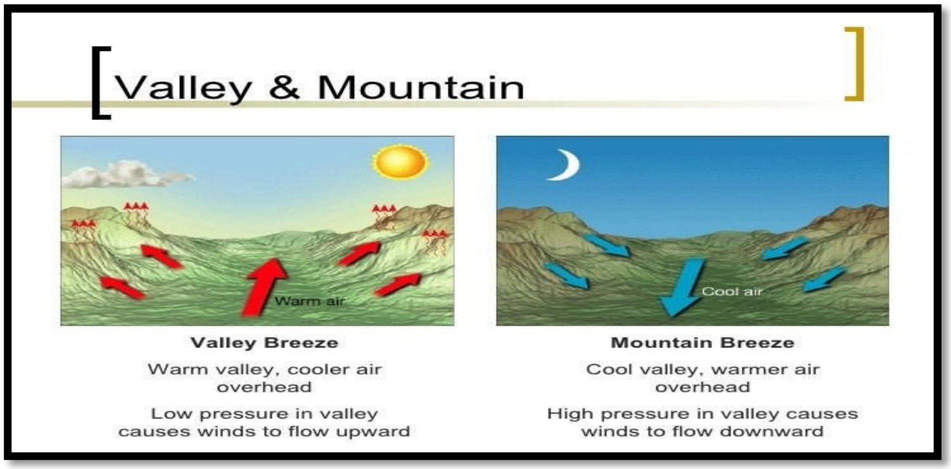



**Fig.: 3.12**
***Source:* *https://www.pinterest.com/***

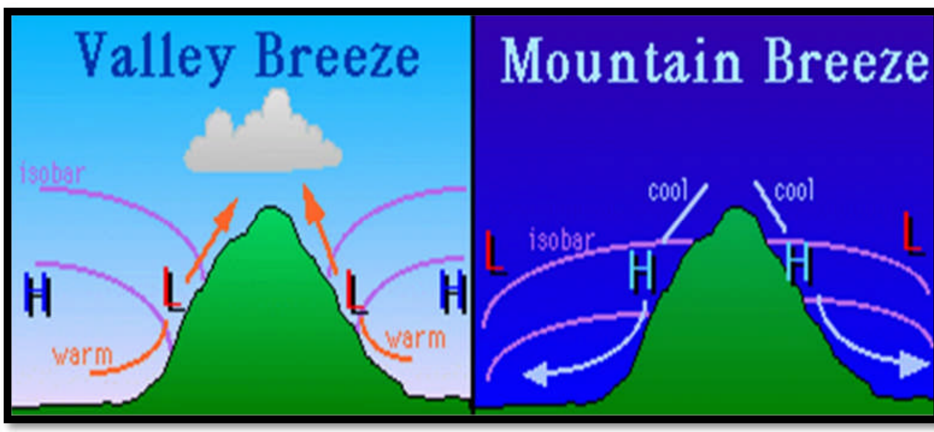



**Fig.: 3.13-Hot Local Winds**
***Sources: https://eschool.iaspaper.net/***

Local winds that are hot and are caused by the advection of hot air from a warm source region. They may also be produced by dynamic heating of air as it descends from an elevated area to lowland. Few famous hot winds are:

**'Loo' is** a hot and dry wind, which blows very strongly over the northern plains of India and Pakistan in the months of May and June. Their direction is from west to east and they are usually experienced in the afternoons. Their temperature varies between 45°C to 50°C**.**

**'Foehn' is** strong, dusty, dry and warm local wind which develops on the leeward side of the Alps mountain ranges. Regional pressure gradient forces the air to ascend and cross the barrier. Ascending air sometimes causes precipitation on the windward side of the mountains. After crossing the mountain crest, the Foehn winds starts descending on the leeward side or northern slopes of the mountain as warm and dry wind. The temperature of the winds varies from 15°C to 20°C which help in melting snow. Thus making pasture land ready for animal grazing and help the grapesto ripe early**.**

**'Chinook'** is the name of hot and dry local wind, which moves down the eastern slopes of the Rockies in U.S.A. and Canada. The literal meaning of chinook is 'snow eater' as they help in melting the snow earlier. They keep the grasslands clear of snow. Hence, they are very helpful to ranchers.

**'Sirocco'** is a hot, dry dusty wind, which originates in the Sahara Desert. It is most frequent in spring and normally lasts for only a few days. After crossing the Mediterranean Sea, the Sirocco is slightly cooled by the moisture from the sea. Still it is harmful for vegetation, crops in that region. Its other local names are Leveche in Spain, Khamsin in Egypt, Gharbi in Aegean Sea area**.**

**Harmattan is** a strong dry wind that blows over northwest Africa from the northeast. Blowing directly from the Sahara Desert, it is a hot, dry and dusty wind. It provides a welcome relief from the moist heat and is beneficial to health of people hence also known as 'the doctor'. It is full of fine desert dust which makes the atmosphere hazy and causes problems to the caravan traders. It may cause severe damage to the crops**.**

### 3.6.3 Cold Local Winds

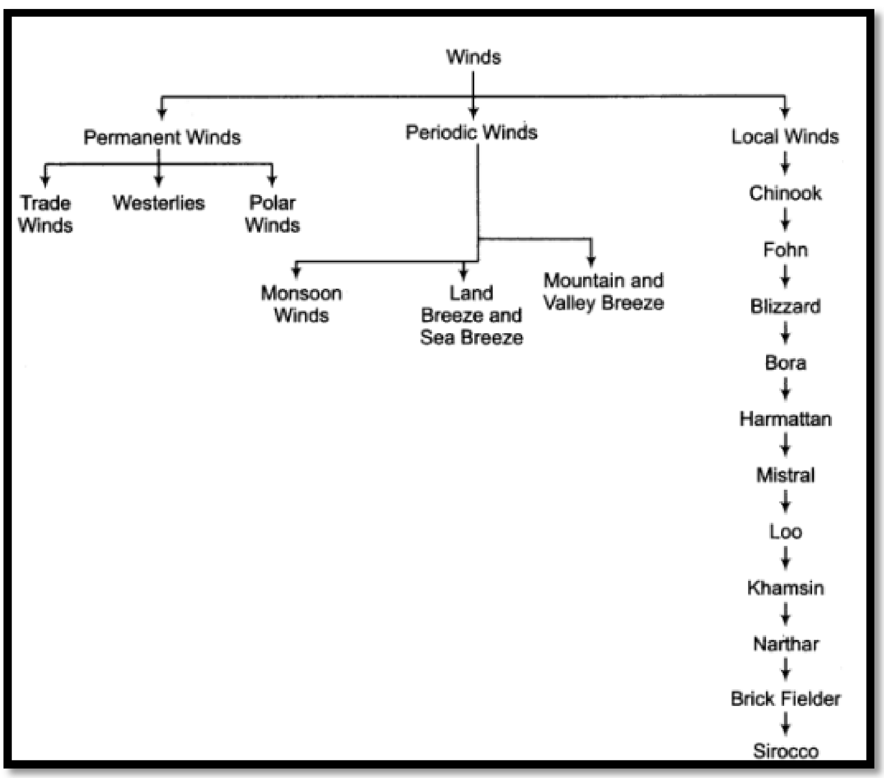
There are certain local winds which originate in the snow-capped mountains during winter and move down the slopes towards the valleys. Few of important these are:

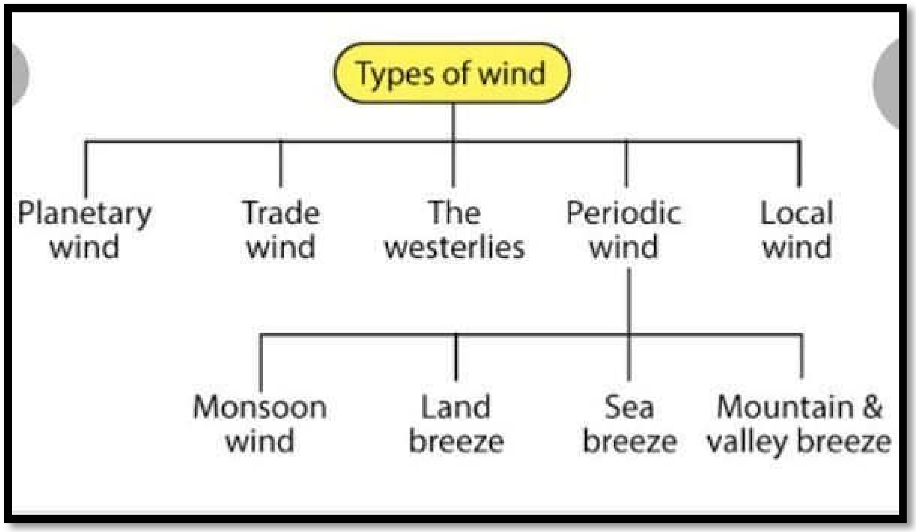
**'Mistral'** originates on the Alps and move over France towards the Mediterranean Sea through the Rhone valley. They are very cold, dry and high velocity winds. They bring down temperature below freezing point in areas of their influence. As a protective measure, many of the houses and orchards of the Rhone valley have thick rows of trees and hedges planted to shield them from the Mistral**.**

**'Bora'** is a cold, dry north-easterly wind blowing down from the mountains in the Adriatic Sea region. It is also caused by pressure difference between continental Europe and the Mediterranean Sea. This is usually occurs in winter. It sometimes attains speeds of over 150 kmph.

**‘Blizzard’** is a violent and extremely cold wind laden with dry snow. Such blizzards are of common occurrence in the Antarctic. Wind velocity sometimes reaches 160 km/ph and temperature is as low as -7$^0$C.


Fig.: 3.14
*Source: https://www.jagranjo*






## 3.7 TRI-CELLULAR MERIDIONAL CIRCULATION

According to the old concept of the mechanism of general circulation of the atmosphere the movement of air is temperature dependent. In other words, tem-perature gradient causes air circulation on the earth's surface. According to the advocates of thermal school of the mechanism of general circulation of the atmos-phere the tropical areas receive maximum amount of solar energy which substantially decreases poleward.

Thus, there is latitudinal imbalance of solar radiation from lower to higher latitudes. Consequently, there is transfer of heat through horizontal air circulation from the areas of high solar radiation (low latitudes) to the areas of low solar radiation (high latitudes) in order to balance the heat energy so that there does not exist too much heat energy in the low latitudes and too low heat energy in the high latitudes.

This old school considers only the horizontal component of the atmospheric circulation and does not consider the potential energy generated by unequal heating of the earth and its atmosphere and its continuous transformation into kinetic energy. It may be pointed out that the potential heat energy is continuously transformed into kinetic energy by the upward movement (ascent) and down-ward movement (descent) of heated and cold air re-spectively.

It may be remembered that the kinetic energy is also dissipated due to friction and small-scale atmospheric disturbances upward. Thus, it is neces-sary that there must exist balance between the rate of generation of kinetic energy and the rate of its dissipa-tion due to friction. The modern concept of the mecha-nism of general circulation of the atmosphere, thus, includes both, the horizontal and vertical components of atmospheric circulation.

The modern school envisages a three-cell model of meridional circulation of the atmosphere, popularly known as tri-cellular meridional circulation of the at-mosphere, wherein it is believed that there is cellular circulation of air at each meridian (longitude). Surface winds blow from high pressure areas to low pressure areas but in the upper atmosphere the general direction of air circulation is opposite to the direction of surface winds.

### 3.7.1 Cells of Tri-Cellular Meridional Circulation

Thus, each meridian has three cells of air circulation in the northern hemisphere e.g.:

(1) Tropical cell or Hadley cell,
(2) Polar front cell or mid-latitude cell or Ferrel cell, and
(3) Polar or subpolar cell

### 3.7.2 Tropical Cell

Tropical cell is also called as Hadley cell because G. Hadley first identified this thermally in-duced cell in both the hemispheres in the year 1735. The winds after being heated due to very high tempera-ture at the equator ascend upward. These ascending warm and moist winds release latent heat after conden-sation which causes further ascent of the winds which after reaching the height of 8 to 12 kilometres in the troposphere over the equator diverge northward and southward or say poleward.

The surface winds in the name of trade winds blow from subtropical high pres-sure belts to equatorial low pressure belt in order to replace the ascending air at the equator. The upper air moving in opposite direction to surface winds (trade winds) is called antitrade. These upper air antitrades descend near 30°-35° latitudes to cause subtropical high pressure belt.

These antitrades after descending near 30°-35° latitudes again blow towards the equator where they are again heated and ascend. Thus, one complete meridional cell of air circulation is formed. This is called tropical meridional cell which is located between the equator and 30° latitudes. It may be pointed out that the regularity and continuity of the antitrade wind systems in the upper air has been refuted by a host of meteorologists on the basis of more upper air data being available during and after Second World War.

### 3.7.3 Polar Front Cell or Mid-Latitude Cell

Polar front cell or mid-latitude cell-Accord-ing to old concept surface winds, known as westerlies, blow from the subtropical high pressure belt to subpolar low pressure belt (60°-65°). The winds ascend near 60°-65° latitudes because of the rotation of the earth and after reaching the upper troposphere diverge in opposite directions (poleward and equator-ward).

These winds (which diverge equator-ward) again descend near horse latitudes (30°-35° latitudes) to reinforce subtropical high pressure belt. After descending these winds again blow poleward as surface westerlies and thus a complete cell is formed.

According to new concept of air circulation the pattern between 30°-60° latitudes consists of surface westerlies. In fact, winds blow from subtropical high pressure belt to subpolar low pressure belt but the winds become almost westerly due to Coriolis force. It may be mentioned that the regularity and continuity of westerlies are frequently disturbed by temperate cy-clones, migratory extra-tropical cyclones and anticy-clones.

Contrary to the existing view of upper air tropospheric easterly winds in the zones extending between 30°-60° latitudes Rossby observed the exist-ence of upper air westerlies in the middle latitudes due to poleward decrease of air temperature.

According to G.T. Trewartha the middle and upper tropospheric westerlies are associated with long waves and jet streams. Warm air ascends along the polar front which is more regular and continuous in the middle tropo-sphere. It may be pointed out that this new concept does not explain the cellular meridional circulation in the middle latitudes.

### 3.7.4 Polar Cell

Polar cell involves the atmospheric circula-tion prevailing between 60° and poles. Cold winds, known as polar easterlies, blow from polar high pres-sure areas to sub-polar or mid- latitude low pressure belt. The general direction of surface polar winds becomes easterly (east to west) due to Coriolis force. These polar cold winds converge with warm westerlies near 60°-65° latitudes and form polar front or mid- latitude front which becomes the centre for the origin of temperate cyclones. The winds ascend upward due to the rotation of the earth at the subpolar low pressure belt and after reaching middle troposphere they turn poleward and equator-ward. The poleward upper air descends at the poles and reinforces the polar high pressure. Thus, a complete polar cell is formed.

Numerous objections have been raised against the concept of tri-cellular meridional circulation of the atmosphere. The temperature gradient should not be taken as the only basis for the origin and maintenance of cellular meridional circulation because not all the high and low pressure belts are thermally induced.

For example, the subtropical high pressure and sub-polar low pressure belts are dynamically induced due to subsidence and spreading of air caused by the rotation of the earth respectively. Upper air anti-trades are not uniformly found over ail the meridians. If the trade winds are exclusively of thermal origin, then the ther-mal gradient must be present boldly throughout the tropics but this is not true. At the height of 500 to 1000m in the atmosphere the winds become almost parallel to the isobars which are generally parallel to the latitude. If this is so, the meridional cell of air circulation may not be possible.

The pressure and winds in most parts of lower atmosphere are found in cellular form rather than in zonal pattern. These pres-sure and winds cells are elliptical, circular or semi - circular in shape. These evidences (cellular form of air circulation) no doubt contradict the old concept of general pattern of atmospheric circulation but the cel-lular meridional circulation has not been fully vali-dated.

## 3.8 UPPER AIR CIRCULATION

It is now realized that the causes of weather on the ground are intricately bound up with what happens at higher levels in the atmosphere. This applies especially to the development of anti- cyclones and depressions and to the general circulation of winds around the globe. Such phenomena can only be appreciated by understanding air circulation in the upper layers. Broadly speaking, wind speed tendto increase with altitude because of lower air density, lower frictional force etc. Direction of wind also is not same. For instance, during the month of July, surface wind(monsoonal) blow from south-west direction in India while at the height of 10km there are swift winds blowing from east to west.

On a global scale, pressure patterns higher up tend to be much simpler than those at the surface level, largely because of the diminished thermal and mechanical effects of land masses. There is a falling pressure gradient from the sub-tropical areas towards the poles. The gradient is strongest in winter, when the temperature contrasts between the respective polar areas and the equator are most marked.

### 3.8.1 Jet Streams

Changes in pressure distribution with height are largely related to changes of temperatures. We can see how this can be so with references to two adjacent columns of air in the troposphere depicted in figure. At ground level the pressure exerted by the two is the same, but important changes ensue if we assume that column A is warmer, and therefore less dense throughout than column B. This means that for any level higher up in the two columns, for instance at 2km, there is a greater pressure of air still above this level of column A than in column B. Therefore, a pressure gradient from A to B gradually develops and intensifies with height, where none existed at the surface. Now, it can be visualized that a gradual change of velocity of the wind with height, the wind at the top of the air layers being very much stronger than that lower down.

Applying this on a global scale by associating poles with cold air column and equator with warm air column, the gradual poleward decrease of temperature in the atmosphere from the equator should result in a large westerly component in the upper winds. It was found in 1940s during Second World War that high-flying aircraft encountered upper winds of very great velocity. These are known to be concentrated bands of rapid air movement, which are termed jet streams. Few of the features of jet streams are:

- These are narrow belts at the high altitude near the top of the troposphere.

- Their speed varies from about 110 km per hour (kmph) in the summer seasonto more than 180 kmph in the winter season.

- Their shape is circular. Speed in the jet streams decreases radially outwards (figure 22(a)). One way of visualizing this is to consider a river. The river's current is generally the strongest in the center with decreasing strength as one approaches the river's bank. It can be said that jet streams are "rivers of air".

- They are several hundred kilometres wide and about 2 km to 5km deep.

- The flow of jet streams is not in form of straight line. Their circulation path iswavy and meandering. These meandering winds are called Rossby waves

- They dip and rise in altitude/latitude, splitting at times and forming eddies, andeven disappearing altogether to appear somewhere else.

- Jet streams also "follow the sun" in that as the sun's elevation increases each day in the spring, the average latitude of the jet stream shifts poleward. (By Summer in the Northern Hemisphere, it is typically found near the U.S. Canadian border.) As autumn approaches and the sun's elevation decreases, the jet stream's average latitude moves toward the equator.

- On occasions the jet stream breaks through the tropopause and enters into the lower stratosphere. Certain amount of water vapour manages to reach in lower stratosphere with jet streams and this layer exhibits occasional cirus clouds. At times, the jet stream effect extends down to an altitude of about 3 km from the earth's surface.

- There is a well-marked longitudinal variation in the strength of the jet stream.

  In winter, the highest wind velocities of the jet stream are found near the east coast of Asia and weakest over the eastern Atlantic and Pacific Oceans. In summer, strongest jet is positioned along the Canadian border and Mediterranean region.

  Two permanent jet stream zones occur in each hemisphere. One is sub-tropical jet stream and another is polar front jet stream. There is another jet stream which moves seasonally near equator. Description of these three streams is give below:

### 3.8.2 The polar front jet stream

- It is originated because of temperature difference.
- It is associated with the polar front zone7 in each hemisphere (figure)
- It runs at a more meandering path than the Sub Tropical Jet Stream
- It extends between 40 and 60 latitudes in both Hemispheres.
- It is found at a height between 6km and 9km in the atmosphere.

- It swings towards poles in summers and towards equator in winter. When swinging to south it takes very cold air with it to subtropical region.

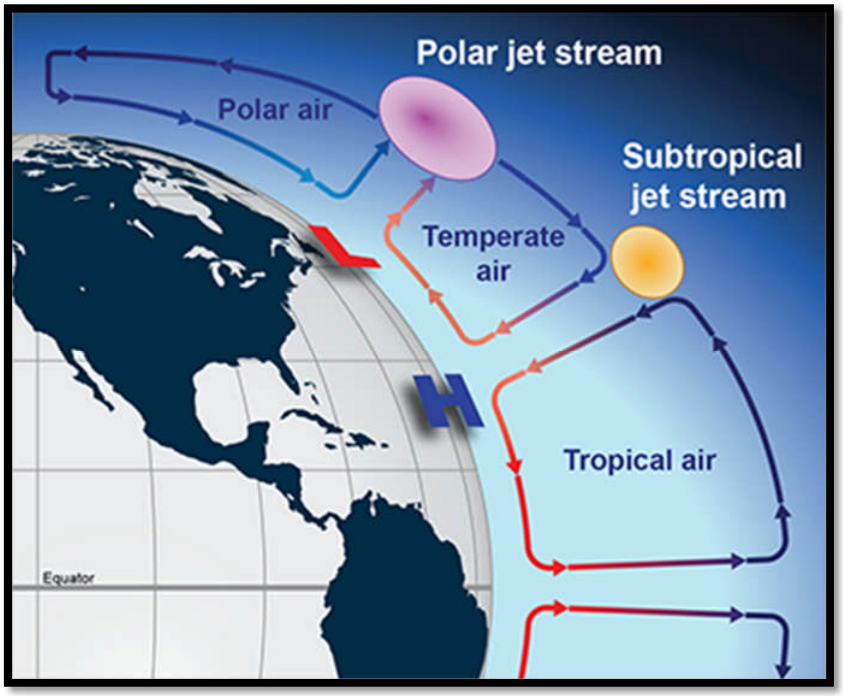



Fig.: 3.15
*Source: https://www.weather.gov*

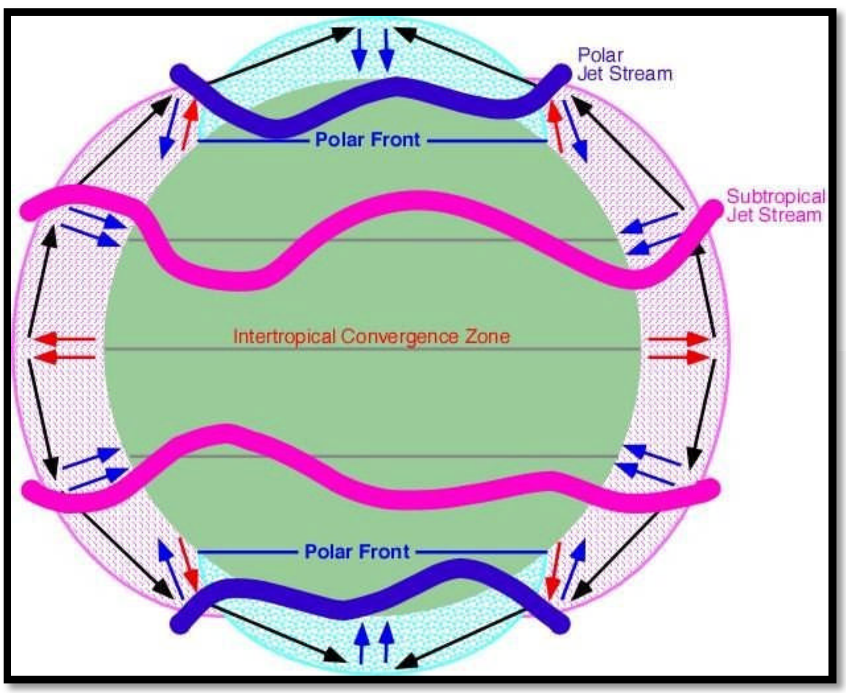



**Fig.: 3.16**
***Source: www.physicalgeography.net***

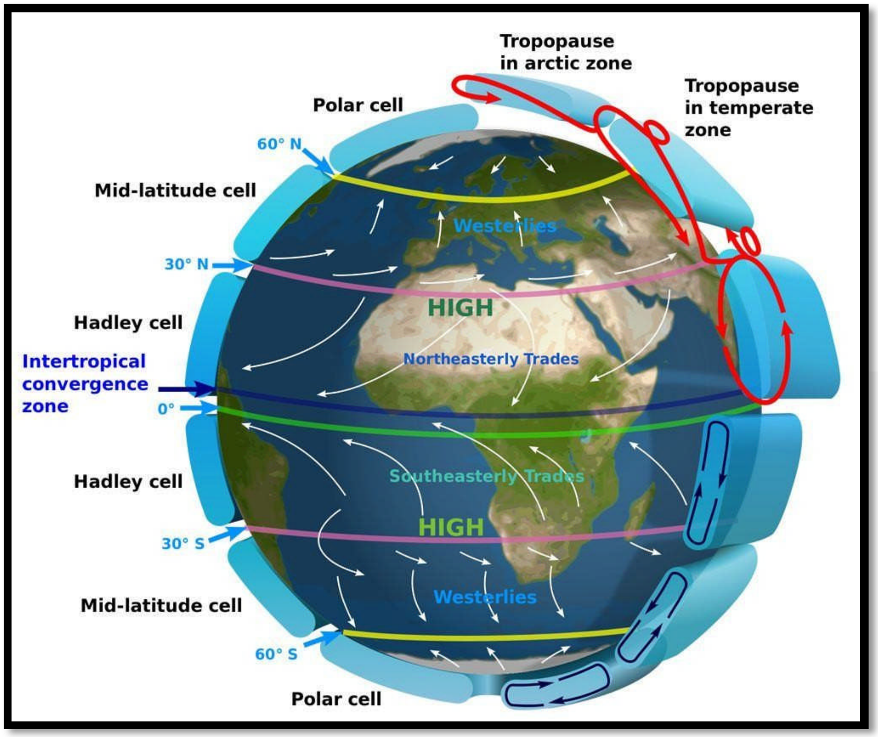



**Fig.: 3.16**
***Source: https://www.nationalgeographic.org/***

### 3.8.3 Sub-tropical jet stream

- It runs between 250 and 300 latitudes in both the hemispheres.
- It blows constantly
- Its speed is comparatively lower than polar jet streams
- The air currents arising near about the equator descend at 300 N and S latitudes. A part of these air currents takes the form of Sub Tropical Jet streams.
- It swings to the north of Himalayas in summer in North India.

### 3.8.4 Eastern Tropical Jet Stream

- It is a seasonal Jet Stream.
- It blows between equator and 200N latitude at the time of South-WestMonsoon in summer over south-east Asia, India and Africa.
- Its direction is opposite to that of other two jet streams. It runs in easterndirection.
- It is located comparatively at higher height between 14km and 16km
- Its speed is around 180 km per hour.

### 3.8.5 Consequence of Jet Stream

- They affect weather conditions
- They substantially contribute to originating cyclones, anticyclones, storms anddepressions and influence their behaviour.
- The bursting of monsoon in India is said to be closely related to EasternTropical Jet streams.
- If the weather is not disturbed the aeroplanes running in their paralleldirections gain great speed and considerably save fuel.
- Sometimes aeroplanes cannot be flown in opposite direction.
- These jet streams are still being investigated with respect to their effect onweather conditions.

## 3.9 ORIGIN OF MONSOON: CLASSICAL AND RECENT VIEWS

The term monsoon is derived from Arabic word 'mausim' meaning 'season'. Arabians were known to general pattern of winds in different seasons. As such, Arabians used to sail their ships for the movement of goods and people. It is believed that seamen used to describe alternating winds in Arabian Sea where they appear to blow from north east for six months and from southwest for another six months. Seasonal alternating of wind direction and speed was used by early seamen to trade from India to Arab and African countries during winter and return trade from African and Arab countries to India during summer.

Scholars engaged in studies of climatology and meteorology have defined monsoon from different angles. Some of the commonly used definitions have been given below to explain the wider context of monsoon.

"Monsoons are large scale seasonal wind systems blowing over vast areas of the globe persistently in the same direction, only to be reversed with change of season." Rama Shastry.

"That the monsoon represents simply a land and sea breeze on a large scale, and that the annual period of the monsoon corresponds to diurnal period of breezes." Angot, Hann and Koppen.

"Whereas monsoon climates appear to be very complex in detail, their fundamental principle that of land and sea breezes on a large scale remains simple and straightforward." Miller

According to Nieuwolt, "The word monsoon is used only for wind systems where the seasonal reversal is pronounced and exceeds a minimum number of degrees." The term has been applied to wind system which shows at least 120 degrees of change of wind direction with the change of a season. These winds are characterized by constancy higher than 40 percent and a mean resultant speed of more than 3 meters /second.

According to Chang-Chia-Ch'ing "Monsoon is a flow pattern of the general atmospheric circulation over a wide geographical area, in which there is a clearly dominant wind in one direction in every part of the region concerned, but in which this prevailing direction of wind is reversed (or almost reversed) from winter to summer and from summer to winter".

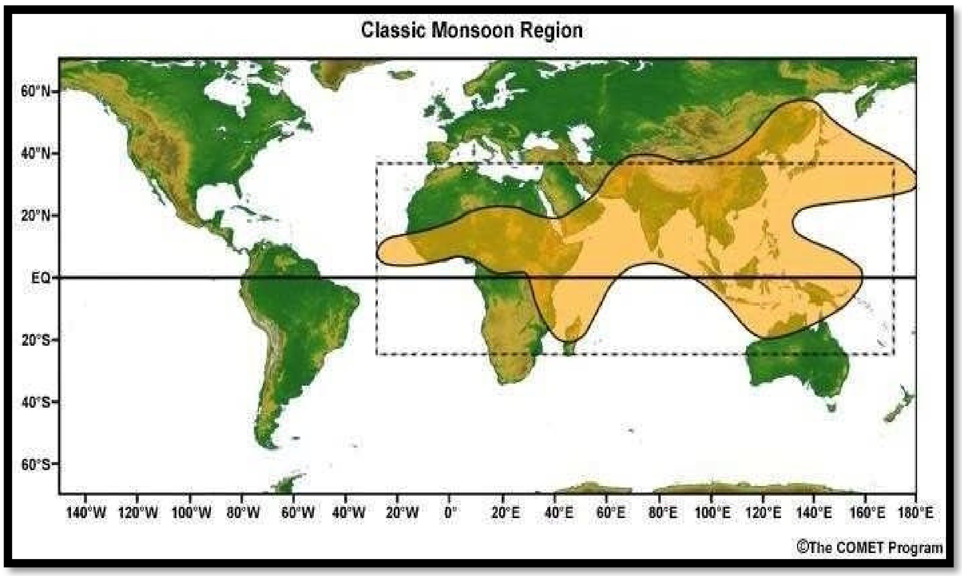



Fig.: 3.17-Monsoon Region of the World
*Source: The COMET Program*

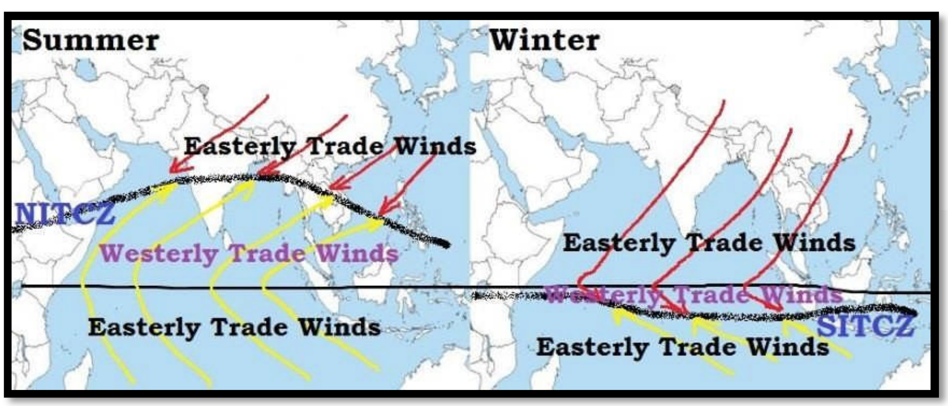



**Fig.: 3.18**
**Source - https://www.pmfias.com/**

### 3.9.1 Theories of The Origin of Monsoon

The origin of monsoon is a complex meteorological and climatological phenomenon. Scientists have developed theories to solve the mystery of the origin of monsoon. These are broadly grouped under the following three:

- Classical Theory
- Dynamic Theory
- Modern Theory

**A brief description about each theory is given below:**

### 3.9.2 Classical Theory

The theory was propounded by Sir Admond Halley in 1686. It was further extended and supported by Hann, Koeppen and Miller. As per theory, monsoons are the extended land breeze and sea breeze on a large scale, produced by the differential heating of continents and oceans. The response of continents and oceans to solar energy creates striking difference in surface pressure conditions and movement of local winds. Most of the solar energy received at the ground by the continents is used up in heating the air. Only a shallow layer of a few meters of soil are heated by energy received at the ground by the continents. Contrary to this, solar energy is able to penetrate much greater depths of oceans because water being a good conductor of heat. Consequently, a smaller part of solar heat is available for heating the air in oceanic areas. The overall result is that rise in temperature in summer is much less over the oceans as compared to the continents. It has been observed that the mean summer temperatures over the continents often exceed those of the oceans by 50 to 100 C across the same latitude. The situation in winter is reversed and greater heat storage of oceans leads to higher temperatures as compared to the continents.

During summer season, in northern hemisphere, a thermally induced low pressure centres develop in the Thar, Arabia and Sahara. An elongated low pressure belt over a large area from Sahara to Thar develops to the north of tropic of Cancer. Conditions of marked thermal contrast between continents and oceanic areas cause a sea to land air pressure gradient during summer season. As a consequence, the normal wind system from north east is reversed to south west. The air moving from oceans towards continents is warm and moist.

Land barriers such as mountains and plateaus obstruct the air motion and lead them to ascend. Warm moist air ascends along the land barriers and causes precipitation. Land barriers such as Western Ghats obstruct south west warm and moist winds and cause rainfall along the west coast of India. Contrary to the above, Aravali Hills, despite having north- south orientation similar to that of Western Ghats, fail to cause rainfall because of its location north of tropics and the absence of oceanic proximity. As such, moisture laden winds from Arabian Sea weaken by the time they approach Aravali areas and hence cause scanty rainfall.

The situation of south west monsoon in July is depicted in Figure 2 when sunis over head at tropic of cancer and two low pressure areas develop one in central India and another in the highlands of central Asia. Because of relatively low temperature (southern winter) a high pressure belt develops in central Australia and southern part of Indian Ocean.

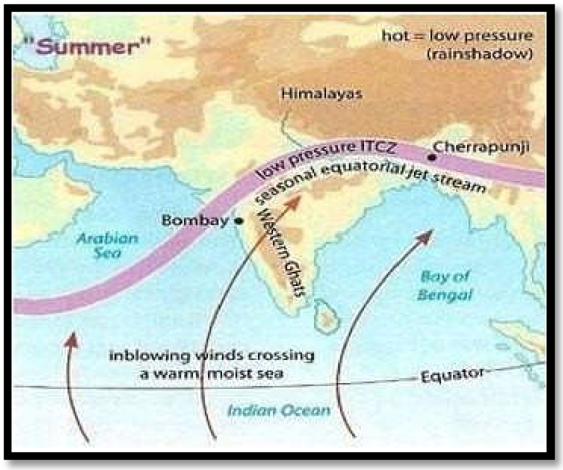



**Fig.: 3.19 -Position of ITCZ and Southwest Monsoon in July**
***Source:* https://www.civilsdaily.com**

Similarly, conditions of thermal contrasts during winter season cause a land to sea air pressure gradient. The change in pressure pattern begins by September in northern hemisphere. With the apparent movement of sun towards Tropic of Capricorn, temperature begins to decrease while air pressure starts increasing in northern hemisphere. By December– January a high air pressure gets fully established in northern hemisphere with its centre near Lake Baikal (1035 mb) and in north Indian plains. Compared to the continental areas which are cold and zones of high air pressure, heat storage of oceans leads to record a higher temperature and low air pressure during winter season. As a consequence, winds blow from continents to oceanic areas in northern tropics. Since air moving from land is cold and dry, it is incapable of giving precipitation unless it comes in contact with large water bodies like sea and ocean. But in case of Tamil Nadu region of India and in Sri Lanka, north- east trades cause sufficient rainfall because they pick up moisture from Bay of Bengal on their way from northeast to southwest.

The position of Sun is overhead close to tropic of Capricorn in December- January. The low pressure develops to the south of equator, along tropic of Capricorn and in central Australia. As a consequence, there is an outflow of air from oceans towards continental areas. North-west monsoon is active in southern hemisphere causing heavy rains in Australia and areas close to tropic of Capricorn.

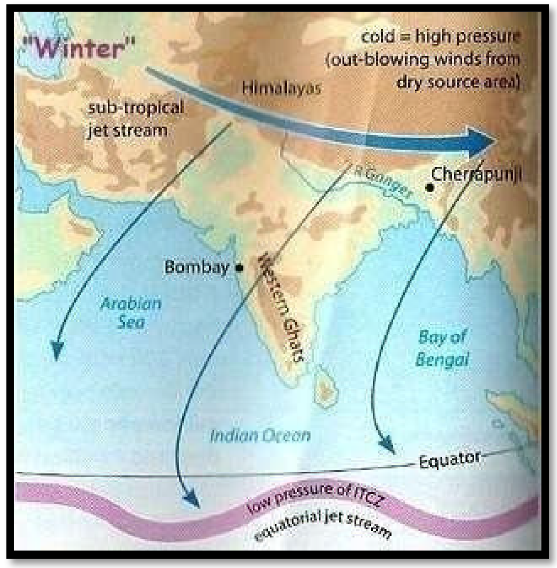



**Fig.: 3.20-Position of ITCZ and Southwest Monsoon in January**
***Source: dspmuranch.ac.in***

**Criticisms**

The theory of thermal contrasts about the origin of monsoon suffers fromcertain limitations which are briefly discussed below:

- The basic premise that high thermal conditions over land cause low atmospheric conditions resulting in air movements from oceans which are related to low thermal conditions during summer season. It does not seem to explain the origin of monsoon fully as the highest temperature in land areas are usually associated with the months of April and May when there is a complete absence of rainfall.
- Monsoonal rainfall are not solely orographic, rather they are a jointly produced phenomenon with convectional and cyclonic situations.
- The surface and upper air circulations are usually opposite in their orientation. Had the origin of monsoons been thermally induced, there need to be an anti- monsoon air-circulation in upper air which is not so in some of the cases.
- The theory does not take into account circulation of oceanic water which is a major cause of thermal contrast among the oceans.
- The theory also ignores upper air circulation which serves as the base for the intensity and extension of summer rainfall in tropics.

### 3.9.3 Dynamic Theory

It was propounded by Flohn, a German Meteorologist, in 1951. The theory was further enriched by the research works of Krishna Rao (1952). It is also known as theory of shifting pressure and wind belts. According to Flohn, monsoon is the result of seasonal migration of planetary winds and pressure belts. The trade winds from both the hemispheres converge near equator and form Inter Tropical Convergence (ITC) zone. The northern and southern limits of ITC are known as NITC and SITC respectively. A narrow belt of doldrums lies in between NITC and SITC and is characterized by 'equatorial westerly's.

During summer solstice, trade winds of southern hemisphere (south-east trade winds) extend and shift northward while during winter solstice trade winds of northern hemisphere (north- east trade winds) extend and shift southward from their normal position. The south-east trades in association with equatorial westerly's produce south-west or summer monsoon around summer solstice when sun is overhead at tropic of Cancer. Similarly, around winter solstice when sun is overhead at tropic of Capricorn, north-east trades in association with equatorial westerly's produce north-west or winter monsoon. Thus, shifting position of pressure and wind belts due to dynamic motion of the earth is responsible for the origin of monsoon and reversal of wind patterns in the tropics. Obviously, the shifting of the ITCZ is responsible for the reorientation of pressure and wind conditions in tropics. The Figure 4 represents the location extent of ITCZ in January and July.

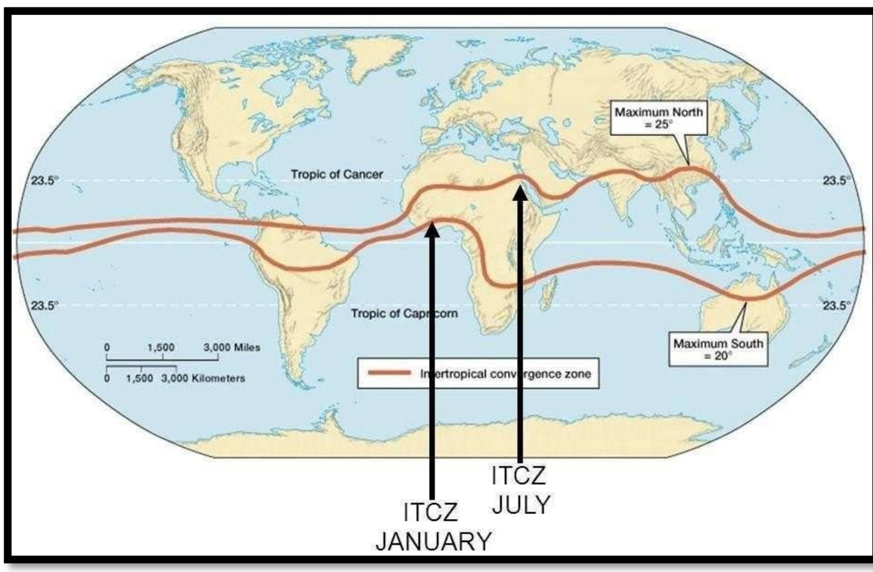



**Fig.: 3.21-Average Position of ITCZ in January and July**
***Source: slideplayer.com***

**Criticisms**

The apparent change in the position of sun causes north and southward shift of ITCZ. There is an associated change in the pressure conditions over land and sea in the tropical belt. The directional change of winds is more pronounced around Indian Ocean which has alternating distribution of land and sea. The theory has a scientific significance in explaining the origin of south-west and north-west monsoon in association with the movements of planetary trade winds. However, theory carries some limitations. They are briefly explained below:

- Theory does not take into account the role of upper air circulation which remains significant in maintaining the rhythm of monsoon for a fairly long period and over extensive areas in tropics.
- Theory also seems to have ignored the oceanic circulation and temperature gradient in oceanic waters.

The position of air masses (warm/cold) and their gradual shift from tropics is one of the potent factors that affect the origin of monsoon. Theory does not seem to include these vital elements.

### 3.9.4 Recent theory

With the advancement in satellite technologies, précised weather recording instruments and global network of meteorological observations, a large and varied data is now available to process through computers, develop models and arrive at very precise results about weather and climate. The recent theory related to the origin of monsoon is based on observations concerning upper air circulation, temperature conditions over Tibetan Plateau, jet streams, Oceanic water circulation, the occurrence of El- Nino and La Nina and Southern Oscillations. A brief discussion on these elements is given below:

### THE MONSOON EXPEDITION

To understand the causes and the mechanism of monsoon an Indo- Soviet joint expedition was carried out in 1973. The Monsoon expedition, popular known as Monex, was jointly organized in May – July 1973. Four Soviet and Two Indian Ships equipped with scientific tools of meteorological observations were used to take precise observations in Indian Ocean, Bay of Bengal and Arabian Sea.

Dr. P. Koteswaram and Professor H. Flohn suggest that the Tibetan Plateauis a source of heat for the upper atmosphere. The rising temperature in higher altitudes generates an area of rising air motion. During summer, Tibetan plateau remains warmer by $2^0$ - $3^0$ C than the adjoining areas. The low pressure created in Tibetan Plateau pushes westerly Jet further northward. It coincides with the arrival of Indian summer monsoon. The southward blow of air from Tibet helps to strengthen the prevailing easterly winds over south India. It explains the appearance of easterly Jet at about the same time as appearance of Indian monsoon. The facts have been shown by a diagram given below

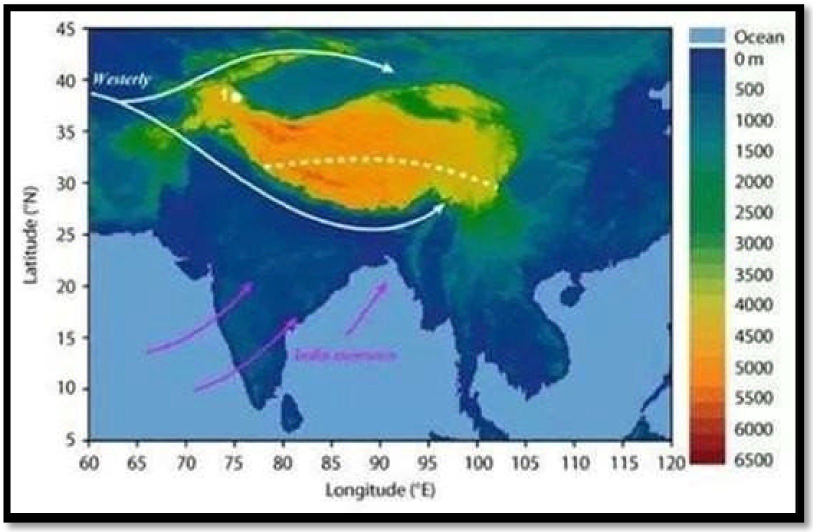



**Fig.:** 3.22-Tibetan Plateau Heating and Westerly Jet Stream Shift
*Source:novascience.wordpress.com*

According to Maung Tun Yin, there is a correspondence between shifting of the Jet and slowing down of the westerly jet over whole of Eurasia. As against this, Plateau of Tibet becomes very cold during winter and serves as the most important factor in advancing the westerly Jet to the south by mid of October. It helps in establishing cold wave and western disturbances over north Indian plains resulting in high pressure over land surface and low pressure over Indian Ocean. These meteorological conditions help in causing favorable monsoon.

## 3.10 EL-NINO AND MONSOON

The effect of El-Nino on summer monsoon is significant. El- Nino is a warm ocean current appearing along the coast of Peru. The literal meaning of El-Nino is Child Christ or little boy and it develops generally in December. Peru or Humboldt is a cold current flowing along the coast of Peru. The appearance of El-Nino reverts the condition of Peru current by developing a warm water and moist air conditions over eastern Pacific (Peru coast) and cold conditions in western Pacific coast (eastern Australia and Indonesia). As a result, eastern Pacific along Peruvian coast in South America records high rain fall while western Pacific along Australian and Indonesian coast record drought conditions. El-Nino results in weakening of the monsoon causing drought conditions and crop failures in Monsoon regions of South and South East Asia. The warming of Indian Ocean, under the influence of El- Nino weakens the intensity of Monsoon.

## 3.11 LA-NINA AND MONSOON

La-Nina, the word originates from Spanish meaning “Little girl”. It is characterized by unusually cold ocean temperatures in equatorial

Pacific. During the period of La-Nina, sea surface temperature across Equatorial eastern central Pacific Ocean will be lower than normal by 30 to 50 C. It has extensive effect on the weather in North America, even affecting Atlantic hurricane season. La-Nina caused heavy rains over Malaysia and Philippines and Indonesia. Western side of the Equatorial Pacific is characterized by warm, wet low pressure weather as the collected moisture is dumped in the form of typhoons and thunderstorms. The ocean is some 60 centimetres higher in western Pacific compared to eastern as a result of this motion. The water and air is return to the east. Both of them are now much cooler and the air in the surface much drier.

## 3.12 SUMMARY

Air pressure is invisible element of weather which influences the other weather elements in a significant way. Air pressure is closely tied to other elements of weather in cause-and-effect relationship. Variations in the air pressure from place to place are responsible for the movement of winds which serve as a means of transporting heat and moisture from one region to another. Like any other material object, the air also has weight. The pressure of air at a given place is defined as a force exerted in all directions in consequence of the weight of all air above it. Thus, the mass of a column of air above a given point determines the atmospheric pressure at that point. Air pressure, therefore, is defined as the force exerted against a surface by continuous collision of gas molecules. The amount of pressure exerted by air at a particular point is determined by two factors, namely, temperature and density. It is obvious that pressure belts are not only induced by thermal factor but they are also induced by dynamic factor. On the basis of mode of genesis pressure belts are divided as Thermally induced pressure belts and Dynamically induced pressure belts.

Wind refers to the horizontal movement of air relative to the earth's surface. Even though horizontal as well vertical movements of air are equally important; far more air is involved in the horizontal movement. Winds are the means by which uneven distribution of pressure over the globe is balanced out. Winds have been considered by meteorologist as an essential part of the thermodynamic mechanism of atmosphere which serves as a means of transporting heat, moisture and other properties from one part of the earth to another. There are numerous factors which affect the wind motion. Some of the most important are pressure gradient, rotation of the earth, frictional forces, centrifugal action of wind, altitude etc. Wind movement in the atmosphere may be classified into three broad categories, Planetary winds, Periodical winds and local winds. Trade winds, Westerlies and Polar easterlies together form the planetary winds. Periodical winds consists of monsoons, land and sea breezes etc, and local winds include all those local winds which are produced by local causes and which only affect the weather and climate of a particular locality and area. According to Trewartha the winds are not so important as weather elements, rather they become crucial to all life forms on the earth as controls of temperature and precipitation.

## 3.13 GLOSSARY

**Equatorial zone:** Latitude zone lying between 100S and 100N and centred on theequator.

**North East Trade winds:** Surface winds of low altitudes that blow steadily from thenorth east.

**North Pole:** Point at which the northern end of the earth's axis of rotation intersectsthe earth surface.

**Pressure gradient force:** causes air to move from areas of higher barometric pressureto areas of lower barometric pressure due to pressure differences.

**Pressure:** force per unit area.

**Monsoon:** derived from the Arabic word Mausim, meaning "Season" refers to an annual cycle of dryness and wetness, with seasonality shifting winds produced by changing atmospheric pressure systems.

***Long Type Question***

1) Define Air pressure. Give the Horizontal distribution of air pressure.
2) Discuss in detail the major pressure belts of the world.
3) Define Air pressure. Give the horizontal distribution of air pressure in the monthsof January and July.
4) Describe the main types of the winds. Discuss their origin.

## 3.14 SUGGESTED READINGS


- Singh, Savindra.,2013, Physical Geography, Pravalika Publications, Allahabad.
- Husain, Majid., 2001, Fundamentals of Physical geography, Rawat publications,Jaipur and New Delhi


## 3.15 REFERENCES


- Monkhouse, F.J., 1993, Principals of Physical geography, Kent, Hodder andSoughton.
- Strahler, S.,1996, Physical Geography, New York, John Wiley & Sons. Lal, D.S., 2000, Climatology, Sharda Pustak Bhawan, Allahabad.
- Tikka, R.N., 1994, Physical Geography, Kedar NathRam Nath & Co, Meerut.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# 4

# TEMPERATURE AND HEAT BUDGET OF EARTH

**Unit Structure**

After going through this unit the students will be able to understand the following features:

## 4.1 OBJECTIVES

a. To provide the students with conceptual clarity about Air masses, Fronts and Extra Tropical Cyclones and help them understand the various climatic phenomena and associated weather conditions that are commonly experienced by humans on a regular basis but since the mechanism behind the appearance of such conditions is unknown, it becomes difficult to identify them or relate to their occurrence.

b. To familiarize the students with the important aspects of the formation of air masses, fronts and temperate cyclones since all the three are very much related and dependent on one another to the extent that without the existence of any one of them the cyclone development wouldn't be possible.

c. To acquaint the students with the diverse climate types presented by two famous climatologists in their respective climate classification of the world. This will help them understand how the world can be divided into separate climate zones and the chief characteristics of these zones.

## 4.2 INTRODUCTION

The students by this time would have got a fair understanding of the nature, scope and importance of the subject of climatology, the structure and composition of the atmosphere, the heat budget, temperature distribution, general circulation of the atmosphere, the planetary, seasonal and local winds and their patterns and the jet streams, monsoon mechanism and the global pressure belts. A clear understanding of these global climatic phenomena shall assist the students in gaining a comprehensive knowledge of the origin, forward movement and types of air present in the earth's atmosphere. These air masses are responsible for generating widespread impact on the regions over which they blow and this in turn alters the weather of the respective regions, while leaving a considerable influence on the air mass itself. These different air masses have a contrasting nature due to their birth in diverse and dissimilar regions of the earth, be it land surface or oceans, and be it hot areas or cold. These air masses of contrasting nature are responsible for the creation of their respective fronts and the process of frontogenesis is initiated. There are varying weather conditions associated with the fronts and how these finally lead to the formation of a full-fledged cyclone. A detailed description of the features, origin and life stages of an extra tropical cyclone is presented in the chapters that follow in an easy to understand and a chronological fashion for the knowledge enrichment of the students.

## 4.3 AIR MASSES: ORIGIN, CLASSIFICATION, TYPES

### 4.3.1 Air Mass:

Barry and Chorley (1968) have defined the term air mass as a large body of air whose physical properties namely; temperature, moisture content and lapse rate are more or less uniform horizontally for hundreds of kilometers.

In the words of Strahler (1978) an air mass is a body of air in which the upward gradients of temperature and moisture are fairly uniform over a large area.

The expanse and extensiveness of the air masses is huge, covering large portions of the continents spanning a distance of thousands of kilometers. These can even extend up to a height of many kilometers into the troposphere. Air masses have a tendency of influencing the weather conditions of the area over which they blow. They do so by altering the temperature and humidity of that area. The two most prominent types of air masses can be classified as warm and cold air mass.

The properties of an air mass and the degree of its uniformity are dependent on 3 major criteria, namely;

a) The direction in which the air mass is moving through the source area, as it absorbs the properties of that region while crossing over it.
b) Changes that take place in the air mass when it leaves the source region and enters newer areas.
c) Air mass age

**Note:** Air masses are an indispensable fragment of the Planetary Wind System. So, are most often related to a specific wind belt. When air masses move to newer places, they alter the weather conditions of those places and themselves also tend to get altered by the surface conditions of the respective places.

### 4.3.2 Source Region:

These are vast areas extending up to several kilometers in their expanse on the earth’s surface and they exhibit uniform characteristics for long distances many a times spanning over thousands of kilometers. These are given the name source regions as these are the regions over which the air masses originate like the birth places of the air masses and the air mass in turn absorbs all the physical properties of this region like- the characteristics of temperature and moisture content. The air mass has a tendency to be in motion after it is formed over the source regions and instead of remaining stationary over that place it moves towards newer destinations, impacting those regions with its inherent characteristics. Following are the characteristics of a source region.

a) There exist uniform characteristics of the atmosphere like- temperature and humidity over vast and homogenous portions of continents.

b) A source region may comprise of either vast stretches of land or ocean. But it never comprises of both types of surfaces since both surfaces have differing characteristics and a source region always exhibits uniform character stretching over thousands of kilometers.

c) The air mass may flow over heterogeneous surfaces, once it leaves the boundaries of its place of origin.

d) The air mass displays signs of divergence (non- convergence) when it flows over the source region, which provides it with more time to remain in that region and absorb the properties thereof.

e) Areas that have pronounced anticyclonic circulation and high or low pressure gradients, are said to be perfect for the development of air masses.

**4.3.2.1 The 6 major source regions** that exist on earth (including land and oceans) are listed below:

i) Polar Oceanic Areas- North Atlantic Ocean between Canada and N. Europe and N. Pacific Ocean between Siberia and Canada during winters.

ii) Polar and Arctic Continental Areas- Snow covered areas of Eurasia, N. America and Arctic Region during Winters

iii) Tropical Oceanic Areas- areas experiencing anticyclonic conditions for entire year.

iv) Tropical Continental Areas- North Africa (Sahara, Asia, Mississippi Valley of USA)

v) Equatorial Regions- Area between trade winds

vi) Monsoon Lands of S.E. Asia

**Note**: Most often, the High Pressure Belts serve as the chief source regions for the origin of air masses. Tropical areas give rise to Tropical Air masses and Polar Areas give rise to Polar Air masses. There exists a heat and moisture balance between the source region and the overlying air.

The middle latitudes are unable to support any key or important source regions due to the dominance of cyclonic or other atmospheric circulation.

### 4.3.3 Air Mass Classification:

Air masses have been classified in several ways by climatologists/scientists but one thing is common in them- the weather properties comprising of lapse rate, temperature and moisture are well taken into account before categorization is carried out. Two basic methods are commonly used here. Firstly, classification based on geography of the region and secondly, classification based on the thermodynamic properties of the region over which the air mass travels while moving to newer destinations.

**4.3.3.1** <u>Classification based on Geography</u>-

This is done keeping the locational properties of the source region in view. Trewartha, a well-known name in the field of climate studies, classified the air masses into two discreet groups namely; Polar and Tropical.

The former air mass is represented by a capital ‘P’ and is inclusive of the air masses originating in the Arctic Region as well. Whereas, the latter one is represented by a capital ‘T’. Tropical type of air encompasses the air originating in the Equatorial areas as well.

These two broad groups have been sub-divided into 2 categories, namely- Continental air mass represented by small ‘c’ and Maritime (Oceanic) air mass represented by small ‘m’.

Continental air mass as the name suggests after originating over continents or landmasses continues to flow over it for several thousand kilometers and thus is dry in nature. But it may absorb moisture, depending upon its capacity, from the underlying seas/oceans, if it happens to travel over them.

On the contrary, maritime air masses have a tendency of being moisture laden due to their origin over huge water bodies and they continue to be humid even after travelling over continental areas.

For better understanding the letters below may be referred:

- Continental Tropical Air- ‘cT’
- Maritime Tropical Air- ‘mT’
- Continental Polar Air- ‘cP’
- Maritime Polar Air- ‘mP’
- Warm Air- small ‘w’ these can also be termed as ‘cw’ and ‘mw’ based on the region
- Cold Air- small ‘k’ these can also be termed as ‘ck’ and ‘mk’ based on the region

**4.3.3.2 <u>Classification based on thermodynamic properties</u>-**

Thermodynamics- as the name tells us, refers to the changes in temperature or moisture content, that take place in an air mass when it traverses mixed portions of the earth, such as hot or cold areas, dry or wet areas. If the underlying surface is warm/hot, the air mass gathers heat from the surface after coming in its contact and this causes instability in the air (as warm air tends to rise upward, leading to cloud formation and precipitation). Whereas, if the underlying surface is cold, the air mass also becomes cold and is comparatively more stable (since cold air tends to settle downward). A wet surface (water-body) induces water vapor into the air mass and a rugged landmass makes it shed its vapor.

**Note:** When Polar air blows over warm surfaces it becomes warm and unstable. On the other hand, when Tropical air blows over cold surfaces, it cools from below and becomes stable due to difficulty in rising higher. When polar and tropical air masses converge, a front is formed. This generally culminates into cyclone formation in the mid latitudes also called, 'temperate zone'.

<u>Warm air</u>: refers to that mass of air whose temperature is *higher* than that of the surface below.

<u>Cold air</u>: refers to that mass of air whose temperature is *lower* than that of the surface below.

**4.3.4 Air Mass Types:**

- Continental Tropical Air- 'cT'- these air masses are hot and dry and so cause very little rain. The areas visited by them also experience hot and arid conditions.
- Maritime Tropical Air- 'mT'- these are warm and humid air masses. These are more humid as compared to the maritime polar air masses due to their greater capacity to absorb and hold moisture.
- Continental Polar Air- 'cP'- these air masses are dry but very cold due to their origin in the Polar Regions. They are associated with clear skies, negligible amounts of precipitation and cause cyclonic circulation on convergence with the maritime tropical air.
- Maritime Polar Air- 'mP'- these are more active in the summer season rather than in winter season and carry vapour in them. They are cold and stable

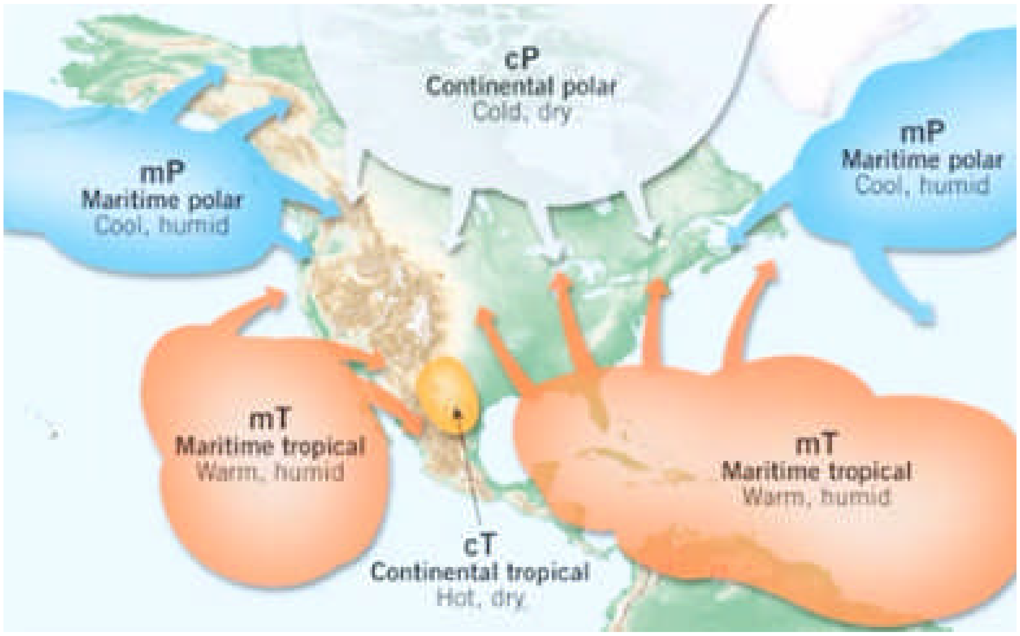



**Diagram 4.3.1: Types of Air Masses**
***Source: Pmfias.com***

### 4.3.5 Exercises:

***a) Fill Ups***

1. _____ and ______ are the 2 basic components of an air mass that influence the weather of the area where it blows.
2. Warm air refers to that mass of air whose temperature is higher than that of _____.
3. ______ air is cold, stable and carries lot of moisture. It is more active in the summers.
4. Continental air originates over the ______.
5. ______ in North Africa is an example of Tropical Continental source region.

***b) Multiple Choice questions (MCQs)***

1. The letters ‘mT’ represent:
    a. Maritime Tropical Air mass
    b. Maritime Temperate Air mass
    c. Meridional Temperature
    d. Maritime Thermal Air mass

2. The letters ‘cP’ represent:
    a. Continental Pressure Air mass
    b. Continental Polar Air mass
    c. Circum Polar Air mass
    d. Cyclonic Pressure Air mass

3. One of these is *not* a major source region. Identify.

a. Monsoonal Lands of South Asia
b. Low pressure area in Mid Latitudes
c. Polar Oceanic Areas
d. Tropical Continental Areas

4. Temperate cyclones form due to convergence of which of the following air masses?

a. North east trades and south east trades
b. Polar easterlies and trade winds
c. Tropical westerlies and polar easterlies
d. Equatorial westerlies and Doldrums

5. Define an air mass.

a. Air blowing over high pressure area
b. Air blowing over low pressure area
c. Air having similar characteristics over a long distance
d. Air having different characteristics over a long distance

6. Pick the odd one out from the list of ‘types of air masses’ given by Trewartha.

a. Continental Polar
b. Continental Tropical
c. Maritime Continental
d. Maritime Polar

7. A cold air mass is depicted by which letter?

a. Capital c
b. Small c
c. Capital k
d. Small k

8. Which of the statements given below is false:

a. The formation of a front is called frontogenesis, its degeneration is called Frontolysis.
b. Xerophytes are the plants that grow in deserts.
c. Hot and moist air rising above the ground is always stable
d. Cold fronts, warm fronts and occluded fronts are examples of temperature inversion.

9. Which out of the following, proves to be the best area for the development of air masses?

a. Areas with anticyclonic circulation
b. Wet areas
c. Low Pressure Areas
d. Equatorial Areas

10. Which of these is a stable air mass?
    a. Hot air mass
    b. Dry air mass
    c. Wet air mass
    d. Cold air mass

### 4.3.6 Answers to Exercises:

**a) Fill ups**

1. Temperature and Moisture content/humidity
2. Underlying surface
3. Maritime Polar
4. Continents/ landmasses
5. Sahara

**b) MCQs**

1. Maritime Tropical Air mass
2. Continental Polar Air mass
3. Low pressure area in Mid Latitudes
4. Tropical westerlies and polar easterlies
5. Air having similar characteristics over a long distance
6. Maritime Continental
7. Small k
8. Hot and moist air rising above the ground is always stable
9. Areas with anticyclonic circulation
10. Cold air mass

### 4.3.7 Task: Long Answer Questions

**Try to attempt the questions given below.**

i. Explain the concept of an air mass and source region and mention the types of source regions.

ii. How is a cold air mass different from a warm air mass?

iii. Write a note describing the classification of the air masses into different categories.

## 4.4 AIR FRONTS, FRONTOGENESIS AND FRONTOLYSIS

Learning about the process of front formation and the types of fronts is important to understand the formation of mid-latitude cyclones. The knowledge of fronts also presents a clear understanding of the dominant weather patterns that exist in the middle latitudes. The middle latitudes extend from $35^0$ to $60^0$ latitude North and South of the Equator. The formation of a front is usually an uncommon phenomena in the Equatorial, Tropical and Polar Regions.

**4.4.1 Definition of Front**:

It is a three dimensional (3-D) boundary zone, also called as a frontal zone or frontal surface which is formed between two converging air masses that have different physical properties, in terms of temperature, moisture holding capacity, wind speed, density and lapse rate. It is neither parallel nor vertical to the ground, but is inclined at a low angle. A front can have a large areal extent, width ranging between 5-80 km, temperature differences, bending isobars and abrupt shifts in wind direction which may lead to the formation of clouds causing precipitation.

**4.4.2 The Opposing Air Masses**:

These are the air masses that have a contrasting nature. At the time of convergence, they arrive from opposite directions and move towards each other and generally, one of the two air masses is cold, dry, dense and has a higher air pressure whereas, the other is warm, moist and lighter in weight due to lower air pressure. The cooler air mass being heavier, tries to occupy the dominant position by invading and penetrating into the area of the lighter, warmer air mass and pushing it upwards. In this process of invasion and pushing each other, the shape of the front changes and it begins to appear like a wave. On the other hand, when the two air masses start diverging and moving away from each other into two different directions, the front begins to disintegrate and is destroyed.

**4.4.3 Front Formation or Frontogenesis**:

Frontogenesis is defined as the process by which a front (i.e. three dimensional boundary zone) is formed between two air masses of contrasting nature, when they are facing each other. The two air masses are in a state of war or are competing against each other to occupy the dominant position. The regeneration of decaying fronts also forms a part of frontogenesis.

The process of frontogenesis takes place in an anticlockwise direction in the Northern hemisphere of the Earth whereas it occurs in a clockwise direction in the southern hemisphere. This happens because of the presence of the Coriolis force, which generates the Coriolis Effect (the effect that is formed due to the rotation of the Earth on its axis).

**4.4.4 Frontolysis**:

This phenomena occurs when one air mass out of the two air masses which were in a state of competition, during the frontogenesis stage, occupies the dominant position by overriding the other air mass. This also means that one particular air mass wins the competition and dominates over the other. This is the situation when the front or the 3-D boundary starts losing its significance and starts to weaken and wither away. This weakening or dying of the front is defined as the stage of frontolysis.

It is important to note here that the stage of frontogenesis involves the convergence or meeting of two different air masses, whereas, the stage of Frontolysis involves the dominance of one air mass over the other causing the front boundary to dissipate. Thereafter, the air masses start diverging in different directions. In other words, frontogenesis causes the convergence of and frontolysis causes the divergence of air masses.

The mid-latitude cyclones are known by two other names as well, i.e. Temperate Cyclones and Extratropical Cyclones. Since these cyclones generally occur/originate in the middle latitude zones, in both the hemispheres, i.e. between $35^0$ to $60^0$ North and South of the Equator, they have been given the name mid-latitude cyclones. These are a result of frontogenesis.

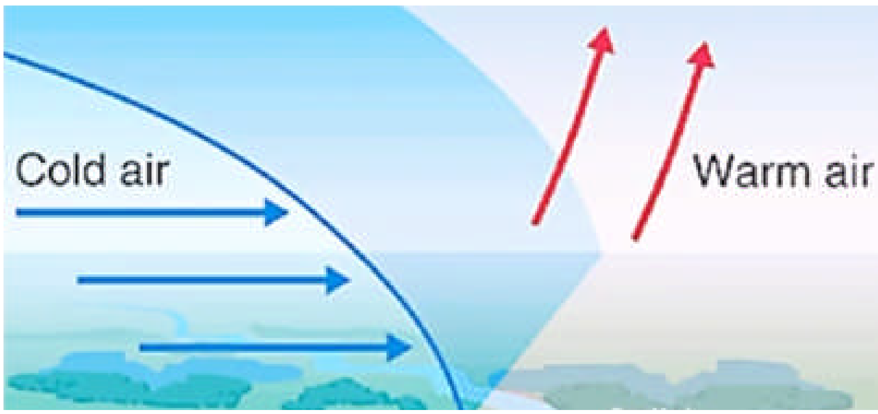



**Diagram 4.4.1: A Front (Curved blue line- formed due to Coriolis force) that forms between 2 air masses of contrasting nature.**
***Source: Pmfias.com***

**4.4.5 Air Circulation and Frontogenesis**:

According to Patterson, there are 4 types of air circulation.

A) Translatory Circulation- here, air moves in a horizontal manner from one place to another in the same direction. Temperature variations cannot be produced in this movement but fronts may be formed.

B) Rotatory Circulation- here, the air moves in a circular pattern i.e. cyclonic or anticyclonic fashion. Temperature variation can be seen but fronts are not created.

C) Convergent and Divergent Circulation- Convergent Circulation involves the meeting of winds coming from different directions at one central point. Whereas, the opposite happens in the case of divergent circulation i.e. from a central point, the winds start moving outwards in all directions. These circulations are not favorable for frontogenesis since the temperature difference exists at a central point whereas, front can only be formed if this difference exists along a line.

D) Deformatory Circulation- this is the most conducive type of circulation for frontogenesis. Here, two axis exist namely; axis of inflow and axis of outflow and the contrasting air masses converge and spread horizontally along the axis of outflow.

**<u>Note</u>** that; the intensity of the fronts depends on the temperature gradient.

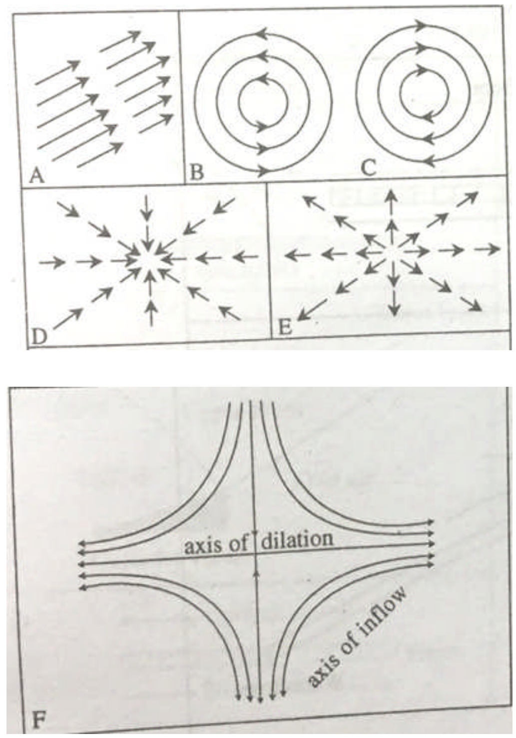



**Diagram 4.4.2: Four types of air circulation**
***Source: Savindra Singh***

A) Translatory Circulation, B & C) Rotatory Circulation, D & E) Convergent and Divergent Circulation, F) Deformatory Circulation

**4.4.6 Classification of Fronts**:
Based on frontogenesis, the fronts can be classified into the following categories on the basis of their characteristics.

**4.4.6.1 Stationary Front-** it forms when two contrasting air masses come face to face but neither of them is able to push the other so there is no displacement or upward movement of the air and no competition for dominance exits. The winds blow parallel to the front. These fronts are an uncommon phenomena and are insignificant from the climate point of view as there is no cloud formation and precipitation when this front forms and there is no forward or backward movement of the front.

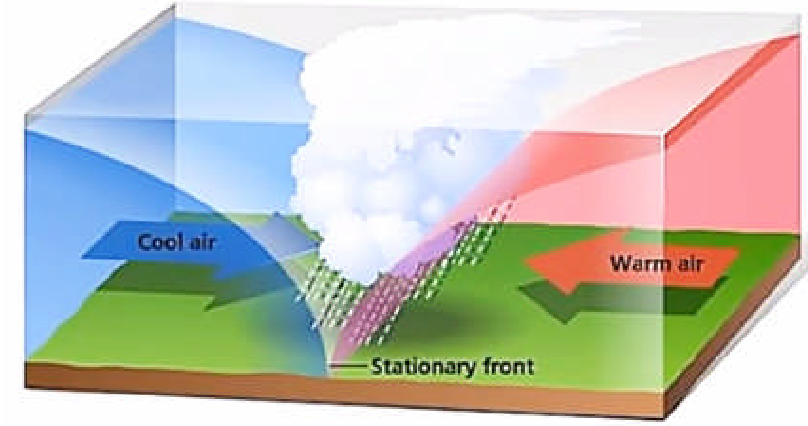



**Diagram 4.4.3: Stationary Front**
***Source: Pmfias.com***

**4.4.6.2 Cold Front-** it forms when the sloping surface of the front becomes very active. The cold air moves along this surface. This air being dense, stays near the earth's surface but is powerful enough to uplift the lighter warm air and thrust it above itself. There is less movement and in the cold air due to force of friction exerted by the ground. But the warm air attains high velocity causing the cold front to become very steep.

Weather associated with Cold Front-

a) Formation of thick Cumulonimbus Clouds
b) Thunderstorms, lightning but for short period of time
c) Sometimes there is hailstorms or snowfall.

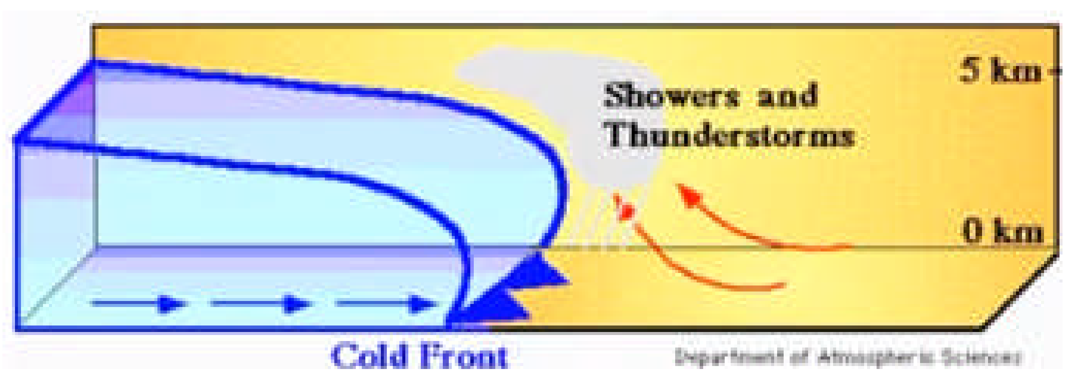



**Diagram 4.4.4: Cold Front**
***Source: Pmfias.com***

**4.4.6.3 Warm Front**: it forms when the sloping surface of the front along which the warm air flows becomes extremely active. In this case, the warm air becomes more dominant and forceful and invades the cold air zone. Due to its light weight, the warm air, on its own starts rising above the dense cold air. The warm front unlike the cold front is gently sloping and the slowly rising warm air cools adiabatically. This cooling effect causes saturation in the warm air. This in turn leads to cloud formation and condensation resulting in precipitation. If the warm air is moist then condensation occurs at a lower height. Contrary to this, if the air is less humid then condensation takes place at a great altitude in the atmosphere.

Weather associated with Warm Front-

a) Formation of thick Clouds, condensation

b) Gentle to moderate precipitation which continues for a long time (many hours)

c) The passage of warm front is marked by decrease in pressure, sudden rise in temperature and specific humidity causing change in weather.

d) The changes in the wind direction and temperature are gradual.

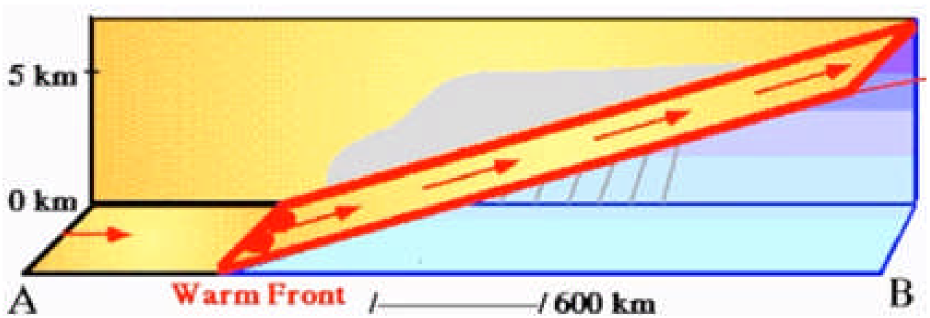



**Diagram 4.4.5: Warm Front**
***Source: Pmfias.com***

**4.4.6.4 Occluded Front**: forms when the cold front becomes dominant and the cold air being heavier settles down and continuously pushes the warm air upward from below. Thus the warm air gets displaced from its original position i.e. near the ground and rapidly rises upward. Its continuous rise leads to the destruction of the warm front.

Weather associated with Occluded Front-

a) There is a mixture of cold and warm front type weather conditions. These are mostly found in Western Europe.

b) The Extra-Tropical Cyclones require the formation of Occluded fronts, which set the stage for the end of the cyclone.

**Note**: Cold front, warm front and occluded front are examples of temperature inversion.

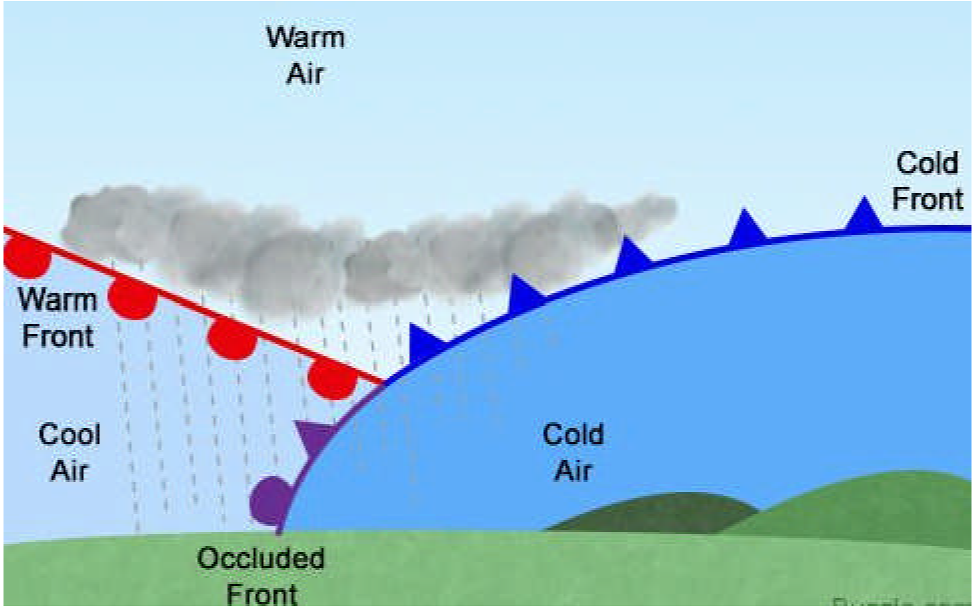



**Diagram 4.4.6: Occluded Front**
***Source: Pinterest.com***

**4.4.7 Exercises:**

***a) Fill Ups.***

1. Intensity of the fronts depends on the _______.

2. Gentle to moderate precipitation continuing for a long time is a characteristic of _____ front.

3. Frontogenesis takes place in ______ direction in the Northern hemisphere.

4. In the ________ air circulation pattern, temperature variation is seen but fronts are not created.

5. ______ clouds are thick, dark and produce heavy rain, thunder and lightning.

***b) Multiple Choice Questions (MCQs).***

1. Rainfall occurring due to rise of moist air and adiabatic cooling caused by convergence of two contrasting air masses is:
   a. Orographic Rain
   b. Frontal Rain
   c. Convectional Rain
   d. Monsoonal Rain

2. Precipitation associated with the cold fronts is always in the form of:
   a. Snowfall
   b. Thunderstorm
   c. Drizzle
   d. Hailstorm

3. Most of the precipitation occurring in the temperate region is _____ in nature.

a. Convectional
b. Orographic
c. Cyclonic
d. Monsoonal

4. Which of the statements given below is false:

a. The formation of a front is called frontogenesis, its degeneration is called Frontolysis.
b. Xerophytes are the plants that grow in deserts.
c. Hot and moist air rising above the ground is always stable
d. Cold fronts, warm fronts and occluded fronts are examples of temperature inversion.

5. Winds always blow from:

a. Low pressure to high pressure areas
b. Wet to dry areas
c. High pressure to low pressure areas
d. Dry to wet areas

6. One of these is not an example of temperature inversion. Identify.

a. Cold front
b. Stationary Front
c. Warm front
d. Occluded front

7. What happens in case of a stationary front?

a. Warm air rises upward
b. Cold air rises upward
c. No displacement or upward movement of air
d. None of these

8. Temperate cyclones are formed where;

a. Two similar air masses meet
b. Two different air masses meet
c. No air masses meet
d. Air masses diverge

9. Where are the Extra Tropical cyclones formed?

a. $80^0$ to $90^0$ latitude
b. $70^0$ to $80^0$ latitude
c. $35^0$ to $60^0$ latitude
d. $20^0$ to $30^0$ latitude

10. The stage of Frontolysis marks the:

a. Weakening of the front
b. Strengthening of the front
c. Formation of a cyclone
d. Destruction of the cold front

**4.4.8 Answers to Exercises:**

**a) Fill ups**

1. Temperature gradient
2. Warm
3. Anticlockwise
4. Rotatory
5. Cumulonimbus

**b) MCQs**

1. Frontal Rain
2. Thunderstorm
3. Cyclonic
4. Hot and moist air rising above the ground is always stable
5. High pressure to low pressure areas
6. Stationary Front
7. No displacement or upward movement of air
8. Two different air masses meet
9. $35^0$ to $60^0$ latitude
10. Weakening of the front

**4.4.9 Task: Long Answer Questions**

**Try to attempt the questions given below.**

i. What do you understand by the term 'Front'? Why do you think is the front formation important?

ii. Identify the difference between Frontogenesis and Frontolysis.

iii. Name and explain the 4 types of fronts in detail with appropriate diagrams.

## 4.5 EXTRA-TROPICAL CYCLONES: FORMATION AND IMPACTS

Cyclones are a peculiar atmospheric phenomena, which can be understood as very high velocity (gale force) storms/disturbances. These are known by different names in different countries. On a map, these can be easily identified by looking at the isobars and their placement. These are characterized by a low pressure at the centre which gradually increases away from the central point, i.e. there is presence of high pressure at the outer most end of the isobars. Closed isobars surround the low pressure and there is movement of air inward from the outer high pressure zone to the inner low pressure zone. It is noteworthy that the inward moving air adopts an anticlockwise flow in the northern hemisphere and clockwise flow movement in the southern hemisphere.

**4.5.1 Cyclones:**

Extra tropical cyclones are also termed as temperate cyclones (as the mid latitude region falls in the temperate zone), wave cyclones, lows, troughs or depressions. These are mainly formed between $35^0$ to $65^0$ lat. North and South of the Equator due to the commencement of the process of Frontogenesis, when there is convergence of warm and cold air. The middle latitudes are said to be the most turbulent region due to a lot of mixing that occurs here. The cold, dry polar air moves downward towards the lower latitudes and converges with the warm, moist tropical air which travels to the higher latitudes after originating in the tropics. Their movement is usually in the Easterly direction.

**Note:** Isobars are lines that join the places having equal pressure on a map. Barometer is the instrument used for measuring atmospheric pressure. The unit for representing pressure is 'mb' (millibars).

### 4.5.2 Types of Extra Tropical Cyclones:

There are 3 distinct categories of these cyclones.

a) Dynamic Cyclones- these are called real and dynamic as they are dynamically created as a result of convergence of two contrasting air masses and the consequent intrusion into each other's territory i.e. cold, dry polar air and warm, moist tropical air. These are fully developed in nature and are responsible for influencing the weather conditions of vast stretches of land in the mid latitudes.

b) Thermal Cyclones- the cyclones that are thermally induced are given the name Thermal Cyclones or Insolation Cyclones. These result due to low pressure, which generally forms on the interior portions of the continents in the summer months and over oceans and seas during the winter months. We know that, air moves from high pressure to low pressure areas. During summers, high pressure is created in the ocean bodies during summers and on the continents during winter months. The air in areas with dominance of high pressure is attracted towards the low pressure, and thus rushes towards such spaces. N.W. Australia, Iberian Peninsula, S.W. USA and Alaska are known for summer cyclones whereas, Norwegian Sea, Okhotsk Sea and Arctic Sea south of Greenland are known for winter cyclones. Note that, thermal cyclones are stationary cyclones and are not controlled by frontogenesis.

c) Secondary Cyclones- these are given the name secondary as these are of lesser intensity and short duration as compared to Dynamic and Thermal Cyclones and are called weak cyclones. Their formation takes place when the cold winds pass over the warm ocean bodies, after the primary cyclone diminishes.

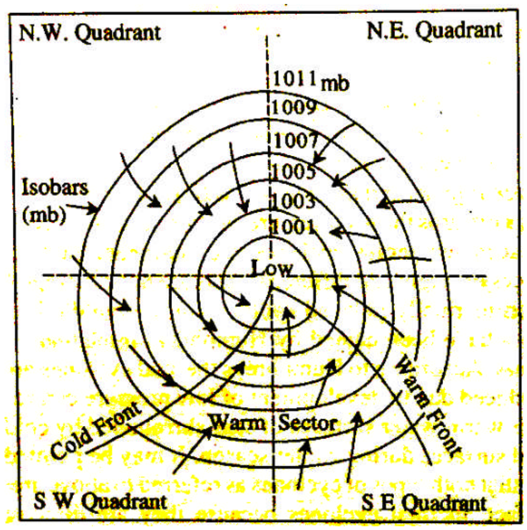



**Diagram 4.5.1: The arrangement of isobars in a temperate cyclone of the northern hemisphere**
***Source: Savindra Singh***

### 4.5.3 Structure, Speed and other characteristics of Extra Tropical Cyclones:

The points listed below help in generating a good understanding about temperate cyclones.

- These cyclones can be of varying sizes, shapes, velocity and extent, but if compared, no cyclone is similar to the other.
- They are circular, elongated, wedge shaped and elliptical.
- There exists a 10-20 mb pressure difference between the core and outermost margin of a cyclone.
- A large cyclone can have a diameter of about 2000 km or more and the diameter of a small cyclone may range between 500 km - 1000 km. area-wise also the temperate cyclones are in no way limited, as they can be enormous enough to cover an area as wide as 10 lakh $km^2$.
- Vertically these cyclones can attain a height of 10 to 12 km in the troposphere.
- They generally have an easterly pattern of movement.
- There is a difference in the average velocity of these cyclones, depending upon the season during which they become active. In summers it is 32 km per hour whereas, in winter season it increases to 48 km per hour.
- Temperature differences also exist in these cyclones. When there is convergence of warm and cold air, the northern portion records a lower temperature due to presence of cold polar air in that portion

and vice-versa for the southern portion due to presence of warm tropical air.

- These cyclones move in specific paths, which are known as *Storm Tracks*. Since these paths are extensive and mostly inconstant, the movement of cyclones is considered zonal instead of linear.
- Cyclones originating in Eastern Colorado, USA are commonly known as '*Colorado Lows'*. The name '*Alberta Lows*' is generally used for those cyclones that originate in the east of Canadian Rocky Mountains.
- The frontogenesis that takes place in Mediterranean Sea, leads to the formation of temperate cyclones. These cyclones adopt an easterly direction and move towards the Indian Subcontinent after crossing over the Middle Eastern countries and are responsible for causing winter rain in parts of Pakistan as well as in North India.
- Generally, the warm and moist tropical air has a westerly direction of flow. Whereas, the cold and dry polar air has an easterly direction of flow.
- When these two contrasting air masses converge, the formation of a warm front, warm sector and cold front and cold sector takes place.
- *'Wind Shift Line'* is the name given to the linear path along which the wind changes its direction of movement.
- Formation of halos around the sun/moon results with the arrival of temperate cyclones. These are thin veneers of cirrus and cirro-stratus clouds.

### 4.5.4 Temperate Cyclones and Associated Weather:

When the cyclone starts drawing closer to the target area, certain changes are observed in the weather of that area. The forward approach of a cyclone, toward the target is associated with lowering of air pressure, rise in temperature, decrease in wind speed, a change in wind direction from easterly to south easterly, formation of a halo around the sun or moon and a heavily overcast sky with thick, dark clouds.

Once the sky becomes overcast with nimbostratus clouds, heavy precipitation/downpour is sure to begin which gradually becomes moderate but continues for several hours. This marks the arrival of the warm front. The warm air being light in weight, begins to rise upward. The water vapor present it this air begins to condense and fall as rain.

The departure of the warm front sets the stage for the arrival of the warm sector in the target area. This leads to changes in the wind direction, making it adopt a southerly flow. The clouds move away, making the sky appear to be clearer, but the specific humidity is very high. The temperature begins to rise again, but intermittent drizzling can be experienced.

When the cold front makes an appearance, the temperature and pressure conditions again get altered, with lower temperatures followed by higher pressures. Cold air being denser, tries to settle downwards but in turn lifts the warm air upward. Wind direction gets altered to south westerly and the sky becomes overcast again with cumulonimbus clouds causing heavy precipitation, thunder and lightning. This only occurs for a short while.

After the cold front passes, the cold sector makes its entry, which is responsible for bringing noticeable changes in the weather like; clear skies, low temperature, high pressure and a fall in specific humidity. The wind direction now adopts a completely westerly flow and slowly the process of Frontolysis begins marking the end of the fury of the cyclone. The end of the cyclone is due to the disappearance of the warm front. This process is commonly known as Occlusion.

If in case a minor and weak cyclone develops after the disintegration of the major cyclone, it is known as a '*secondary cyclone*' or '*sub-cyclone*'.

A sub-cyclone is the result of left over warm air in the cold front, which reestablishes a low pressure at the centre, causing the air from all the high pressure portions to rush in towards the low pressure and a very low intensity cyclone is formed.

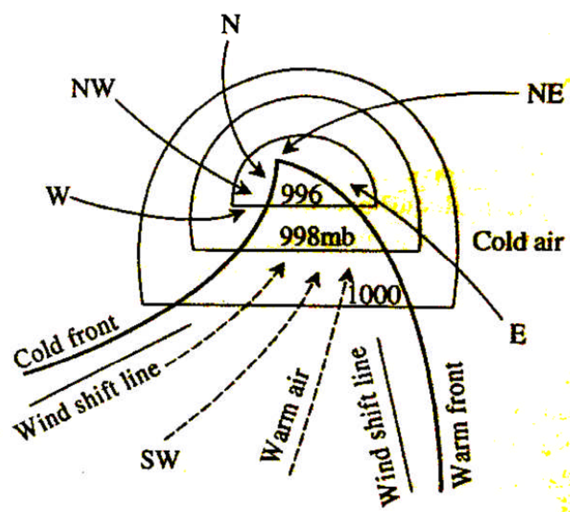



Diagram 4.5.2: Wind pattern in a temperate cyclone (N. Hemisphere)
*Source: Savindra Singh*

**4.5.5 Origin of Cyclone:**

Several theories have been propounded and put forth by many scientists but the most widely accepted and acclaimed theory is the one given by V. Bjerknes and J. Bjerknes , about the origin of temperate cyclones which is also known as the Frontal Theory, Polar Front Theory, Wave Theory or Bergen Theory. They propounded the theory in 1918, emphasizing the fact that the formation of the extra tropical cyclones can be safely attributed to the formation of fronts. These fronts are responsible for the convergence of the air masses of contrasting nature. These air masses are born in regions which are altogether different from each other (Polar and Tropical).

There are some stages through which each cyclone has to pass before it starts to diminish. All these stages combined together form the 'Life Cycle of the Cyclone' i.e. from its genesis till its occlusion. First of all, a '*Surface of Discontinuity*' is formed between the two contrasting air masses. This acts like a separating agent between the polar air and tropical air. Initially, this surface is stable and linear but it slowly becomes unstable and adopts a wave like appearance, when the 2 air masses begin to enter into each other's territory. This wave like surface is the polar front.

It is important to note that, this front has two parts. The first part indicates the arrival of the cold air from the western direction and the second part marks the arrival of the warm air from the eastern direction. Both these air masses become strong and form their respective fronts in the direction in which they are advancing. The presence of the warm sector in the south-west and cold sector in the north-west portion of the cyclone is essential for its full development. The eastern part of the cyclone develops low pressure due to presence of warm air. Thus, winds from high pressure portions quickly start moving towards low pressure and finally on the arrival of the cold front, the cold air drives the warm air upwards. This leads to disintegration of the warm front and the life cycle of the cyclone nears its end.

### 4.5.5.1 Six Stages of the Cyclone:

During its life cycle, an extra tropical cyclone has to pass through the following six stages right from its genesis till its destruction.

A) Formation of a stationary front- this type of front is a linear front and it takes shape when 2 contrasting air masses coming from opposite direction meet each other. Due to absence of any invasion activity from both sides, the weather conditions continue to remain stable in this first stage.

B) Incipient stage- in this stage, the linear front begins to assume a wave like structure. This is the time when the warm and cold air masses start converging and invading into each other's territory.

C) Mature stage- this is the third stage which marks the progress of the cyclone towards maturity. Now the isobars start assuming a circular shape, and come in close proximity to one another.

D) Shrinking of the warm front- as the cold front advances, becomes aggressive and begins to take over the warm front by pushing the warm air upwards, the warm front begins to narrow down.

E) Formation of Occluded front- when the cold front is successful in completely invading and overtaking the warm front, forcing it to diminish and disintegrate, at that time the occluded front begins to form and the cyclone is now nearing the phase of Frontolysis.

F) Final Stage- At this time, the cyclone begins to collapse by experiencing the extinction of the warm front, followed by the termination of the occluded front and this results in the fading away of the entire cyclone.

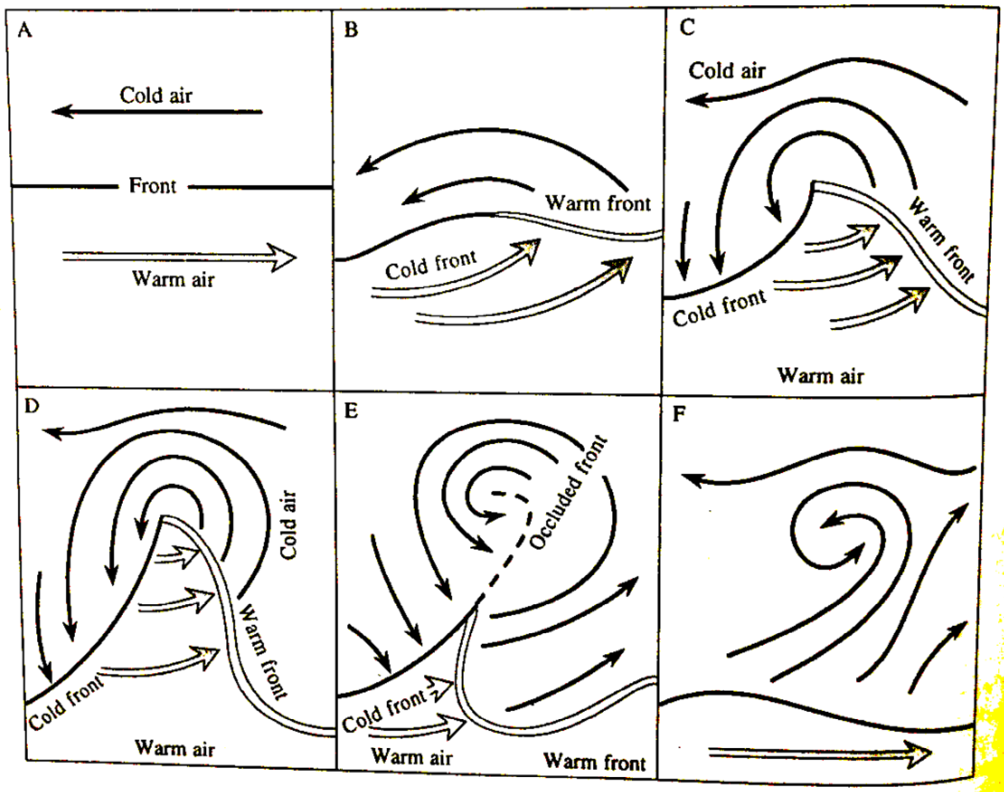



**Diagram 4.5.3: Life cycle of an Extra-Tropical Cyclone**
***Source: Savindra Singh***

### 4.5.6 Points to Remember:

- 3 types of temperate cyclones- Dynamic, Thermal and Secondary.
- People who gave different theories about Temperate Cyclones-

1. Fitzroy, 2. Lempfert and Shaw, 3. V. Bjerknes and J. Bjerknes- propounded the Polar Front Theory also called as Wave Theory.

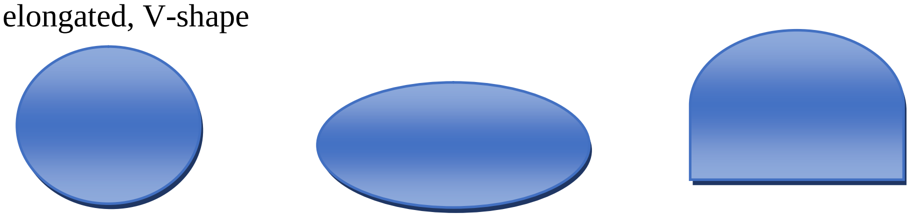
- Surface of Discontinuity- separates two contrasting air masses
- Shape of temperate cyclones- Circular, semi-circular, elliptical, elongated, V-shape
- 

Diagram 4.5.3: Shapes of cyclones 1. Circular, 2. Elliptical, 3. Semi-Circular

- Eye of the cyclone- The pressure in the cyclone increases from the centre towards the outer portion i.e. there is low pressure at the center and high pressure in the surrounding of the center.
- Area covered by the cyclone- 1lakh - 10 lakh $km^2$
- Halo around Sun or moon is formed by- Cirrus or Cirrostratus clouds on arrival of the cyclone.

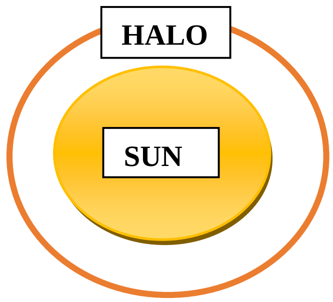



**Diagram 4.5.4: Formation of Halo around the Sun**

- Vertical extent- from the Mean sea level to 10 or 12 km in height
- Speed- winds move at 32 km per hour to 48 km per hour velocity.
- Diameter- 640 miles (1000 km) to 1200 miles (1900 km).

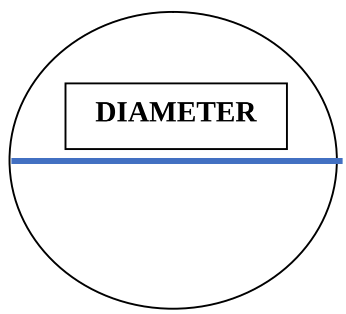



**Diagram 4.5.5: Diameter of the Cyclone**

### 4.5.7 Exercises:

***a) Fill Ups.***

1. The life cycle of a cyclone is completed in ____ stages.
2. The name given to the path of the cyclone is _______.
3. Halo around Sun or moon is formed by ________ on arrival of the cyclone.
4. Cyclones originating in the east of Canadian Rocky Mountains are called ______.
5. The warm and moist tropical air has a _____ direction of flow in the mid latitude region.

***b) Multiple Choice Questions (MCQs).***

1. Cyclonic Circulation in which water body causes winter rain in N. India?
   a. Indian Ocean
   b. Arabian Sea
   c. Mediterranean Sea
   d. Black Sea

2. Temperate cyclones are also called:
   a. Depressions
   b. Lows
   c. Troughs
   d. All of these

3. Temperate cyclones are formed where;
   a. Two similar air masses meet
   b. Two different air masses meet
   c. No air masses meet
   d. Air masses diverge

4. Where are the Extra Tropical cyclones formed?
   a. $55^0$ to $65^0$ latitude
   b. $45^0$ to $55^0$ latitude
   c. $35^0$ to $65^0$ latitude
   d. $25^0$ to $35^0$ latitude

5. Which cyclones are called 'Real Temperate' cyclones?
   a. Thermal
   b. Dynamic
   c. Secondary
   d. Tropical

6. Thermal cyclones develop over what kind of surfaces in summers?
   a. Undulating
   b. Sea
   c. Land
   d. None of these

7. Cyclone developing over Norwegian Sea during winter season is an example of:
   a. Thermal Cyclone
   b. Dynamic cyclone
   c. Secondary cyclone
   d. Tropical cyclone

8. Large and extensive temperate cyclones can spread over:
   a. 100 km
   b. 1000 km
   c. 10,000 km
   d. More than 1,00,000 km

9. An average cyclone can extend up to a vertical limit of _____ km.
   a. 0-5
   b. 5-10
   c. 10-12
   d. 15-20

10. The lines joining the places of equal pressure at sea level are called:
   a. Isotherm
   b. Isobars
   c. Isohyet
   d. Isopleth

**4.5.8 Answers to Exercises:**

**a) Fill ups**

1. Six
2. Storm Tracks
3. Cirrus or Cirrostratus clouds
4. Alberta Lows
5. Westerly

**b) MCQs**

1. Mediterranean Sea
2. All the above
3. Two different air masses meet
4. $35^0$ to $65^0$ latitude
5. Dynamic
6. Land
7. Thermal Cyclone
8. More than 1, 00,000 km
9. 10-12
10. Isobars

**4.5.9 Task: Long Answer Questions**

**Try to attempt the questions given below.**

i. Give a detailed account of the life cycle of an Extra-Tropical Cyclone with suitable diagrams.

ii. Varied weather conditions are associated with the arrival and departure of a temperate cyclone. Justify this statement.

iii. How are dynamic cyclones different from the thermal cyclones?

## 4.6 CLIMATIC CLASSIFICATION: KOPPEN AND THORNTHWAITE

The world encompasses an unimaginably vast geographical area. This huge area comprises of landmasses in the form of continents and water bodies. The water bodies consist of fresh water which exists in small quantities and occupy a limited space on the continents and the salty water bodies namely; oceans and seas. As a matter of fact, all these oceans and continents are not concentrated in any one particular zone, rather they are distributed across several latitudes and span several longitudes as well. Due to their distribution in a specific fashion across the earth's surface, they occupy their current positions in the Torrid Zone, Temperate Zone and Frigid Zone of the earth. It must be clearly understood that all these zones have separate set of geographic and climatic characteristics and the places situated in these zones are also influenced by these characteristics. The degree of hotness or coldness, wetness or dryness and the specific type of flora and fauna existing therein, are all likely to be influenced by the location of the landmasses in these zones. Moreover, these three zones are further subdivided into several categories depending on the available data in the form of observable or statistical data, also called empirical data and genetic data. Several scientist and climatologists have tried to attempt a classification of the various types of climates that exist on the planet and carefully bring out the major and minor details of these climates while quantifying their sub climatic types, for the better understanding of the students of climatology and others who may be interested. In this chapter, the climatic classification attempted by two famous scientists and scholars has been brought out. Also, these are the most commonly used climate classification schemes, based on empirical and genetic data.

### 4.6.1 Koeppen's Classification:

Wladimir Koeppen was a botanist and climatologist of German origin. He presented his first descriptive climatic classification in 1900 and kept revising it with further improvements and modifications. His classification is easy to understand, quantitative and numerical. He made use of alphabets for naming the various climates of the world as well as temperature and precipitation data values to distinguish between the boundaries of different areas and their corresponding climates. His classification is based on the major vegetation zones of the world namely; Megatherms, Xerophytes, Mesotherms, Microtherms and Hekistotherms, because according to him any specific type of vegetation, growing in a given location, can substantially denote the climate that exists in that region. He identified the major world climates and denoted then using 5 capital alphabets from A to E.

- Climate A- tropical humid type of climate, no winter season, warm-humid conditions and avg. temperature $>18^0$ persisting throughout the year.
- Climate B- Dry type of climate where evaporation is more than precipitation (Rainfall/ snowfall). It suffers from water scarcity.
- Climate C- warm temperate type of climate usually in the mid latitudes. Winters are mild. Avg. temperature of warmest month ranges from $8^0$-$18^0$C, and Avg. temperature of coldest month is below $8^0$C.

- <u>Climate D</u>- cold and humid forest type of climate. Winters are severe. Avg. temperature of warmest month= >$10^0$C and that of coldest month = $3^0$C.
- <u>Climate E</u>- represents the polar type of climate having no summer season and avg. temperature of the warmest month is also much less that $10^0$C.

**4.6.1.2 Climate A in detail:**

This type of climate is also referred to as 'tropical monsoon' type of climate. Here, the temperature in the winter season remains more than $18^0$C, even in the coldest month. Depending on the rainfall regime, this type of climate is further sub-divided into:

<u>Af</u> or Equatorial rainforest climate, <u>Aw</u> or Savanna climate, <u>Am</u> or monsoon climate and <u>As</u> types. The 'As' climate is rarely found as it represents distinct dry season in summer months in the tropical regions.

Koeppen has made use of the lower case (small) alphabets for denoting the minor details in the major climate zones. These are enlisted below.

- Small 'f'- Uniform distribution of rainfall can be experienced for the entire year. There is no distinct dry season. Even in the months that receive lesser precipitation, it is not less than 6 cm. The diurnal range of temperature is very low.
- Small 'm'- represents *monsoon type of climate* where the dry season is very short but records precipitation of 6 cm. It can support dense forests and the ground mostly remains wet.
- Small 'w'- denotes presence of dry season in winter months. Rainfall of less than 6 cm is experienced in just one month in a year. High temperature experienced throughout the year.
- Small's'- denotes presence of distinct dry season in summer months.
- Small 'n'- denotes minimum fog.
- Small 'i' - refers to a temperature difference of less than $5^0$C between the hottest and coldest month.
- Small 'g'- denotes prevalence of very hot season before the beginning of precipitation.

**Note:** Due to presence of a lot of similarity between Am and Aw type of climates, Koeppen devised a formula to easily differentiate between them i.e., '$a = 3.94 – r/ 25$' (where, '*a*' represents rainfall of the driest month and '*r*' means annual rainfall). According to this formula, if the driest month rainfall comes out to be higher than the value of '*a*' then it is called as 'Am' type of climate and in case the value is lower than '*a*' then the climate type is said to be 'Aw'.

#### 4.6.1.2 Climate B in detail:

This type of climate is also referred to as 'Dry or desert' type of climate. Here, the amount of evaporation of water is almost always more than that of precipitation. This means that insufficient rain makes it difficult to maintain a stable water table in such regions. Based on yearly temperature and precipitation in the wettest month, two sub divisions exist in this type of climate, with both alphabets in capital. I.e., BW or Desert/Arid type of climate (Very Dry) and BS or Semi-Arid/ Steppe type of climate.

Due to presence of a lot of similarity between BW and BS type of climates, Koeppen devised a formula to easily differentiate between them i.e., $r = 0.44t - 8.5 / 2$ (here, '*r*' means annual rainfall in inches, whereas,'*t*' means temperature).

According to this formula, if the annual precipitation comes out to be higher than the value of '*r*' then it is called as 'BS' type of climate and in case the value is lower than '*r*' then the climate type is said to be 'BW'.

There also exists a third sub-division of the B climate, comprising of two capital alphabets and one small alphabet which is given below.

- 'BWh'- represents tropical *desert* type of climate where the mean annual temperature is >$18^0$C.
- 'BSh'- represents tropical *steppe* type of climate where the mean annual temperature is >$18^0$C.
- 'BWk'- denotes mid-latitude *cold desert* climate. The mean annual temperature is <$18^0$C.
- 'BSk'- denotes mid-latitude *cold steppe* climate. The mean annual temperature is <$18^0$C.
- Small 'a'- refers to dry summer months and wet winters. The wettest winter month receives 3 times more rain/snow than the driest summer month.
- Small 'w'- refers to dry winter months and wet summer months. The wettest summer month receives 10 times more rain/snow than the driest winter month.

#### 4.6.1.3 Climate C in detail:

This type of climate is also referred to as 'warm temperate rainy' type of climate. Here, the avg. temperature in the winter season remains >$3^0$C but is always <$13^0$C, even in the coldest month. Precipitation is experienced in every season. Three sub divisions exist in this type of climate, with first alphabet in capital and the other in lower case, based on precipitation distribution, namely;

- 'Cf' or Western Europe type of climate- such regions receive precipitation of >1.2 inches for the whole year, even in the driest months. Cf has a third sub division as well i.e. 'Cfa' meaning subtropical humid climate and 'Cfb' meaning Marine west coast climate

- 'Cw' or China type of climate- such regions receive 10 times more rain/snow in summers than the driest winter month
- 'Ca' or Mediterranean type of climate- such regions receive 3 times more rain/snow in winters than the driest summer month. This month of summer season gets <1.2 inches of rain/snow.

Some more minor details were identified by Koeppen in Climate C so he added these alphabets to the existing climate types:

- Small 'a'- Such regions witness warm summer season
- Small 'b'- Such regions witness cold winter season and warmest month has a temperature of <22$^0$C.
- Small 'c'- Such regions witness summers which are short but very cool.

**4.6.1.4 Climate D in detail:**

This type of climate is also referred to as 'Cold snow forest' or 'Cold humid' type of climate. Here, the avg. temperature in the coldest month remains >-3$^0$C and that of the warmest month is always <10$^0$C. Ground remains frozen (snow covered) for most part of the year. Climatic sub divisions, as provided by Koeppen, can be seen in climate D as well. These are enlisted below, with first Alphabet in capital and second alphabet in lower case.

- 'Df' type of climate- represents cold humid temperate type of climate without any dry season. This type of climate has 3 more sub-divisions also, namely;

  (i) 'Dfa' which denotes continental type of cold humid climate. Such regions experience *long but warm summers*.

  (ii) 'Dfb' denotes cold humid temperate regions which experience *long but cool summers*.

  (iii) 'Dfc' denotes cold humid temperate regions which experience *very short but cool summers*.

- 'Dw' type of climate - represents cold humid temperate type of climate with a distinct dry season in winters. This type of climate has 3 more sub-divisions also, namely;

  (i) 'Dwa' which denotes continental type of cold humid climate. Such regions experience *long but cool summers*.

  (ii) 'Dwb' denotes cold humid temperate regions which experience *short but cool summers*.

  (iii) 'Dwc' denotes severe winters. The temperature dips to minus 38$^0$C in the coldest month. No defined summers.

#### 4.6.1.5 Climate E in detail:

This type of climate is also referred to as 'Polar or tundra' type of climate. There doesn't exist ant well defined summer season in regions experiencing such type of climate. Here, the avg. temperature in the warmest month remains $<10^0$C. The sub divisions are (Both alphabets in capital):

'ET'type of climate- it is experienced by people living in tundra regions near the North and South poles of the Earth. The warmest month the temperature ranges between $0^0$C to $10^0$C.

'EF'type of climate- it is experienced by people living in tundra regions. The earth's surface is permanently covered with ice and snow (permafrost). The temperature remains $<0^0$C throughout the year.

### 4.6.2 Critical Assessment of Koeppen's Climatic Classification:

This elaborate classification given by Koeppen in order to describe the various climates that exist across the world has its own set of merits and demerits. These are enlisted as follows:

**Merits:**

- Koeppen considered temperature and precipitation as the fundamental factors influencing the nature of climate present in different regions of the world. It is important to note that these two factors still continue to remain the most effective and significant factors in identifying any weather or climatic controls present in any given place/area.
- He based his climate scheme on vegetation types existing in the different world regions. This makes his classification more relevant and relatable, since vegetation is a very good indicator of the type of climatic conditions prevalent in any given region. This attribute of his classification is better appreciated by the geographers across several countries.
- He understood the necessity of paying attention to the rate of evaporation and potential evapotranspiration in his scheme. This is important, as loss of moisture from vegetation and other sources of water should be understood well if, the rate of effective precipitation needs to be calculated.
- His classification is better since it is a very popular generalized account of the world climate types. It is easy to understand and is nicely described paying equal attention to major and minor details of various climate regimes.

**Demerits:**

- Important weather elements like; diurnal range of temperature, direction and speed of winds, intensity of precipitation, number of rainy/ snowfall days, extent of cloudiness in the sky and the impact of different types of air masses present across the world, were totally ignored by Koeppen and he attached too much importance to avg. monthly temperature and precipitation values.

- He eliminated the significance of the causative elements of the climate.
- There is too much use of alphabets in his classification that it is very difficult to remember all the alphabets and their respective climate type. Also few alphabets keep on repeating all along in the sub-divisions of the climate types which is somewhat confusing.

### 4.6.3 Thorn Thwaite's Classification:

C.W. Thorn Thwaite was a climatologist of American origin. He presented his first descriptive climatic classification for the climates of the continent of North America in 1931 and revised it with further improvements and modifications and came up with a description/classification of the 'world climates' in the year 1948.

- He even published a map of North America depicting his climate scheme of 1931.
- His classification is also based on the prominent vegetation types growing in a given climate zone in order to highlight the climate of that region.
- He believed that temperature, precipitation and evaporation controlled the vegetation to a very large extent. For this purpose, he included Temperature Effectiveness and Precipitation Effectiveness index in his classification to mark the boundaries of various climatic zones.
- Moreover, this scheme is a bit more complicated and is based on observable and statistical data.

#### 4.6.3.1 Climate classification presented by Thorn Thwaite in 1931:

a) Concept of Temperature Effectiveness-

Since temperature is a key factor governing the growth of different types of plants in different climates, Thorn Thwaite, developed a Temperature Effectiveness index to understand the extent to which the mean monthly temperature of a place deviates from the freezing point. He devised two formulae to calculate two things.
Firstly, Thermal Efficiency Ratio (TER)
$TER = (t-32) / 4$
Secondly, Thermal Efficiency Index (TEI)

$$TEI = \sum_{i=1}^{12} (t-32)/4$$

Here, *t* represents Avg. Monthly Temperature in degree Fahrenheit.

Thermal Efficiency Index is the sum total of TER for one complete year (12 months).

Based on Temperature Effectiveness, Thorn Thwaite made an alphabetical scheme for classifying the various types of climates into 6 broad categories, which he called Temperature Provinces. These are mentioned in the table below:

Table 4.6.1: Temperature provinces and the respective thermal indices, given by Thorn Thwaite

| **Sl. No.** | **Thermal Efficiency Index** | **Temperature Provinces** |
|---|---|---|
| 1 | 127 | **A'** - Tropical |
| 2 | 64-127 | **B'** – Mesothermal |
| 3 | 32-63 | **C'** – Microthermal |
| 4 | 16-31 | **D'** – Taiga |
| 5 | 1.15 | **E'** – Tundra |
| 6 | 0 | **F'**- Frost |

*Source: Savindra Singh*

**b) <u>Concept of Precipitation Effectiveness:</u>**

Since Thorn Thwaite was considering vegetation as a chief indicator of the world climate zones, he understood the importance of precipitation as a fundamental criteria in governing the growth and development of the flora because availability of water plays an integral role in the life cycle of all types of plants. He defined Precipitation Effectiveness as - only that much amount of water received through rainfall, which is available to the plants for their growth and development. For the purpose of calculating the Precipitation Effectiveness Ratio (PER) and Precipitation Effectiveness Index (PEI), he developed two formulae:

(i) $PER = 11.5\,(r / t - 10)^{10/9}$

(ii) $\text{PEI} = \sum_{i=1}^{12} 11.5\,(r/t - 10)^{10/9}$

Here, *r* refers to avg. monthly Rainfall in inches and *t* refers to avg. monthly Temperature in degree Fahrenheit.

Based on Precipitation Effectiveness index, Thorn Thwaite made an alphabetical scheme for classifying the various types of climates into 5 broad categories, which he called Humidity Zones. These are mentioned in the table below:

Table 4.6.2: Humidity Zones and the respective Precipitation indices, as given by Thorn Thwaite

| Sl. No. | PEI | Vegetation | Humidity Zones |
|---|---|---|---|
| 1 | 127 | Rainforest | A - Wet |
| 2 | 64-127 | Forest | B - Humid |
| 3 | 32-63 | Grassland | C - Sub-humid |
| 4 | 16-31 | Steppe | D - Semi- arid |
| 5 | < 16 | Desert | E - Arid |

*Source: Savindra Singh*

Thorn Thwaite further sub divided the humidity zones to represent the minor details that exist in different regions, within his classification scheme. For this he used small alphabets, namely;

- Small ‘r’- denotes sufficient rainfall in all seasons
- Small ‘s’- denotes deficient rainfall in summers
- Small ‘w’- denotes deficient rainfall in winters
- Small ‘d’- denotes deficient rainfall in all seasons

There are 20 combinations of the sub humidity zones as identified by Thorn Thwaite, enlisted below.

- Climate A- Ar, As, Aw, Ad
- Climate B- Br, Bs, Bw, Bd
- Climate C- Cr, Cs, Cw, Cd
- Climate D- Dr, Ds, Dw, Dd
- Climate E- Er, Es, Ew, Ed

Keeping in view the three key indicators of world climate regions, used by Thorn Thwaite, namely; Thermal Efficiency, Precipitation Effectiveness and seasonal distribution of rainfall approximately 120 diverse climate types can be thought of but only 32 combinations were picked by him. These are:

- Climate A- AA’r, AB’r, AC’r,
- Climate B- BA’r, BA’w, BB’r, BB’w, BB’s, BC’r, BC’s
- Climate C- CA’r, CA’w, CA’d, CB’r, CB’w, CB’s, CB’d, CC’r, CC’s, CC’d
- Climate D- Da’w, DA’d, DB’w, DB’s, DB’d, DC’d
- Climate E- EA’d, EB’d, EC’d
- Climate D’ (taiga), E’ (tundra), F’ (polar permafrost)

**4.6.3.2 Climate classification presented by Thorn Thwaite in 1948:**

Several alterations and additions were made by Thorn Thwaite to his previous classification which he presented only for the continent of North America. In 1948, he came up with a new and revised version of his climatic classification which he presented, keeping in mind the whole world. Thus, this scheme included the ingredients of diverse parts of the earth in order to become suitable for identifying and relating to the respective climates.

- Apart from revising his three key indicators of Thermal Efficiency, Precipitation Effectiveness and seasonal distribution of rainfall, used in the first classification, he even introduced Potential Evapotranspiration (PE) in place of vegetation types, in his scheme.
- PE is a specific indicator which is inclusive of Water Loss and Temperature Effectiveness.
- He stated that sun being the ultimate source of heat and light energy, provides it for the whole earth and this energy is responsible for evaporation of water/moisture from the soils and vegetation i.e. transpiration as well as for heat loss from these two sources.
- The water enters into the atmosphere as vapor and heat enters as terrestrial radiation.
- Note that- PE is a function of avg. monthly temperature obtained during 12 hours of daylight. The formula that he used for this calculation is: $PE\ in\ cm = 1.6\ (10\ t\ /\ I)^a$
- He further devised 3 separate indices namely; moisture index (Im), Aridity and humidity index and index of concentration of PE.
- For calculating the moisture index he gave the formula: Im= (100S-60D) / PE

  Here, S means monthly surplus of moisture and D means monthly deficit of moisture.
- He has mentioned 9 humidity provinces based on Im, namely; A- per-humid, $B_4$, $B_3$, $B_2$ and $B_1$ – Humid, $C_2$- moist sub humid, $C_1$- dry sub humid, D- semi arid and E- Arid.
- He has mentioned 9 Thermal provinces as well. Namely; A'- Megathermal, $B'_4$, $B'_3$, $B'_2$ and $B'_1$ – Mesothermal, $C_2$ and $C_1$- Microthermal, D'- Tundra and E'- Frost

**4.6.4 Critical Assessment of Thorn Thwaite's Climatic Classification:**

It is pretty clear by now, and worth mentioning that the climatic classifications presented by Koeppen and Thorn Thwaite respectively, are similar and comparable to each other in many respects, like;

Usage of English alphabets by both climatologists to depict the various world climates.

Use of types of vegetation data and observable, statistical data to demarcate the climate zones.

Finally, use of temperature and precipitation data as the key indicators of changes in climate patterns in different regions of the world.

It should also understood that the classification presented by Thorn Thwaite, is not completely appropriate and accurate due to some inherent drawbacks in his scheme.

Firstly, this classification involves too much use of alphabets, is lengthy, difficult to memorize and somewhat confusing.

Secondly, it involves too many numerical values and calculations plus regular input of data, which may not always be available. This makes it cumbersome.

Thirdly, he didn't include the causative climatic factors that play a vital role in influencing diverse climates in many ways.

Fourthly, though he revised the previous scheme and put forth a new one with the necessary modifications but still, his classification suffers from insufficiency of data (as it is not readily available at all times), especially the evaporation data and PE data of all places.

Fifthly, he included too many indices in his classification that the cartographers found it very difficult to present all these details in a quantitative manner on the world map. This hampers the creation of world maps and the cartographers are unable to mark the climate boundaries properly, thus hampering the study of the climate patterns present across the world.

Considering these cons, the meteorologists and climatologists disapproved of his scheme and so it could not get its due share of appreciation and thus remained unpopular and less documented, although the botanists and zoologists accepted it.

### 4.6.5 Exercises:

***a) Fill Ups.***

1. In 1931, Thorn Thwaite, published a climatic map of ______ continent.
2. 'Cf' in Koppen's classification represents ______ type of climate.
3. ____ letters in Koeppen's classification denote permafrost.
4. Letter D denotes ___ and D' denotes ____ in Thorn Thwaite's classification of 1931.
5. Polar climates have no defined summer season and maximum is less than $10^0$C. These are represented by letter ____ in Koeppen's classification.

***b) Multiple Choice Questions (MCQs).***

1. Who among the following used Precipitation effectiveness and Temperature effectiveness for the classification of climate?
   a. Thornbury
   b. Chorley
   c. Thorn Thwaite
   d. Koeppen

2. According to Koeppen, which of the following alphabets represent dry climate where evaporation exceeds precipitation and there is constant water deficit throughout the year.

a. B
b. D
c. C
d. A

3. Who among these presented a new concept in his climate classification in 1948 and termed it as 'Potential Evapotranspiration'?

a. Trewartha
b. Thorn Thwaite
c. Koeppen
d. Critchfield

4. The China type of climate is characterized by:

a. Less rain
b. Abundant rain
c. Moderate Rain
d. No rain

5. According to Koeppen, which of the following climate is represented by Bwh?

a. China Type climate
b. Mid latitude Steppe climate
c. Sahara Type climate
d. Mid latitude Desert climate

6. According to Koeppen what does Am refer to?

a. Mid-Latitude Desert Climate
b. Temperate Oceanic Climate
c. Tropical Monsoon Climate
d. Sub-Tropical Humid Climate

7. Tropical wet and dry (Savanna Climate) is represented by which of the following?

a. Ar
b. Df
c. Bwh
d. Aw

8. According to Koeppen, 'D' type of climate represents:

a. Humid mesothermal
b. Humid microthermal or cold humid climate
c. Humid tropical climate
d. Dry climate

9. Which of these is not a part of Koeppen's classification
   a. Megatherms
   b. Microtherms
   c. Hekistotherms
   d. None of these

10. Identify the limitation of the 1948 scheme of climatic classification presented by Thorn Thwaite.
   a. Non availability of data of evaporation of all the places
   b. No inclusion of causative factors of climates into the classification
   c. Non availability of any world map indicating the different climate types
   d. All of these

**4.6.6 Answers to Exercises:**

**a) Fill ups**

1. North American
2. Western Europe
3. EF
4. Semi-arid steppe, Taiga
5. E

**b) MCQs**

1. Thorn Thwaite
2. B
3. Thorn Thwaite
4. Abundant rain
5. Sahara Type climate
6. Tropical Monsoon Climate
7. Aw
8. Humid microthermal or cold humid climate
9. None of these
10. All of these

**4.6.7 Task: Long Answer Questions**

**Try to attempt the questions given below.**

i. Give a detailed account of the 1948 climatic classification of Thorn Thwaite.

ii. Critically evaluate the climatic classification given by Koeppen.

iii. Describe the A, B and C climate types along with their sub divisions, as put forth by Koeppen.

## 4.7 SUMMARY

After gaining a thorough understanding of this unit, the students will now become fluent with the concepts that have been systematically elaborated in the various chapters of this study material and will be able to identify the opposing nature of the air masses, their source regions, their attributes, the different fronts formed by opposing air masses and the weather conditions that result due to the front formation, besides, gaining knowledge about the meaning and concept of a Temperate cyclone, the most popular and accepted theory of its formation and the mechanism involved in the genesis of a cyclone with its stages of development. These interrelated and interdependent atmospheric phenomena exert an enormous influence on the daily lives of the humans inhabiting the earth. By reading the concepts, illustrated with the necessary diagrams, the students will become well versed with the aforementioned and will be in a position to relate to the global atmospheric conditions that exist perennially and those phenomena that exist seasonally and locally. The last chapter of this fold includes the climate schemes presented by two prominent climatologist, which shall enhance the knowledge of the students regarding the quantification of various climate zones existing across the world and help them in taking note of the patterns in which one climate differs from the other based on the vegetation types that thrive there and how the temperature, precipitation and evapotranspiration (heat and moisture) data prove to be useful in gaining insight into the climates of the world.

## 4.8 REFERENCES


Barry, R.S. & Chorley, R.J. Atmosphere, Weather and Climate, 1968. *U.S.A.: ELBS, Methuen & Co. Ltd.*

Singh, S. Physical Geography, 2009. *Allahabad: Prayag Pustak Bhawan*.

Internet: www.pmfias.com/fronts-frontogenesis-stationary-front-cold-front-warm-front-occluded-front/

Internet: www.pinterest.com/pin/170644273368806899/


## 4.9 TEXT FOR FURTHER READING


- Frederick K. and Edward J. Tarbuck, The Atmosphere: An Introduction to Meteorology, Prentice Hall of India Pvt. Ltd., New Delhi, 1995.

- Strahler, A.N., Modern Physical Geography, John Wiley and Sons, New York, Singapore, 1987.

- Trewartha, G.T., An Introduction to Climate, McGraw Hill, New York, 1980, Fifth Edition (International Student Edition).

- Lydolph, P.E., The Climate of the Earth, Rowman Nad Allanheld, Totowa, New Jersey, 1985.

* Rumney, G.R., Climatology and the World Climates, Macmillan, London, 1968.

* Thompson Russell D., Applied Climatology - Principles & Practice, John Willey, New York, 1997.

* Lal, D.S., Climatology, Sharda Pustak Bhawan, Allahabad, 1997.

* Mather, J. R., Climatology: Fundamentals and Applications, McGraw Hill Book Co. New York, 1974.

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