This unit deals with
• Atmosphere — compositions and structure; elements of weather and climate
• Insolation — angle of incidence and distribution; heat budget of the earth — heating and cooling of atmosphere (conduction, convection, terrestrial radiation, advection); temperature — factors controlling temperature; distribution of temperature — horizontal and vertical; inversion of temperature; Pressure — pressure belts; winds-planetary seasonal and local, air masses and fronts; tropical and extra tropical cyclones
• Precipitation — evaporation; condensation — dew, frost, fog, mist and cloud; rainfall — types and world distribution
• World climates — classification (Koeppen), greenhouse effect, global warming and climatic changes

CHAPTER EIGHT
What is the importance of atmosphere?
Air is essential to the survival of all organisms. Some organisms like humans may survive for some time without food and water but can’t survive even a few minutes without breathing air. That shows the reason why we should understand the atmosphere in greater detail.

Define The Atmosphere
Atmosphere is a mixture of different gases and it envelopes the earth all round. It contains life-giving gases like oxygen for humans and animals and carbon dioxide for plants.

What is the average height of the Atmosphere?
The air is an integral part of the earth’s mass and 99 per cent of the total mass of the atmosphere is confined to the height of 32 km from the earth’s surface. The air is colourless and odourless and can be felt only when it blows as wind.

Can you imagine what will happen to us in the absence of ozone in the atmosphere? In the absence of Ozone life is not possible on the earth surface.

COMPOSITION OF THE ATMOSPHERE
The atmosphere is composed of gases, water vapour and dust particles. The proportion of gases changes in the higher layers of the atmosphere in such a way that oxygen will be almost in negligible quantity at the height of 120 km. Similarly, carbon dioxide and water vapour are found only up to 90 km from the surface of the earth.

COMPOSITION AND STRUCTURE OF ATMOSPHERE

![Atmosphere Structure Diagram]

### Table 8.1: Permanent Gases of the Atmosphere

<table>
<thead>
<tr>
<th>Constituent</th>
<th>Formula</th>
<th>Percentage by Volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>N₂</td>
<td>78.08</td>
</tr>
<tr>
<td>Oxygen</td>
<td>O₂</td>
<td>20.95</td>
</tr>
<tr>
<td>Argon</td>
<td>Ar</td>
<td>0.93</td>
</tr>
<tr>
<td>Carbon dioxide</td>
<td>CO₂</td>
<td>0.036</td>
</tr>
<tr>
<td>Neon</td>
<td>Ne</td>
<td>0.002</td>
</tr>
<tr>
<td>Helium</td>
<td>He</td>
<td>0.0005</td>
</tr>
<tr>
<td>Krypton</td>
<td>Kr</td>
<td>0.001</td>
</tr>
<tr>
<td>Xenon</td>
<td>Xe</td>
<td>0.00009</td>
</tr>
<tr>
<td>Hydrogen</td>
<td>H₂</td>
<td>0.00005</td>
</tr>
</tbody>
</table>

Study the above table showing the composition of the atmosphere and answer the following questions.
1. Which gas constitutes the highest % of atmosphere? 2. Name the gas which constitutes least % of atmosphere
Gases

**Carbon dioxide** is meteorologically a very important gas as it is transparent to the incoming solar radiation but opaque to the outgoing terrestrial radiation. It absorbs a part of terrestrial radiation and reflects back some part of it towards the earth’s surface. It is largely responsible for the *green house effect*. The volume of carbon dioxide has been rising in the past few decades mainly because of the burning of fossil fuels. This has also increased the temperature of the air.

**Ozone** is another important component of the atmosphere found between 10 and 50 km above the earth’s surface and acts as a filter and absorbs the *ultra-violet rays* radiating from the sun and prevents them from reaching the surface of the earth.

**Water Vapour**

Water vapour is also a variable gas in the atmosphere, which decreases with altitude. In the warm and wet tropics, it may account for four per cent of the air by volume, while in the dry and cold areas of desert and polar regions, it may be less than one per cent of the air. Water vapour also decreases from the equator towards the poles. It also absorbs parts of the insolation from the sun and preserves the earth’s radiated heat. It thus, acts like a blanket allowing the earth neither to become too cold nor too hot. Water vapour also contributes to the stability and instability in the air.

**Dust Particles**

Atmosphere has a sufficient capacity to keep small solid particles, which may originate from different sources and include sea salts, fine soil, smoke-soot, ash, pollen, dust and disintegrated particles of meteors. Dust particles are generally concentrated in the lower layers of the atmosphere; yet, convectional air currents may transport them to great heights. The higher concentration of dust particles is found in subtropical and temperate regions due to dry winds in comparison to equatorial and polar regions. Dust and salt particles act as hygroscopic nuclei around which water vapour condenses to produce clouds.

**STRUCTURE OF THE ATMOSPHERE**

1. The atmosphere consists of different layers with varying density and temperature.  
2. Density is highest near the surface of the earth and decreases with increasing altitude.
3. The column of atmosphere is divided into five different layers depending upon the temperature condition.

**Name the layers of atmosphere**

They are: troposphere, stratosphere, mesosphere, thermosphere and exosphere.

**The troposphere**

1. It is the lowermost layer of the atmosphere.  
2. Its average height is 13 km  
3. extends roughly to a height of 8 km near the poles and about 18 km at the equator.  
4. Thickness of the troposphere is greatest at the equator because heat is transported to great heights by strong convectional currents.  
5. This layer contains dust particles and water vapour.  
6. All changes in climate and weather take place in this layer.  
7. The temperature in this layer decreases at the rate of 1 °C for every 165 m of height.  
8. This is the most important layer for all biological activity.  
9. The zone separating the troposphere from stratosphere is known as the *tropopause*.  
The air temperature at the tropopause is about minus 800 °C over the equator and about minus 45°C over the poles.  

The temperature here is nearly constant, and hence, it is called the *tropopause*.

**The stratosphere**

1. It is found above the tropopause and extends up to a height of 50 km.  
2. One important feature of the stratosphere is that it contains the *ozone layer*.  
3. This layer absorbs ultra-violet radiation and shields life on the earth from intense, harmful form of energy.

**The mesosphere**

1. It lies above the stratosphere,  
2. which extends up to a height of 80 km.  
3. In this layer, once again, temperature starts decreasing with the increase in altitude and Up to minus 100 °C at the height of 80 km.
4. The upper limit of mesosphere is known as the **mesopause**.

**The ionosphere**
1. It is located between 80 and 400 km above the mesopause. 2. It contains electrically charged particles known as ions, and hence, it is known as ionosphere.
3. Radio waves transmitted from the earth are reflected back to the earth by this layer. 4. Temperature here starts increasing with height.
5. The uppermost layer of the atmosphere above reaches up to minus 100

**Exosphere**
1. The thermosphere is known as the **exosphere**. 2. This is the highest layer but very little is known about it.
3. Whatever contents are there, these are extremely rarefied in this layer, and it gradually merges with the outer space.

**Elements of Weather and Climate**
The main elements of atmosphere which are subject to change and which influence human life on earth are
1. temperature, 2. pressure,
3. winds,
4. humidity, 5. clouds
6. precipitation.
This chapter deals with Solar radiation, variability of insolation at the surface of the earth heating and cooling of atmosphere, terrestrial radiation, heat budget of the planet earth, latitudinal variation in net radiation balance, temperature, factors influencing the temperature (such as the latitude, altitude, distance from the sea, air mass, ocean currents), distribution of temperature, isotherm.

Define insolation.
The earth’s surface receives most of its energy in short wavelengths. The energy received by the earth is known as incoming solar radiation which in short is termed as insolation.

Which factor is responsible for the varied distribution of energy?
As the earth is a Geoid resembling a sphere, the sun’s rays fall obliquely at the top of the atmosphere and the earth intercepts a very small portion of the sun’s energy.

What is the average amount of energy received by the earth?
On an average the earth receives 1.94 calories per sq. cm per minute at the top of its atmosphere. Give the reasons why it is summer when earth is far away from the sun and winter when it is nearest to the Sun.

The solar output received at the top of the atmosphere varies slightly in a year due to the variations in the distance between the earth and the sun. During its revolution around the sun, the earth is farthest from the sun (152 million km) on 4th July. This position of the earth is called aphelion. On 3rd January, the earth is the nearest to the sun (147 million km). This position is called perihelion.

Therefore, the annual insolation received by the earth on 3rd January is slightly more than the amount received on 4th July. However, the effect of this variation in the solar output is masked by other factors like the distribution of land and sea and the atmospheric circulation. Hence, this variation in the solar output does not have great effect on daily weather changes on the surface of the earth.

Variability of Insolation at the Surface of the Earth
The amount and the intensity of insolation vary during a day, in a season and in a year. The factors that cause these variations in insolation are
(i) the rotation of earth on its axis;
(ii) the angle of inclination of the sun’s rays;
(iii) the length of the day;
(iv) the transparency of the atmosphere;
(v) the configuration of land in terms of its aspect.
The last two however, have less influence. The fact that the earth’s axis makes an angle of 66° with the plane of its orbit round the sun has a greater influence on the amount of insolation received at different latitudes.

Note: The variations in the duration of the day at different latitudes on solstices are given in the Table below.

Table 9: Length of the Day in Hours and Minutes on Winter and Summer Solstices in the Northern Hemisphere

<table>
<thead>
<tr>
<th>Latitude</th>
<th>December 22</th>
<th>June 21</th>
</tr>
</thead>
<tbody>
<tr>
<td>20°</td>
<td>12h 00m</td>
<td>12h</td>
</tr>
<tr>
<td>40°</td>
<td>13h 12m</td>
<td>14h 52m</td>
</tr>
<tr>
<td>60°</td>
<td>18h 27m</td>
<td>6 months</td>
</tr>
</tbody>
</table>

The incoming radiation is not fully reached to the earth surface. Why?
1. The atmosphere is largely transparent to short wave solar radiation. The incoming solar radiation passes through the atmosphere before striking the earth’s surface.
2. Within the troposphere water vapor, ozone and other gases absorb much of the near infrared radiation.
3. Very small-suspended particles in the troposphere scatter visible spectrum both to the space and towards the earth surface.
4. This process adds colour to the sky.
5. The red colour of the rising and the setting sun and the blue colour of the sky are the result of scattering of light within the atmosphere.

What is the average distribution of insolation on the surface? Give the reasons for such variation.

Spatial Distribution of Insolation on the Earth's Surface

The insolation received at the surface varies from about 320 Watt/m in the tropics to about 70 Watt/m in the poles. Maximum insolation is received over the subtropical deserts, where the cloudiness is the least. Equator receives comparatively less insolation than the tropics. Generally, at the same latitude the insolation is more over the continent than over the oceans. In winter, the middle and higher latitudes receive less radiation than in summer.

HEATING AND COOLING OF ATMOSPHERE

Name the ways of heating the atmosphere.


1. Horizontal movement of the air is relatively more important than the vertical movement.
2. In middle latitudes, most of diurnal (day and night) variation in daily weather are caused by advection alone.
3. In tropical regions particularly in northern India during summer season local winds called 'loo' is the outcome of advection process.

Terrestrial Radiation

1. The insolation received by the earth is in shortwaves forms and heats up its surface.
2. The earth after being heated itself becomes a radiating body and it radiates energy to the atmosphere in long wave form.
3. This energy heats up the atmosphere from below. 4. This process is known as terrestrial radiation.
5. The long wave radiation is absorbed by the atmospheric gases particularly by carbon dioxide and other greenhouse gases. Thus, the atmosphere is indirectly heated by the earth's radiation. The atmosphere in turn radiates and transmits heat to the space. Finally the amount of heat received from the sun is returned to space, thereby maintaining constant temperature at the earth’s surface and in the atmosphere.

With the help of a diagram explain the Heat Budget of the Planet Earth.

Figure 9.2 depicts the heat budget of the planet earth. The earth as a whole does not accumulate or loose heat. It maintains its temperature.

This can happen only if the amount of heat received in the form of insolation equals the amount lost by the earth through terrestrial radiation.
3. Consider that the insolation received at the top of the atmosphere is 100 percent. 4. While passing through the atmosphere some amount of energy is reflected, scattered and absorbed.
5. Only the remaining part reaches the earth surface.
6. Roughly 35 units are reflected back to space even before reaching the earth's surface. 7. Of these, 27 units are reflected back from the top of the clouds.
8. Only 2 units from the snow and ice-covered areas of the earth. 9. The remaining 65 units are absorbed, 10. 14 units within the atmosphere and 51 units by the earth’s surface. **TERRESTRIAL RADIATION**

1. The earth radiates back 51 units in the form of terrestrial radiation. 2. 17 units are radiated to space directly

3. the remaining 34 units are absorbed by the atmosphere 4.6 units absorbed directly by the atmosphere, 5.9 units through convection and turbulence 6. 19 units through latent heat of condensation 7.48 units absorbed by the atmosphere(14 units from insolation +34 units from terrestrial radiation) are also radiated back into space.

Thus, the total radiation returning from the earth and the atmosphere respectively is 17+48=65 units which balance the total of 65 units received from the sun. This is termed the heat budget or heat balance of the earth.

This explains, why the earth neither warms up nor cools down despite the huge transfer of heat that takes place.

What do you mean by ‘Albedo’?
The reflected amount of radiation is called the **albedo of the earth**. **Variation in the Net Heat Budget at the Earth’s Surface**

As explained earlier, there are variations in the amount of radiation received at the earth’s surface. Some part of the earth has surplus radiation balance while the other part has deficit.

Figure 9.3 depicts the latitudinal variation in the net radiation balance of the earth the atmosphere system.

The figure shows that there is a surplus of net radiation balance between 40 degrees north and south and the regions near the poles have a deficit.

The surplus heat energy from the tropics is redistributed pole wards and as a result the tropics do not get progressively heated up due to the accumulation of excess heat or the high latitudes get permanently frozen due to excess deficit.

**W**hat is the difference between heat and temperature?

**Temperature**
The interaction of insolation with the atmosphere and the earth’s surface creates heat which is measured in terms of temperature.

While heat represents the molecular movement of particles comprising a substance, the temperature is the measurement in degrees of how hot (or cold) a thing (or a place) is.

**Factors Controlling Temperature Distribution**
The temperature of air at any place is influenced by

- the latitude of the place;
- the altitude of the place;
- distance from the sea, the air mass circulation;
- the presence of warm and cold ocean currents;
- (v) local aspects.

(i) **The latitude** : The temperature of a place depends on the insolation received. It has been explained insolation

Figure 9.3 (b): The Distribution of surface air temperature for the month of July

- Solar Radiation
- Terrestrial Radiation

![Figure 9.3 : Latitudinal variation In net radiation balance](image)

The rate of decrease of temperature with height is

Solar Radiation

---

Terrestrial Radiation

**Natural Temperature**

earth’s surface creates heat which is measured in terms of temperature.

While heat represents the molecular movement of particles comprising a substance, the temperature is the measurement in degrees of how hot (or cold) a thing (or a place) is.

**Factors Controlling Temperature Distribution**

The temperature of air at any place is influenced by

- the latitude of the place;
- the altitude of the place;
- distance from the sea, the air mass circulation;
- the presence of warm and cold ocean currents;
- (v) local aspects.

(i) **The latitude** : The temperature of a place depends on the insolation received. It has been explained insolation

Figure 9.3 (b): The Distribution of surface air temperature for the month of July

- Solar Radiation
- Terrestrial Radiation

![Figure 9.3 : Latitudinal variation In net radiation balance](image)

The rate of decrease of temperature with height is

Solar Radiation

---

Terrestrial Radiation

**Natural Temperature**

earth’s surface creates heat which is measured in terms of temperature.
termed as the normal lapse rate. It is 6.5°C per 1,000 m. /1°C@ 165 meter of ascent.

**Distance from the sea:** Another factor that influences the temperature is the location of a place with respect to the sea. Compared to land, the sea gets heated slowly and loses heat slowly. Land heats up and cools down quickly. Therefore, the variation in temperature over the sea is less compared to land. The places situated near the sea come under the moderating influence of the sea and land breezes which moderate the temperature.

**Air-mass:** Like the land and sea breezes, the passage of air masses also affects the temperature. The places, which come under the influence of warm air-masses experience higher temperature and the places that come under the influence of cold air masses experience low temperature. **Ocean currents** Similarly, the places located on the coast where the warm ocean currents flow record higher temperature than the places located on the coast where the cold currents flow.

**Isotherms** are lines joining places having equal temperature.

**Figure 9.4 (a) and (b) show the distribution of surface air temperature in the month of January and July.**

1. In general the effect of the latitude on temperature is well pronounced on the map, 2. the isotherms are generally parallel to the latitude.

3. The deviation from this general trend is more pronounced in January than in July, especially in the northern hemisphere.
4. In the northern hemisphere the land surface area is much larger than in the southern hemisphere. Hence, the effects of land mass and the ocean currents are well pronounced.

In January the isotherms deviate to the north over the ocean and to the south over the continent. This can be seen on the North Atlantic Ocean.

**INVERSION OF TEMPERATURE**

Normally, temperature decreases with increase in elevation. It is called normal lapse rate. At times, the situations is reversed and the normal lapse rate is inverted. It is called Inversion of temperature. Inversion is usually of short duration but quite common nonetheless. A long winter night with clear skies and still air is ideal situation for inversion. The heat of the day is radiated off during the night, and by early morning hours, the earth is cooler than the air above.
This chapter deals with atmospheric pressure, vertical variation pressure, horizontal distribution of pressure, world distribution of sea level pressure, factors affecting the velocity and direction of wind (pressure gradient force, frictional force, carioles force, pressure and wind), general circulation of the atmosphere, ENSO, seasonal wind, local winds, land and sea breezes, mountain and valley winds, air masses, fronts, extratropical cyclone, tropical cyclones, thunderstorms, tornadoes.

The pressure decreases with height. At any elevation it varies from place to place and its variation is the primary cause of air motion, i.e. wind which moves from high pressure areas to low pressure areas.

**Vertical Variation of Pressure**
In the lower atmosphere the pressure decreases rapidly with height. The decrease amounts to about 1 mb for each 10 m increase in elevation. It does not always decrease at the same rate. Table 10.1 gives the average pressure and temperature at selected levels of elevation for a standard atmosphere.

<table>
<thead>
<tr>
<th>Level</th>
<th>Pressure in mbar</th>
<th>Temperature °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sea Level</td>
<td>1,013.25</td>
<td>15.2</td>
</tr>
<tr>
<td>1 km</td>
<td>898.76</td>
<td>8.7</td>
</tr>
<tr>
<td>5 km</td>
<td>540.48</td>
<td>-17.3</td>
</tr>
<tr>
<td>10 km</td>
<td>265.00</td>
<td>-49.7</td>
</tr>
</tbody>
</table>

The vertical pressure gradient force is much larger than that of the horizontal pressure gradient. But, it is generally balanced by a nearly equal but opposite gravitational force. Hence, we do not experience strong upward winds.

**Horizontal Distribution of Pressure**
Small differences in pressure are highly significant in terms of the wind direction and velocity. Horizontal distribution of pressure is studied by drawing isobars at constant levels. Isobars are lines connecting places having equal pressure. In order to eliminate the effect of altitude on pressure, it is measured at any station after being reduced to sea level for purposes of comparison.

**World Distribution of Sea Level Pressure**

The world distribution of sea level pressure in January and July has been shown in Figures 10.2 and 10.3. Near the equator the sea level pressure is low and the area is known as **equatorial low**. Along 30° N and 30° S found the high-pressure areas known as the **subtropical highs**. Further pole wards along 60° N and 60° S, the low-pressure belts are termed as the **sub polar lows**. Near the poles the pressure is high and it is known as the **polar high**.

These pressure belts are not permanent in nature. They oscillate with the apparent movement of the sun. In the northern hemisphere in winter they move southwards and in the summer northwards.

---

**Table 10.1 : Standard Pressure and Temperature at Selected Levels**

The vertical pressure gradient force is much larger than that of the horizontal pressure gradient. But, it is generally balanced by a nearly equal but opposite gravitational force. Hence, we do not experience strong upward winds.

**Horizontal Distribution of Pressure**
Small differences in pressure are highly significant in terms of the wind direction and velocity. Horizontal distribution of pressure is studied by drawing isobars at constant levels. Isobars are lines connecting places having equal pressure. In order to eliminate the effect of altitude on pressure, it is measured at any station after being reduced to sea level for purposes of comparison.

**World Distribution of Sea Level Pressure**

The world distribution of sea level pressure in January and July has been shown in Figures 10.2 and 10.3. Near the equator the sea level pressure is low and the area is known as **equatorial low**. Along 30° N and 30° S found the high-pressure areas known as the **subtropical highs**. Further pole wards along 60° N and 60° S, the low-pressure belts are termed as the **sub polar lows**. Near the poles the pressure is high and it is known as the **polar high**.

These pressure belts are not permanent in nature. They oscillate with the apparent movement of the sun. In the northern hemisphere in winter they move southwards and in the summer northwards.
Forces Affecting the Velocity and Direction of Wind

You already know that the air is set in motion due to the differences in atmospheric pressure. The air in motion is called wind. The wind blows from high pressure to low pressure. In addition, rotation of the earth also affects the wind movement. The force exerted by the rotation of the earth is known as the Coriolis force.

The horizontal winds near the earth surface respond to the combined effect of three forces – the pressure gradient force, the frictional force and the Coriolis force. In addition, the gravitational force acts downward.

Pressure Gradient Force

The differences in atmospheric pressure produce a force. The rate of change of pressure with respect to distance is the pressure gradient. The pressure gradient is strong where the isobars are close to each other and is weak where the isobars are apart.

Coriolis Force

It affects the speed of the wind. It is greatest at the surface and its influence generally extends up to an elevation of 1 - 3 km. Over the sea surface the friction is minimal.

The horizontal winds near the earth surface respond to the combined effect of three forces – the pressure gradient force, the frictional force and the Coriolis force. In addition, the gravitational force acts downward.
Pressure gradient force. The pressure gradient force is perpendicular to an isobar. The higher the pressure gradient force, the more is the velocity of the wind and the larger is the deflection in the direction of wind. As a result of these two forces operating perpendicular to each other, in the low-pressure areas the wind blows around it. At the equator, the Coriolis force is zero and the wind blows perpendicular to the isobars. The low pressure gets filled instead of getting intensified. That is the reason why tropical cyclones are not formed near the equator.

Pressure and Wind

The velocity and direction of the wind forces. The winds in surface, are free controlled mainly by When isobars are balanced by the parallel to the isobar.

Figure 10.4 : Geostrophic Wind

The wind circulation around a low is called cyclonic circulation. Around a high it is called anti cyclonic circulation.

The direction of winds around such systems changes according to their location in different hemispheres (Table 10.2). The wind circulation at the earth’s surface closely related to the wind circulation at higher level. Generally, over low pressure area the air will converge and rise. Over high pressure area the air will subside from above and diverge at the surface (part from convergence, some eddies, convection currents, orographic uplift and uplift along fronts cause the rising of air, which is essential for the formation of clouds and precipitation.
The pattern of planetary winds largely depends on:

(i) latitudinal variation of atmospheric heating;
(ii) emergence of pressure belts;
(iii) the migration of belts following apparent path of the sun;
(iv) the distribution of continents and oceans;
(v) the rotation of earth.

The pattern of the movement of the planetary winds is called the general circulation of the atmosphere. The general circulation of the atmosphere also sets in motion the ocean water circulation which influences the earth's climate. A schematic description of the general circulation is shown in Figure 10.6. 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 with the convective cell. 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° 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 30° N and S latitudes.

Down below near the land surface the air flows towards the equator as the easterlies. The easterlies from either side of the equator converge in the Inter Tropical Convergence Zone (ITCZ). Such circulations from the surface upwards and vice-versa are called cells. Such a cell in the tropics is called Hadley Cell.

In the middle latitudes the circulation is that of sinking cold air that comes from the poles and the rising warm air that blows from the subtropical high. At the surface these winds are called westerlies and the cell is known as the Ferrel cell. At polar latitudes the cold dense air subsides near the poles and blows towards middle latitudes as the polar easterlies. This cell is called the polar cell.

General Atmospheric Circulation and its Effects on Oceans

Warming and cooling of the Pacific Ocean is most important in terms of general atmospheric circulation. The warm water of the central Pacific Ocean slowly drifts towards South American coast and replaces the cool Peruvian current. Such appearance of warm water off the coast of Peru is known as the El Nino. The El Nino event is closely associated with the pressure changes in the Central Pacific and Australia. This change in pressure condition over Pacific is known as the southern oscillation. The combined phenomenon of southern oscillation and El Nino is known as ENSO. In the years when the ENSO is strong, large-scale variations in weather occur over the world. The arid west coast of South America receives heavy rainfall, drought occurs in Australia and sometimes in India and floods in China. This phenomenon is closely monitored and is used for long range forecasting in major parts of the world.
**Seasonal Wind**

The pattern of wind circulation is modified indifferent seasons due to the shifting of regions of maximum heating, pressure and wind belts. The most pronounced effect of such a shift is noticed in the monsoons, especially over southeast Asia.

### SEASONAL WIND

![Seasonal Wind Diagram](image)

### LOCAL WIND

The other local deviations from the general circulation system are as follows.

**Local Winds**

Differences in the heating and cooling of earth surfaces and the cycles those develop daily or annually can create several common, local or regional winds.

**Land and Sea Breezes**

As explained earlier, the land and sea absorb and transfer heat differently. During the day the land heats up faster and becomes warmer than the sea. Therefore, over the land the air rises giving rise to a low pressure area, whereas the sea is relatively cool and the pressure over sea is relatively high. Thus, pressure gradient from sea to land is created and the wind blows from the sea to the land as the sea breeze. In the night the reversal of condition takes place. The land loses heat faster and is cooler than the sea. The pressure gradient is from the land to the sea and hence land breeze results (Figure 10.7).
Mountain and Valley Winds

In mountainous regions, during the day the slopes get heated up and air moves upslope and to fill the resulting gap the air from the valley blows up the valley. This wind is known as the valley breeze. 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 katabatic wind. Another type of warm wind occurs on the leeward side of the mountain ranges. The moisture in these winds, while crossing the mountain ranges condense and precipitate. When it descends down the leeward side of the slope the dry air gets warmed up by adiabatic process. This dry air may melt the snow in a short time.

Air mass

When the air remains over a homogenous area for a sufficiently longer time, it acquires the characteristics of the area. The homogenous regions can be the vast ocean surface or vast plains. The air with distinctive characteristics in terms of temperature and humidity is called an air mass. It is defined as a large body of air having little horizontal variation in temperature and moisture. The homogenous surfaces, over which air masses form, are called the source regions.

The air masses are classified according to the source regions. There are five major source regions. These are:

(i) Warm tropical and subtropical oceans;  The subtropical hot deserts;
(ii) The relatively cold high latitude oceans;
(iv) The very cold snow covered continents in high latitudes;
(v) Permanently ice covered continents in the Arctic and Antarctica. Accordingly, following types of air masses are recognised:
(i) Maritime tropical (mT);  (ii) Continental tropical (cT);
Maritime polar (mP);  (iv) Continental polar (cP);
Continental arctic (cA).

Tropical air masses are warm and polar air masses are cold.
Fronts
When two different air masses meet, the boundary zone between them is called a front. The process of formation of the fronts is known as frontogenesis. There are four types of fronts:
(a) Cold; (b) Warm; (c) Stationary; (d) Occluded.
When the front remains stationary, it is called a stationary front.
When the cold air moves towards the warm air mass, its contact zone is called the cold front, whereas if the warm air mass moves towards the cold air mass, the contact zone is a warm front. If an air mass is fully lifted above the land surface, it is called the occluded front.

The fronts occur in middle latitudes and are characterized by steep gradient in temperature and pressure. They bring abrupt changes in temperature and cause the air to rise to form clouds and cause precipitation.

Extra Tropical Cyclones
The systems developing in the mid and high latitude, beyond the tropics are called the **middle latitude or extra tropical cyclones**.

The passage of front causes abrupt changes in the weather conditions over the area in the middle and high latitudes. Extra tropical cyclones form along the polar front. Initially, the front is stationary. In the northern hemisphere, warm air blows from the south and cold air from the north of the front.

When the pressure drops along the front, the warm air moves northwards and the cold air moves towards, south setting in motion an anticlockwise cyclonic circulation. The cyclonic circulation leads to a well developed extra tropical cyclone, with a warm front and a cold front.

### Tropical Cyclones

Tropical cyclones are violent storms that originate over oceans in tropical areas and large scale destruction caused by violent winds, very heavy rainfall and storm surges. This is one of the most devastating natural calamities. They are known as **Cyclones** in the Indian Ocean, **Hurricanes** in the Atlantic, **Typhoons** in the Western Pacific and South China Sea, and **Willy-willies** in the Western Australia.

Tropical cyclones originate and intensify over warm tropical oceans.

The **conditions favourable for the formation and intensification of tropical storms are**:

1. Large sea surface with temperature higher than 27°C;
2. Presence of the Coriolis force;
3. Small variations in the vertical wind speed;
4. A pre-existing weak low-pressure area or low-level-cyclonic circulation;
5. Upper divergence above the sea level system.

The energy that intensifies the storm, comes from the condensation process in the towering cumulonimbus clouds, surrounding the centre of the storm. With continuous supply of moisture from the sea, the storm is further strengthened. On reaching the land the moisture supply is cut off and the storm dissipates. The place where a tropical cyclone crosses the coast is called the landfall of the cyclone. The cyclones, which cross 20 N latitude generally, reserve and they are more...
destructive. A schematic representation of the vertical structure of a mature tropical cyclonic storm is shown in Figure given below.

**Physical Structure of Tropical Cyclone**

To best understand the structure of tropical cyclones, you may find useful to briefly review the concept of thermal wind and vorticity.

A mature tropical cyclone is characterized by the strong spirally circulating wind around the centre, called the eye. The diameter of the circulating system can vary between 150 and 250 km. The eye is a region of calm with subsiding air. Around the eye is the eye wall, where there is a strong spiraling ascent of air to greater height reaching the tropopause. The wind reaches maximum velocity in this region, reaching as high as 250 km per hour. Torrential rain occurs here. From the eye wall rain bands may radiate and trains of cumulus and cumulonimbus clouds may drift into the outer region. The diameter of the storm over the Bay of Bengal, Arabian sea and Indian ocean is between 600 - 1200 km. The system moves slowly about 300 - 500 km per day. The cyclone creates storm surges and they inundate the coastal low lands. The storm peters out on the land.
Other severe local storms are **thunderstorms and tornadoes**. They are of short duration, occurring over a small area but are violent. **Thunderstorms** are caused by intense convection on moist hot days. From severe thunderstorms sometimes spiralling wind descends like a trunk of an elephant with great force, with very low pressure at the centre, causing massive destruction on its way. Such a phenomenon is called a **tornado**. Tornadoes generally occur in middle latitudes. The tornado over the sea is called **water sprouts**.

These violent storms are the manifestation of the atmosphere’s adjustments to varying energy distribution. The potential and heat energies are converted into kinetic energy in these storms and the restless atmosphere again returns to its stable state.
This chapter deals with Humidity, types of humidity, relative humidity, absolute humidity, specific humidity, dew point, condensation, saturated air, types of precipitation—dew, frost, fog, mist, clouds cirrus, cumulus, stratus, nimbus, precipitation, types—(rainfall, sleet, snowfall, hailstones), rainfall types convectional type, orographic rainfall, cyclonic rainfall, world distribution of rainfall.

Air contains water vapour. It varies from zero to four per cent by volume of the atmosphere and plays an important role in the weather phenomena. Water is present in the atmosphere in three forms namely—gaseous, liquid and solid. The moisture in the atmosphere is derived from water bodies through evaporation and from plants through transpiration. Thus, there is a continuous exchange of water between the atmosphere, the oceans and the continents through the processes of evaporation, transpiration, condensation and precipitation.

Water vapour present in the air is known as humidity. It is expressed quantitatively in different ways. The actual amount of the water vapour present in the atmosphere is known as the absolute humidity. It is the weight of water vapour per unit volume of air and is expressed in terms of grams per cubic metre. The ability of the air to hold water vapour depends entirely on its temperature. The absolute humidity differs from place to place on the surface of the earth.

The percentage of moisture present in the atmosphere as compared to its full capacity at a given temperature is known as the relative humidity. The air containing moisture to its full capacity at a given temperature is said to be saturated. The temperature at which saturation occurs in a given sample of air is known as dew point.

WATER IN THE ATMOSPHERE EVAPORATION AND CONDENSATION

The amount of water vapour in the atmosphere is added or withdrawn due to evaporation and condensation respectively.

Evaporation is a process by which water is transformed from liquid to gaseous state. Heat is the main cause for evaporation. The temperature at which the water starts evaporating is referred to as the latent heat of vaporization.

Hence, the greater the movement of air, the greater is the evaporation. The transformation of water vapour into water is called condensation. Condensation is caused by the loss of heat. When moist air is cooled, it may reach a level when its capacity to hold water vapour ceases. Then, the excess water vapour condenses into liquid form. If it directly condenses into solid form, it is known as sublimation. In free air, condensation results from cooling around very small particles termed as hygroscopic condensation nuclei. Particles of dust, smoke and salt from the ocean are particularly good nuclei because they absorb water.

Condensation also takes place when the moist air comes in contact with some colder object and it may also take place when the temperature is close to the dew point. Condensation, therefore, depends upon the amount of cooling and the relative humidity of the air. Condensation is influenced by the volume of air, temperature, pressure and humidity. Condensation takes place:

- When the temperature of the air is reduced to dew point with its volume remaining constant;
- When both the volume and the temperature are reduced;
- When moisture is added to the air through evaporation. However, the most favourable condition for condensation is the decrease in air temperature.

After condensation the water vapour or the moisture in the atmosphere takes one of the following forms—dew, frost, fog and clouds.

Forms of condensation can be classified on the basis of temperature and location.
Condensation takes place when the dew point is lower than the freezing point as well as higher than the freezing point.

Dew

When the moisture is deposited in the form of water droplets on cooler surfaces of solid objects (rather than nuclei in air above the surface) such as stones, grass blades and plant leaves, it is known as **dew**.

The ideal conditions for its formation are 1. clear sky, 2. calm air, 3. high relative humidity, 4. cold and long nights.

For the formation of dew, it is necessary that the dew point is above the freezing point. **Frost** forms on cold surfaces when condensation takes place below freezing point (0°C), i.e. the dew point is at or below the freezing point. The excess moisture is deposited in the form of minute ice.
crystals instead of water droplets. The ideal conditions for the formation of white frost are the same as those for the formation of dew, except that the air temperature must be at or below the freezing point.

**Fog and Mist**

When the temperature of an air mass containing a large quantity of water vapour falls all of a sudden, condensation takes place within itself on fine dust particles. So, the fog is a cloud with its base at or very near to the ground. Because of the fog and mist, the visibility becomes poor to zero. In urban and industrial centres smoke provides plenty of nuclei which help the formation of fog and mist. Such a condition when fog is mixed with smoke, is described as smog. The only difference between the mist and fog is that mist contains more moisture than the fog. In mist each nuclei contains a thicker layer of moisture. Mists are frequent over mountains as the rising warm air up the slopes meets a cold surface. Fogs are drier than mist and they are prevalent where warm currents of air come in contact with cold currents. Fogs are mini clouds in which condensation takes place around nuclei provided by the dust, smoke, and the salt particles.

**Clouds**  
Clouds are minute water droplets or tiny crystals of ice formed by the condensation of the water vapour in free air at considerable elevations. As the clouds are formed at some height over the surface of the earth, they take various shapes. According to their height, expanse, density and transparency or opaqueness clouds are grouped under four types:

(i) cirrus; (ii) cumulus; (iii) stratus; (iv) nimbus.  
**Cirrus**  
Cirrus clouds are formed at high altitudes (8,000 - 12,000 m). They are thin and detached clouds having a feathery appearance. They are always white in colour.

**Cumulus**  
Cumulus clouds look like cotton wool. They are generally formed at a height of 4,000 - 7,000 m. They exist in patches and can be seen scattered here and there. They have a flat base.

**Stratus**  
As their name implies, these are layered clouds covering large portions of the sky. These clouds are generally formed either due to loss of heat or the mixing of air masses with different temperatures.

**Nimbus**  
Nimbus clouds are black or dark gray. They form at middle levels or very near to the surface of the earth. These are extremely dense and opaque to the rays of the sun. Sometimes, the clouds are so low that they seem to touch the ground. Nimbus clouds are shapeless masses of thick vapour.  
A combination of these four basic types can give rise to the following types of clouds: **high clouds** - cirrus, cirrostratus, cirrocumulus;  
**middle clouds** - altostratus and altocumulus;
**low clouds** - stratocumulus and nimbostratus
and **clouds with extensive vertical development** - cumulus and cumulonimbus.

**Precipitation**
The process of continuous condensation in free air helps the condensed particles to grow in size. When the resistance of the air fails to hold them against the force of gravity, they fall on to the earth's surface. So after the condensation of water vapour, the release of moisture is known as **precipitation**. This may take place in liquid or solid form.
The precipitation in the form of water is called **rainfall**, when the temperature is lower than the 0 °C, precipitation takes place in the form of fine flakes of snow and is called **snowfall**. Moisture is released in the form of hexagonal crystals. These crystals form flakes of snow. Besides rain and snow, other forms of precipitation are **sleet** and **hail**, though the latter are limited in occurrence and are sporadic in both time and space.

**Sleet** is frozen raindrops and refrozen melted snow-water. When a layer of air with the temperature above freezing point overlies a subfreezing layer near the ground, precipitation takes place in the form of sleet. Raindrops, which leave the warmer air, encounter the colder air below. As a result, they solidify and reach the ground as small pellets of ice not bigger than the raindrops from which they are formed.

Sometimes, drops of rain after being released by the clouds become solidified in to small rounded solid pieces of ice and which reach the surface of the earth are called **hailstones**.
These are formed by the rainwater passing through the colder layers. Hailstones have several concentric layers of ice one over the other.

**Types of Rainfall**
On the basis of origin, rainfall may be classified into three main types -
1. **the convectional**, 2. **orographic or relief and 3. the cyclonic or frontal**.

**Convectional Rain**
The, air on being heated, becomes light and rises up in convection currents. As it rises, it expands and loses heat and consequently, condensation takes place and cumulous clouds are formed. With thunder and lightening, heavy rainfall takes place but this does not last long. Such rain is common in the summer or in the hotter part of the day. It is very common in the equatorial regions and interior parts of the continents, particularly in the northern hemisphere.

**cyclonic Rainfall**

**Orographic rainfall**

**CONVECTIONAL RAIN FALL**

When the saturated air mass comes across a mountain, it is forced to ascend

and as it rises ,it expands; the temperature falls, and the moisture is condensed. The chief characteristic of this sort of rain is that the windward slopes receive greater rainfall. After giving rain on the windward side, when these winds reach the other slope, they
descend, and their temperature rises. Then their capacity to take in moisture increases and hence, these leeward slopes remain rainless and dry. The area situated on the leeward side, which gets less rainfall is known as the rain-shadow area. It is also known as the relief rain. Cyclonic Rain World Distribution of Rainfall

Different places on the earth’s surface receive different amounts of rainfall in a year and that too in different seasons.
1. In general, as we proceed from the equator towards the poles, rainfall goes on decreasing steadily.
2. The coastal areas of the world receive greater amounts of rainfall than the interior of the continents.
3. The rainfall is more over the oceans than on the landmasses of the world because of being great sources of water.
4. Between the latitudes 35 and 40 N and S of the equator,
5. the rain is heavier on the eastern coasts and goes on decreasing towards the west.
6. But, between 45 and 65 N and S of equator, due to the westerlies, the rainfall is first received on the western margins of the continents and it goes on decreasing towards the east.
7. Wherever mountains run parallel to the coast, the rain is greater on the coastal plain, on the windward side and it decreases towards the leeward side.

ON THE BASIS OF THE TOTAL AMOUNT OF ANNUAL PRECIPITATION, MAJOR PRECIPITATION REGIMES OF THE WORLD ARE IDENTIFIED AS FOLLOWS.
1. The equatorial belt, the windward slopes of the mountains along the western coasts in the cool temperate zone and the coastal areas of the monsoon land receive heavy rainfall of over 200 cm per annum.
2. Interior continental areas receive moderate rainfall varying from 100 - 200 cm per annum.
3. The coastal areas of the continents receive moderate amount of rainfall.
4. The central parts of the tropical land and the eastern and interior parts of the temperate lands receive rainfall varying between 50 - 100 cm per annum.
5. Areas lying in the rain shadow zone of the interior of the continents and high latitudes receive very low rainfall-less than 50 cm per annum.
6. Seasonal distribution of rainfall provides an important aspect to judge its effectiveness.
7. In some regions rainfall is distributed evenly throughout the year such as in the equatorial belt and in the western parts of cool temperate regions.
This chapter deals with

The world climate can be studied by organizing information and data on climate and synthesizing them in smaller units for easy understanding, description and analysis. Three broad approaches have been adopted for classifying climate. They are empirical, genetic and applied. Empirical classification is based on observed data, particularly on temperature and precipitation. Genetic classification attempts to organize climates according to their causes. Applied classification is for specific purpose.

**KOEPPEN'S SCHEME OF CLASSIFICATION OF CLIMATE**

![Koeppen classification map](image)

The most widely used classification of climate is the empirical climate classification scheme developed by V. Koeppen. Koeppen identified a close relationship between the distribution of vegetation and climate. He selected certain values of temperature and precipitation and related them to the distribution of vegetation and used these values for classifying the climates.

It is an empirical classification based on mean annual and mean monthly temperature and precipitation data. He introduced the use of capital and small letters to designate climatic groups and types. Although developed in 1918 and modified over a period of time, Koeppen’s scheme is still popular and in use.

Koeppen recognized five major climatic groups, four of them are based on temperature and one on precipitation. Table 12.1 lists the climatic groups and their characteristics according to Koeppen.

**The capital letters : A, C, D and E delineate humid climates and B dry climates.**

The climatic groups are subdivided into types, designated by small letters, based on seasonality of precipitation and temperature characteristics.
The seasons of dryness are indicated by the small letters: f, m, w, and s, where f corresponds to no dry season,
m - monsoon climate, w - winter dry season and s - summer dry season. The small letters a, b, c, and d refer to the degree of severity of temperature. The B-Dry Climates are subdivided using the capital letters S for steppe or semi-arid and W for deserts.

### Table 12.1: Climatic Groups According to Köppen

<table>
<thead>
<tr>
<th>Group</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>A - Tropical</td>
<td>Average temperature of the coldest month is 18°C or higher</td>
</tr>
<tr>
<td>B - Dry Climates</td>
<td>Potential evaporation exceeds precipitation</td>
</tr>
<tr>
<td>C - Warm Temperate</td>
<td>The average temperature of the coldest month of the (Mid-latitude) climates years is higher than minus 3°C but below 18°C</td>
</tr>
<tr>
<td>D - Cold Snow Forest Climates</td>
<td>The average temperature of the coldest month is minus 3°C or below</td>
</tr>
<tr>
<td>E - Cold Climates</td>
<td>Average temperature for all months is below 10°C</td>
</tr>
<tr>
<td>H - High Land</td>
<td>Cold due to elevation</td>
</tr>
</tbody>
</table>

### Table 12.2: Climatic Types According to Köppen

<table>
<thead>
<tr>
<th>Group</th>
<th>Type</th>
<th>Letter Code</th>
<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-Tropical</td>
<td>Tropical monsoon</td>
<td>Af</td>
<td>Monsoonal. short dry season</td>
</tr>
<tr>
<td></td>
<td>Tropical wet</td>
<td>Am</td>
<td>Winter dry season</td>
</tr>
<tr>
<td></td>
<td>Tropical wet and dry</td>
<td>Aw</td>
<td>Low-latitude semi arid or dry</td>
</tr>
<tr>
<td></td>
<td>Subtropical steppe</td>
<td>BSh</td>
<td>Low-latitude arid or dry</td>
</tr>
<tr>
<td>B-Dry Climate</td>
<td>Subtropical desert</td>
<td>BWh</td>
<td>Mid-latitude semi arid or dry</td>
</tr>
<tr>
<td></td>
<td>Mid-latitude desert</td>
<td>BSk</td>
<td>Mid-latitude arid or dry</td>
</tr>
<tr>
<td></td>
<td>Humid subtropical</td>
<td>BWk</td>
<td>No dry season</td>
</tr>
<tr>
<td></td>
<td>Mediterranean west coast</td>
<td>Cfa</td>
<td>Dry hot summer</td>
</tr>
<tr>
<td></td>
<td>Marine</td>
<td>Cs</td>
<td>No dry season, season warm and cool summer</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CCl</td>
<td>season warm and cool summer</td>
</tr>
<tr>
<td>D-Cold</td>
<td>Subarctic</td>
<td>Df</td>
<td>No dry season</td>
</tr>
<tr>
<td></td>
<td>Tundra</td>
<td>Dw</td>
<td>Winter dry and very severe</td>
</tr>
<tr>
<td>E-Cold</td>
<td>Polar ice cap</td>
<td>ET</td>
<td>No true summer</td>
</tr>
<tr>
<td></td>
<td>Highland</td>
<td>EF</td>
<td>Perennial ice</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H</td>
<td>Highland with snow cover</td>
</tr>
</tbody>
</table>

**Group A: Tropical Humid Climates**
1. Tropical humid climates exist between Tropic of Cancer and Tropic of Capricorn. 2. The sunbeing overhead throughout the year and the presence of Inter Tropical Convergence Zone (ITCZ) make the climate hot and humid.
3. Annual range of temperature is very low and annual rainfall is high. 4. The tropical group is divided into three types, namely
   - Af - Tropical wet climate;
   - Am - Tropical monsoon climate; (ii) Aw - Tropical wet and dry climate.
Tropical Wet Climate (Af)
1. Tropical wet climate is found near the equator.
2. The major areas are the Amazon Basin in South America, western equatorial Africa and the islands of East Indies.
3. Significant amount of rainfall occurs in every month of the year as thunder showers in the afternoon.
4. The temperature is uniformly high and the annual range of temperature is negligible.
5. The maximum temperature on any day is around 30° C while the minimum temperature is around 20° C.
6. Tropical evergreen forests with dense canopy cover and large biodiversity are found in this climate.

Tropical Monsoon Climate (Am)
Tropical monsoon climate (Am) is found sub-continent, North Eastern part of and Northern Australia. Heavy rainfall in summer. Winter is dry.

Tropical Wet and Dry Climate (Aw)
Tropical wet and dry climate occurs north and south of Af type climate regions. It borders with dry climate on the western part of the continent and Cf or Cw on the eastern part.
Extensive Aw climate is found to the north and south of the Amazon forest in Brazil and adjoining parts of Bolivia and Paraguay in South America, Sudan and south of Central Africa. The annual rainfall in this climate is considerably less than that in Af and Am climate types and is variable also.
The wet season is shorter and the dry season is longer with the drought being more severe.
Temperature is high throughout the year and diurnal ranges of temperature are the greatest in the dry season. Deciduous forest and tree-shredded grasslands occur in this climate.

Dry Climates : B
Dry climates are characterized by very low rainfall that is not adequate for the growth of plants.
These climates cover a very large area of the planet extending over large latitudes from 15° - 60° north and south of the equator.
At low latitudes, from 15° - 30°, they occur in the area of subtropical high where subsidence and inversion of temperature do not produce rainfall.
On the western margin of the continents, adjoining the cold current, particularly over the west coast of South America, they extend more equator wards and occur on the coast land.
In middle latitudes, from 35° - 60° north and south of equator, they are confined to the interior of continents where maritime-humid winds do not reach and to areas often surrounded by mountains.
Dry climates are divided into steppe or semi-arid climate (BS) and desert climate (BW).
They are further subdivided as subtropical steppe (BSh) and subtropical desert (BWh) at latitudes from 15° - 35° and mid-latitude steppe (BSk) and mid-latitude desert (BWk) at latitudes between 35° - 60°.

Subtropical Steppe (BSh) and Subtropical Desert (BWh) Climates
Subtropical steppe (BSh) and subtropical desert (BWh) have common temperature characteristics.
Located in the transition zone between humid and dry climates, subtropical steppe receives slightly more rainfall than the desert, adequate enough for the growth of sparse grasslands. The rainfall in both the climates is highly variable. The variability in the rainfall affects the life in the steppe much more than in the desert, more often causing famine. Rain occurs in short intense thundershower in deserts and is ineffective in building soil moisture. Fog is common in coastal deserts bordering cold currents. Maximum temperature in the summer is very high. The highest shade temperature of 58°C was recorded at Al Aziziyah, Libya on 13 September 1922. The annual and diurnal ranges of temperature are also high.

Warm Temperate (Mid-Latitude) Climates—C

Warm temperate (mid-latitude) climates extend from 30° - 50° of latitude mainly on the eastern and western margins of continents. These climates generally have warm summers with mild winters. They are grouped into four types:

(i) Humid subtropical, i.e. dry in winter and hot in summer (Cwa);
(ii) Mediterranean (Cs);
(iii) Humid subtropical, i.e. no dry season and mild winter (Cfa);
(iv) Marine west coast climate (Cfb).

The climate is similar to Aw climate except that the temperature in winter is warm.

**Mediterranean Climate (Cs)**

As the name suggests, Mediterranean climate occurs around Mediterranean sea, along the west coast of continents in subtropical latitudes e.g. California, Central Chile, along the coast in southeastern and southwestern United States. These areas come under the influence of sub tropical high in summer and westerly wind in winter. Hence, the climate is characterised by hot, dry summer and mild, rainy winter. Monthly average temperature in summer is around 25°C and in winter below 10°C. The annual precipitation is 35 - 90 cm.

**Humid Subtropical Climate (Cwa)**

Humid subtropical climate occurs pole ward of Tropic of Cancer and Capricorn, mainly in North Indian plains and South China interior plains.

**Humid Subtropical (Cfa) Climate**

Humid subtropical climate lies on the eastern parts of the continent in subtropical latitudes. In this region the air masses are generally unstable and cause rainfall throughout the year.

They occur in eastern United States of America, southern and eastern China, southern Japan, northeastern Argentina, coastal southern Africa and eastern coast of Australia. The annual averages of precipitation vary from 75-150 cm. Thunderstorms in summer and frontal precipitation in winter are common. Mean monthly temperature in summer is around 27°C, and in winter it varies
from 5°-12° C. The daily range of temperature is small.

**Marine West Coast Climate (Cfb)**
Marine west coast climate is located poleward from the Mediterranean climate on the west coast of the continents.
The main areas are: Northwestern Europe, west coast of North America, Southern Chile, southeastern Australia and New Zealand.
Due to marine influence, the temperature is moderate and in winter, it is warmer its latitude. The mean temperature in summer months ranges from 15°-20° C and in winter 4°-10° C. The annual and daily ranges of temperature are small. Precipitation occurs throughout the year. Precipitation varies greatly from 50-250cm.

**Snow Forest Climates (D)**
Large continental areas occur in the hemisphere between 40°-70° north latitude, divided into two types:

(i) Cold climate with humid winters (Df)
Cold climate with humid winter occurs poleward of marine west coast climate and mid latitude steppe.
The winters are cold and snowy. The frost free season is short.
The annual ranges of temperature are large.
The weather changes are abrupt and short. Poleward, the winters are more severe. 

(ii) Cold climate with dry winters (Dw)
Cold climate with dry winter occurs mainly over North eastern Asia. The development of pronounced winter anticyclone and its weakening in summer sets in monsoon like reversal of wind in this region.
Poleward summer temperatures are lower and winter temperatures are extremely low with many point temperatures for up to seven months in a year. 
Precipitation is low from 12-15 cm. 
The annual range in summer. Locations experiencing below freezing 
Precipitation occurs in

**Tundra Climate (ET)**
The tundra climate (ET) is so called after the types of vegetation, like low growing mosses, lichens and flowering plants.
This is the region of permafrost where the sub soil is permanently frozen. Waterlogging support only low growing plants. 
Regions have very long duration of day light.
Ice Cap Climate (EF)

The ice cap climate (EF) occurs over interior Greenland and Antarctica. Even in summer, the temperature is below freezing point. This area receives very little precipitation. The snow and ice get accumulated and the mounting pressure causes the deformation of the ice sheets and they break. They move as icebergs that float in the Arctic and Antarctic waters. Plateau Station Antarctica, 79° S, portray this climate. HIGH LATITUDE CLIMATE ICE CAP CLIMATE

Highland climates are governed by topography. In high mountains, large changes in mean temperature occur over short distances. Precipitation types and intensity also vary spatially across high lands. There is vertical zonation of layering of climatic types with elevation in the mountain environment.

CLIMATE CHANGE
The type of climate we experience now might be prevailing over the last 10,000 years with minor and occasionally wide fluctuations. India also witnessed alternate wet and dry periods. Archaeological findings show that the Rajasthan desert experienced wet and cool climate around 8,000 B.C. The period 3,000-1,700 B.C. had higher rainfall. From about 2,000-1,700 B.C., this region was the centre of the Harappan civilization. Dry conditions since then. In the geological past, the earth was warm some 500-300 million years ago, through the Cambrian, Ordovician and Silurian periods. During the Pleistocene epoch, glacial and inter-glacial periods occurred, the last major peak glacial period ago. The present inter-glacial period started 10,000 years ago.

Climate in the recent past
Variability in climate occurs all the time. The 1990s recorded the warmest temperature of the century and some of the worst floods around the world. The worst devastating drought in the Sahel region, south of the Sahara desert, from 1967-1977 is one such variability.
During the 1930s, severe drought occurred in southwestern Great Plains of the United States, described as the **dust bowl**. Historical records of crop yield or crop failures, of floods and migration of people tell about the effects of changing climate.

A number of times Europe witnessed warm, wet, cold and dry periods, the significant episodes were the warm and dry conditions in the tenth and eleventh centuries, when the Vikings settled in Greenland. Europe witnessed —Little Ice Age‖ from 1550 to about 1850. From about 1885-1940 world temperature showed an upward trend. After 1940, the rate of increase in temperature slowed down.

**Causes of Climate Change**
The causes for climate change are many. They can be grouped into **Astronomical** 2. **Terrestrial causes**. The astronomical causes are:

A. the changes in solar output associated with sunspot activities. Sunspots are dark and cooler patches on the sun which increase and decrease in a cyclical manner.
B. According to some meteorologists, when the number of sunspots increase, cooler and wetter weather and greater storminess occur.
C. decrease in sunspot numbers is associated with warm and drier conditions. Yet, these findings are not statistically significant.
D. Another astronomical theory is Millankovitch oscillations, which infer cycles in the variations in the earth’s orbital characteristics around the sun, the wobbling of the earth and the changes in the earth’s axial tilt.
E. All these alter the amount of insolation received from the sun, which in turn, might have a bearing on the climate.

F. Volcanism is considered as another cause for climate change. Volcanic eruption throws up lots of aerosols into the atmosphere. These aerosols remain in the atmosphere for a considerable period of time reducing the sun’s radiation reaching the Earth’s surface. After the recent Pinatoba and El Cion volcanic eruptions, the average temperature of the earth fell to some extent for some years.

The most important anthropogenic effect on the climate is the increasing trend in concentration of greenhouse gases in the atmosphere which is likely to cause global warming.

**Global Warming**
Due to the presence of greenhouse gases, the atmosphere is behaving like a greenhouse. The atmosphere also transmits the incoming solar radiation but absorbs the vast majority of long wave radiation emitted upwards by the earth’s surface. The gases that absorb long wave radiation are called greenhouse gases. The processes that warm the atmosphere are often collectively referred to as the **greenhouse effect**.

The term **greenhouse** is derived from the analogy to a greenhouse used in cold areas for preserving heat. A **greenhouse** is made up of glass. The glass which is transparent to incoming short wave solar radiation is opaque to outgoing long wave radiation. The glass, therefore, allows in more radiation and prevents the long wave radiation going outside the glass house, causing the temperature inside the glasshouse structure warmer than outside. (GHGs)

The primary GHGs are carbon dioxide (CO2),
and ozone \((O_3)\). Some other gases such as nitric oxide \((NO)\) and carbon monoxide \((CO)\) easily react with GHGs and affect their concentration in the atmosphere.

The effectiveness of any given GHG will depend on the magnitude of the increase in its concentration, its life time in the atmosphere and the wavelength of radiation that it absorbs. The chlorofluorocarbons \((CFCs)\) are highly effective. Ozone which absorbs ultra violet radiation in the stratosphere is very effective in absorbing terrestrial radiation when it is present in the lower troposphere. Another important point to be noted is that the more time the GHG molecule remains in the atmosphere, the longer it will take for earth’s atmospheric system to recover from any change brought about by the latter.

The largest concentration of GHGs in the atmosphere is carbon dioxide. 1. The emission of CO\(_2\) comes mainly from fossil fuel combustion (oil, gas and coal). 2. Forests and oceans are the sinks for the carbon dioxide. 3. Forests use CO\(_2\) in their growth. 4. So, deforestation 5. due to changes in land use, also increases the concentration of CO\(_2\). The time taken for atmospheric CO\(_2\) to adjust to changes in sources to sinks is 20-50 years. It is rising at about 0.5 per cent annually.

Doubling of concentration of over pre-industrial level is used as an index for estimating the changes in climate in climatic models. Chlorofluorocarbons \((CFCs)\) are products of human activity. Ozone occurs in the stratosphere where ultra-violet rays convert oxygen into ozone. Thus, ultra violet rays do not reach the earth's surface. The CFCs which drift into the stratosphere destroy the ozone. Large depletion of ozone occurs over Antarctica. The depletion of ozone in the stratosphere is called the ozone hole. This allows the ultra violet rays to pass through the troposphere. International efforts have been initiated for reducing the emission of GHGs into the atmosphere. The most important one is the Kyoto protocol proclaimed in 1997. Kyoto protocol entered into force in 2005. It is ratified by 181 nations to reduce their emissions by the year 2012 to 5 per cent less than the levels prevalent in the year 1990.

The increasing trend in the concentration of GHGs in the atmosphere may, in the long run, warm up the earth. Once the global warming sets in, it will be difficult to reverse it. The effect of global warming may not be uniform everywhere. Nevertheless, the adverse effect due to global warming will adversely affect the life supporting system.

Rise in the sea level due to melting of glaciers and ice-caps and thermal expansion of the sea may inundate large parts of the coastal area and islands, leading to social problems.

This is another cause for serious concern for the world community. Efforts have already been initiated to control the emission of GHGs and to arrest the trend towards global warming. One of the major concerns of the world today is global warming.
The annual average near-surface air temperature of the world is approximately 14°C. The greatest warming of the 20th century was during the two periods, 1901-44 and 1977-99. Over each of these two periods, global temperatures rose by about 0.4°C. In between, there was a slight cooling, which was more marked in the Northern Hemisphere. The globally averaged annual mean temperature at the end of the 20th century was about 0.6°C above that recorded at the end of the 19th century. The seven warmest years during the 1856-2000 were recorded in the last decade. The year 1998 was the warmest year, probably not only for the 20th century but also for the whole millennium.

Kyoto declaration

(a) Implement and/or further elaboration policies and measures in accordance with its national circumstances, such as:

(ii) Enhancement of energy efficiency in relevant sectors of the national economy;

(iii) Protection and enhancement of sinks and reservoirs of greenhouse gases not controlled by the Montreal Protocol, taking into account its commitments under relevant international environmental agreements: promotion of sustainable forest management practices, afforestation and reforestation;

(iv) Promotion of sustainable forms of agriculture in light of climate change considerations;

(v) Research, development and increased use of new and renewable forms of energy, of carbon dioxide sequestration technologies and of advanced and innovative environmentally sound technologies;

(vi) Progressive reduction or phasing out of market imperfections, fiscal incentives, tax and duty exemptions and subsidies in all greenhouse gas emitting sectors that run counter to the objective of the Convention and application of market instruments;

(vii) Encouragement of appropriate reforms in relevant sectors aimed at promoting policies and measures which limit or reduce emissions of greenhouse gases not controlled by the Montreal Protocol;

(viii) Measures to limit and/or reduce emissions of greenhouse gases not controlled by the Montreal Protocol in the transport sector.

(x) Limitation and/or reduction of methane emissions through recovery and use in waste management, as well as in the production, transport and distribution of energy: