Chapter 10

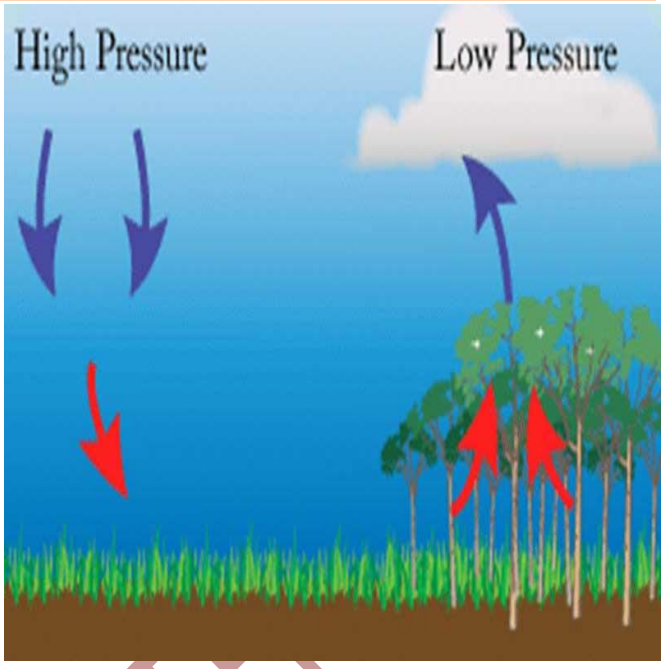
Atmospheric Circulation and Weather Systems

- **Atmospheric pressure:** 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. The atmospheric pressure is expressed in units of millibar.
- **Wind:** The air in motion is called wind.
- **Pressure gradient force:** The differences in atmospheric pressure produces a force. The rate of change of pressure with respect to distance is the pressure gradient.
- **Frictional force:** It affects the speed of the wind. It is greatest at the surface and its influence generally extends upto an elevation of 1 – 3 km. Over the sea surface the friction is minimal.
- **Coriolis force:** The rotation of the earth about its axis affects the direction of the wind. This force is called the Coriolis force after the French physicist who described it in 1844.
- **Geostrophic wind:** When isobars are straight and when there is no friction, the pressure gradient force is balanced by the Coriolis force and the resultant wind blows parallel to the isobar. This wind is known as the geostrophic wind.
- **General circulation of the atmosphere;** The pattern of the movement of the planetary winds is called the general circulation of the atmosphere.
- **Cell:** The easterlies from either side of the equator converge in the Inter Tropical Convergence Zone (ITCZ). Such circulations from the surface upwards and viceversa are called cells.

- **Hadley cells:** A cell in the tropics is called Hadley cell.
- **Ferrel cells:** 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.
- **Polar 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.
- **Valley breeze:** 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.
- **Polar high:** Near the poles the pressure is high and it is known as the polar high.
- **El Nino:** 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
- **Southern oscillation:** The change in pressure condition over Pacific is known as the southern oscillation.
- **ENSO:** The combined phenomenon of southern oscillation and El Nino is known as ENSO.
- **Katabatic wind:** 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.
- **Air mass:** 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.

- **Source regions:** The homogeneous surfaces which are formed over air masses are called the source regions.
- **Fronts:** When two different air masses meet, the boundary zone between them is called a front.
- **Cold front:** When the cold air moves towards the warm air mass, its contact zone is called the cold front.
- **Warm front:** If the warm air mass moves towards the cold air mass, the contact zone is called warm front.
- **Occluded front:** If an air mass is fully lifted above the land surface, it is called the occluded front.
- **Extra tropical cyclone:** The systems developing in the mid and high latitude, beyond the tropics are called the middle latitude or extra tropical cyclones.
- **Landfall of the cyclone:** The place where a tropical cyclone crosses the coast is called the landfall of the cyclone
- **A mature tropical cyclone:** It 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.
- **Tropical cyclones:** Tropical cyclones are violent storms that originate over oceans in tropical areas and shift to the coastal areas bringing about large scale destruction caused by violent winds, very heavy rainfall and storm surges. This is one of the most devastating natural calamities.
- **Tornado:** 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.
- **Water spouts:** The tornado over the sea is called water spouts.

Atmospheric pressure



- 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.
- It is measured in force per unit area. • It is expressed in 'milibar' or mb unit.
- In application level, the atmospheric pressure is stated in kilopascals.
- It is measured by the aneroid barometer or mercury barometer.
- In lower atmosphere, pressure declines rapidly with height.
- The vertical pressure gradient force is much larger than that of the horizontal pressure gradient and is commonly balanced by an almost equal but opposite gravitational force.
- Low-pressure system is encircled by one or more isobars with the lowest pressure at centre.
- High pressure system is also encircled by one or more isobars with highest pressure in centre
- Isobars are lines connecting places having equal pressure

Pressure belts

- There is a pattern of alternate high and low-pressure belts over the earth.
- There are seven pressure belts. • Except the Equatorial low, there are two Sub-Tropical highs (in North and South), the two

Sub-polar lows (in North and South), and the two Polar highs (in North and South).

- The above-given pressure belts oscillate with the movement of the sun.
- In the northern hemisphere, they move southwards in winter, and in summers they move northwards.
- The Equatorial region gets abundant heat and warm air being light, the air at the Equator rises, generating a low pressure.

- **Equatorial low**
  - It is found near the equator.
  - The sea level pressure is low.
- **Subtropical high**
  - The region in 30 degrees North and 30 degrees South, which are high-pressure areas.
- Sub-polar Lows
  - The region in 60 degrees North and 60 degrees South, which are low-pressure belts.
- **Polar Highs**
  - These occur near poles which have high pressure.

Pressure Gradient Force

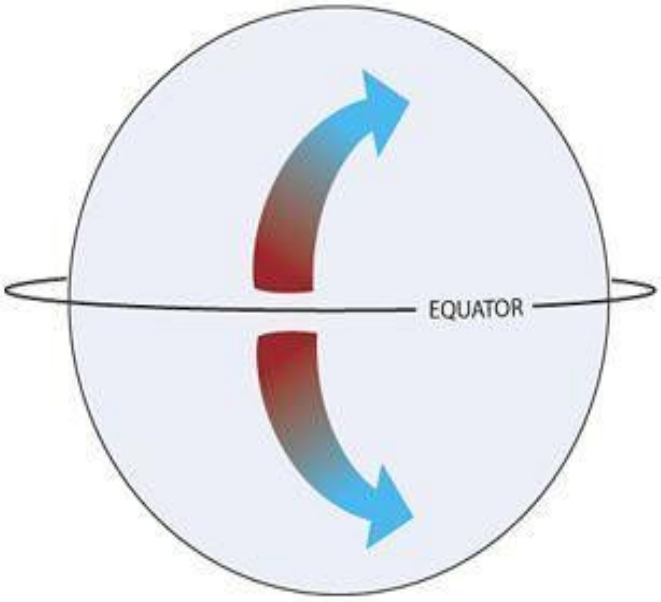
The differences in atmospheric pressure produces a force. The rate of change of pressure with respect to distance is the pressure gradient. The pressure gradient is strong where the isobars are close to each other and is weak where the isobars are apart.

Frictional Force

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

Coriolis Force and Wind Movement

- The rotation of the earth about its axis affects the direction of the wind. This force is called the Coriolis force. It has great impact on the direction of wind movement.



- Due to the earth's rotation, winds do not cross the isobars at right angles as the pressure gradient force directs, but get deflected from their original path.
- This deviation is the result of the earth's rotation and is called the Coriolis effect or Coriolis force.
- Due to this effect, winds in the northern hemisphere get deflected to the right of their path and those in the southern hemisphere to their left, following Farrell's Law (the law that wind is deflected to the right in the Northern Hemisphere and to the left in the Southern Hemisphere, derived from the application of the Coriolis effect to air masses).
- This deflection force does not seem to exist until the air is set in motion and increases with wind velocity, air mass and an increase in latitude.
- •the Coriolis force acts perpendicular to the pressure gradient force (pressure gradient force is perpendicular to an isobar)
- As a result of these two forces operating perpendicular to each other, in the low-pressure areas the wind blows around it (cyclonic conditions).

Pressure Systems

- Air expands when heated and gets compressed when cooled. This results in variations in the atmospheric pressure.
- The differences in atmospheric pressure causes the movement of air from high pressure to low pressure, setting the air in motion. Atmospheric pressure also determines when the air will rise or sink.
- Air in horizontal motion is wind. The wind redistributes the heat and moisture across latitudes, thereby, maintaining a constant temperature for the planet as a whole.
    - The vertical rising of moist air forms clouds and bring precipitation.

Air Pressure

- Since air has mass, it also has weight. The pressure of air at a given place is defined as a force exerted in all directions by virtue of the weight of all the air above it.
- 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. The atmospheric pressure is expressed in various units.

Measurement of Air Pressure

- Atmospheric pressure is the weight of the column of air at any given place and time. It is measured by means of an instrument called **barometer**.
- The units used by meteorologists for this purpose are called **millibars (mb)**.

- **One millibar is equal to the force of one gram on a square centimeter. A pressure of 1000 millibars is equal to the weight of 1.053 kilograms per square centimeter.**
- In other words, it will be equal to the weight of a column of mercury 75 cm high.
- The normal pressure at sea level is taken to be about **76 centimeters (1013.25 millibars).**

Vertical Variation of Pressure

- In the lower atmosphere the pressure decreases rapidly with height.
- At the height of Mt. Everest, the air pressure is about two-thirds less than what it is at the sea level.
- The decrease in pressure with altitude, however, is not constant. Since the factors controlling air density – temperature, amount of water vapour and gravity are variable, there is no simple relationship between altitude and pressure.
- In general, the atmospheric pressure decreases on an average at the rate of about 34 millibars every 300 metres of height.
- 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.
- Due to gravity the air at the surface is denser and hence has higher pressure. Since air pressure is proportional to density as well as temperature, it follows that a change in either temperature or density will cause a corresponding change in the pressure.

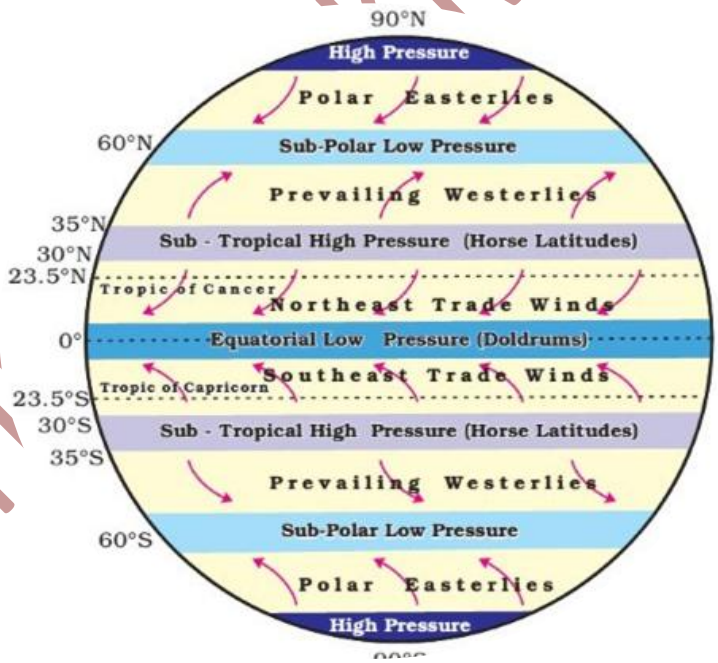
• The pressure decreases with height. At any elevation it varies from place to place and its variation is the primary cause of air

motion, i.e. wind which moves from high pressure areas to low pressure areas.

- A rising pressure indicates fine, settled weather, while a falling pressure indicates unstable and cloudy weather.

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.



- The spacing of isobars expresses the rate and direction of pressure changes and is referred to as pressure gradient
- Close spacing of isobars indicates a steep or strong pressure gradient, while wide spacing suggests weak gradient. The pressure gradient may thus be defined as the decrease in pressure per unit distance in the direction in which the pressure decreases most rapidly
- There are distinctly identifiable zones of homogeneous horizontal pressure regimes or 'pressure belts'. On the earth's surface, there are in all seven pressure belts.

- The seven pressure belts are :

1. equatorial low,

2. the sub-tropical highs,

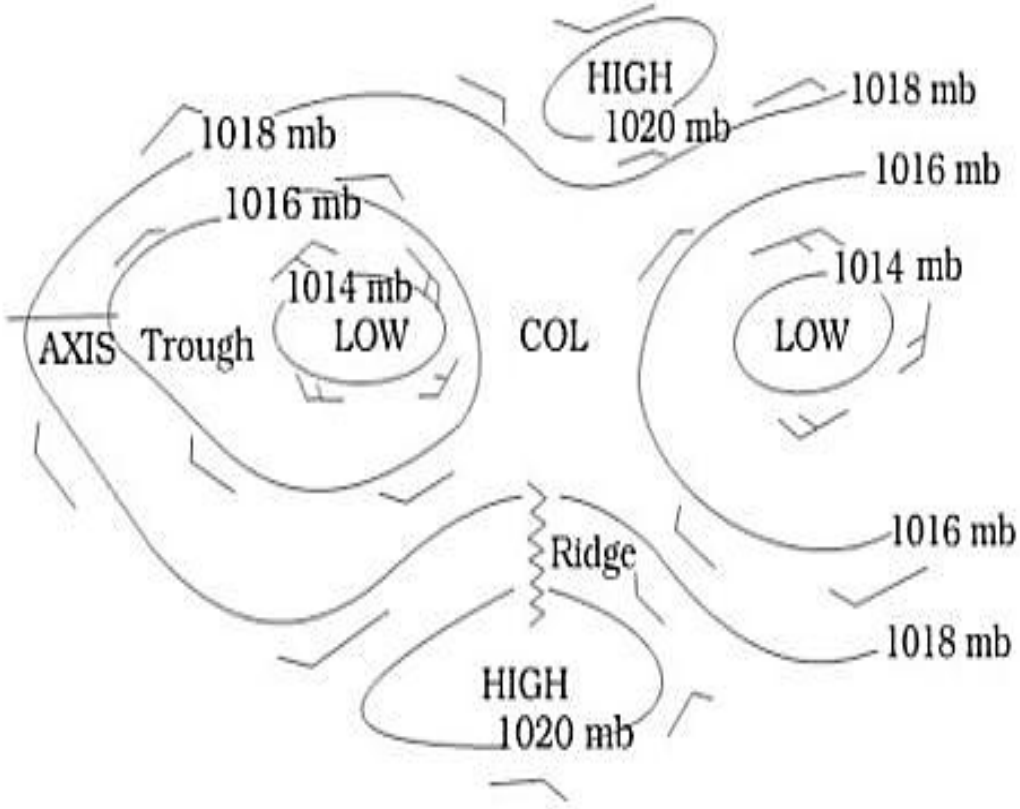
3. the sub-polar lows, and

4. the polar highs.

• Except the equatorial low, all others form matching pairs in the northern and southern hemispheres.

Closed Isobars or Closed Pressure centers

- Low pressure system is enclosed by one or more isobars with the lowest pressure in the centre. Highpressure system is also enclosed by one or more isobars with the highest pressure in the centre.



World Distribution of Sea Level Pressure

- The atmosphere exerts a pressure of **1034 gm per square cm** at sea level. This amount of pressure is exerted by the atmosphere at sea level on all animals, plants, rocks, etc.
- Near the equator the sea level pressure is low and the area is known as **equatorial low**. Along 30° N and 30° S are 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

Equatorial Low Pressure Belt or 'Doldrums'

- Lies between 10°N and 10°S latitudes.
- Width may vary between 5°N and 5°S and 20°N and 20°S.
- This belt happens to be the zone of convergence of trade winds from two hemispheres from sub-tropical high pressure belts.
- This belt is also called the Doldrums, because of the extremely calm air movements.
- The position of the belt varies with the apparent movement of the Sun.

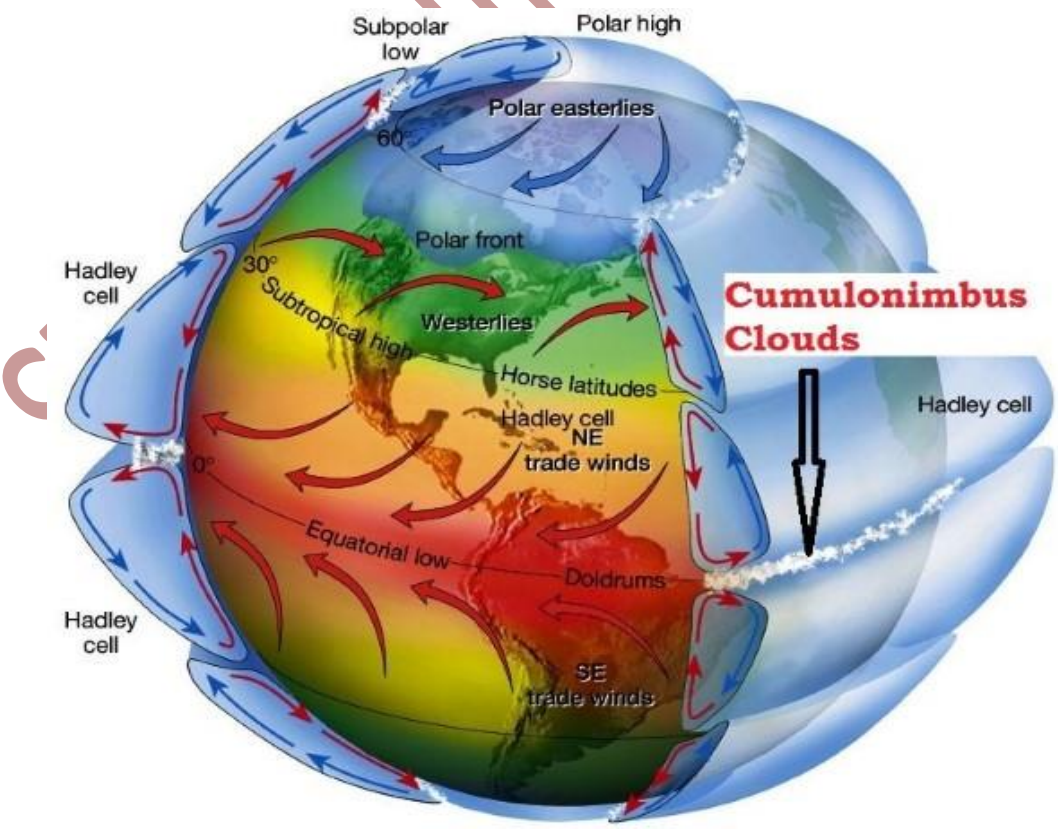
Formation

- As this region lies along the equator, it receives highest amount of insolation.
- Due to intense heating, air gets warmed up and rises over the equatorial region (convection).

- Whenever there is vertically upward movement of air, the region at the surface will be at low pressure. Thus the belt along the equator is called equatorial low pressure belt.

Climate

- This belt is characterized by extremely low pressure with calm conditions.
- This is because of the absence of Surface winds since winds approaching this belt begin to rise near its margin. Thus, only vertical currents are found.
- As the larger part of the low pressure belt passes along the oceans, the winds obtain huge amount of moisture.
- Vertical winds (convection) carrying moisture form cumulonimbus clouds and lead to thunderstorms (convectional rainfall)
- Inspite of high temperatures, cyclones are not formed at the equator because of 'zero' coriolis force. (we will see more later)



Sub-Tropical High Pressure Belt or Horse Latitudes

• The sub-tropical highs extend from near the tropics to about 35°N and S.

Formation

• After saturation (complete loss of moisture) at the ITCZ, the air moving away from equatorial low pressure belt in the upper troposphere becomes dry and cold.

• This dry and cold wind subsides at 30°N and S.

• So the high pressure along this belt is due to subsidence of air coming from the equatorial region which descends after becoming heavy.

• The high pressure is also due to the blocking effect of air at upper levels because of the Coriolis force.

Climate

• The subsiding air is warm and dry, therefore, most of the deserts are present along this belt, in both hemispheres.

• A calm condition (anticyclonic) with feeble winds is created in this high pressure belt.

• The descending air currents feed the winds blowing towards adjoining low pressure belts.

• This belt is frequently invaded by tropical and extra-tropical disturbances

Horse Latitudes

• The corresponding latitudes of sub-tropical high pressure belt are called horse latitudes.

• In early days, the sailing vessels with cargo of horses found it difficult to sail under calm conditions of this high pressure belt.

• They used to throw horses into the sea when fodder ran out. Hence the name horse latitudes.

Sub-Polar Low Pressure Belt

- Located between 45°N and S latitudes and the Arctic and the Antarctic circles (66.5° N and S latitudes).
- Owning to low temperatures in these latitudes the sub polar low pressure belts are not very well pronounced year long.
- On long-term mean climatic maps, the sub polar low-pressure belts of the northern hemisphere are grouped into two centers of atmospheric activity: the Iceland low and the Aleutian depression (Aleutian low).
- Such belts in the southern hemisphere surround the periphery of Antarctica and are not as well differentiated

Formation

- These are dynamically produced due to Coriolis Force produced by rotation of the earth on its axis, and. Ascent of air as a result of

convergence of westerlies and polar easterlies (we will more about these in next topic – wind systems).

- Sub polar low-pressure belts are mainly encountered above

Seasonal behavior

- During winter, because of a high contrast between land and sea, this belt is broken into two distinct low centers – one in the vicinity of the Aleutian Islands and the other between Iceland and Greenland.
- During summer, a lesser contrast results in a more developed and regular belt.

Climate

- The area of contrast between cold and warm air masses produces polar jet streams which encircles the earth at 60 degrees latitudes and is focused in these low pressure areas

Due to a great contrast between the temperatures of the winds from sub-tropical and polar source regions, extra tropical cyclonic storms or lows' (temperate cyclones or frontal cyclones) are produced in this region.

Polar High Pressure Belt

- The polar highs are small in area and extend around the poles.
- They lie around poles between 80 – 90° N and S latitudes.

Formation

- The air from sub-polar low pressure belts after saturation becomes dry. This dry air becomes cold while moving towards poles through upper troposphere.

- The cold air (heavy) on reaching poles subsides creating a high pressure belt at the surface of earth.

Climate

- The lowest temperatures are found over the poles.

Pressure belts in July

- In the northern hemisphere, during summer, with the apparent northward shift of the sun, the thermal equator (belt of highest temperature) is located north of the geographical equator.
- The pressure belts shift slightly north of their annual average locations.

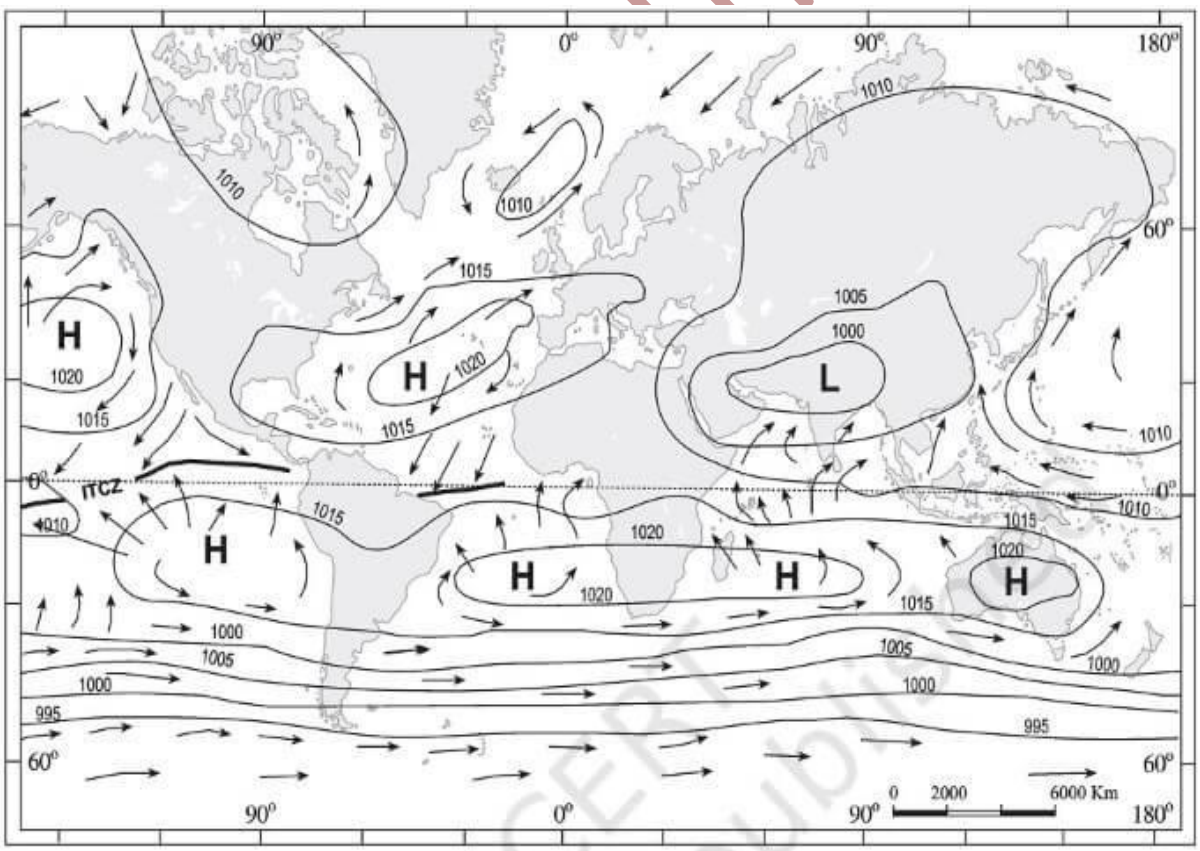


Figure 10.3 : Distribution of pressure (in millibars) — July

Pressure belts in January

- During winter, these conditions are completely reversed and the pressure belts shift south of their annual mean locations. Opposite conditions prevail in the southern hemisphere. The amount of shift is, however, less in the southern hemisphere due to predominance of water.
- Similarly, distribution of continents and oceans have a marked influence over the distribution of pressure. In winter, the continents are cooler than the oceans and tend to develop high pressure centres, whereas in summer, they are relatively warmer and develop low pressure. It is just the reverse with the oceans

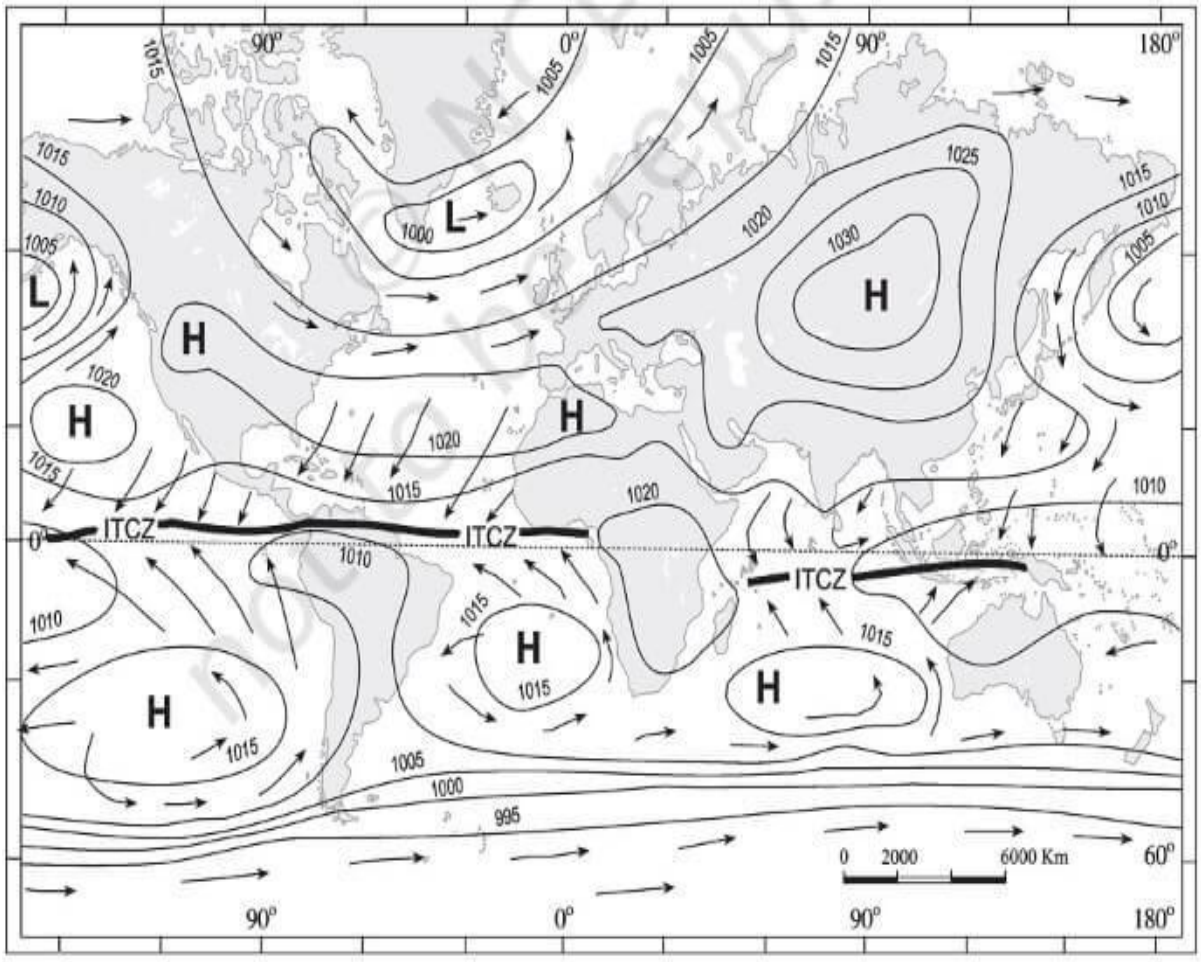


Figure 10.2 : Distribution of pressure (in millibars) — January

Factors Controlling Pressure Systems

• There are two main causes, thermal and dynamic, for the pressure differences resulting in high and low pressure systems.

Thermal Factors

- When air is heated, it expands and, hence, its density decreases. This naturally leads to low pressure. On the contrary, cooling results in contraction. This increases the density and thus leads to high pressure.
- Formation of equatorial low and polar highs are examples of thermal lows and thermal highs, respectively

Dynamic Factors

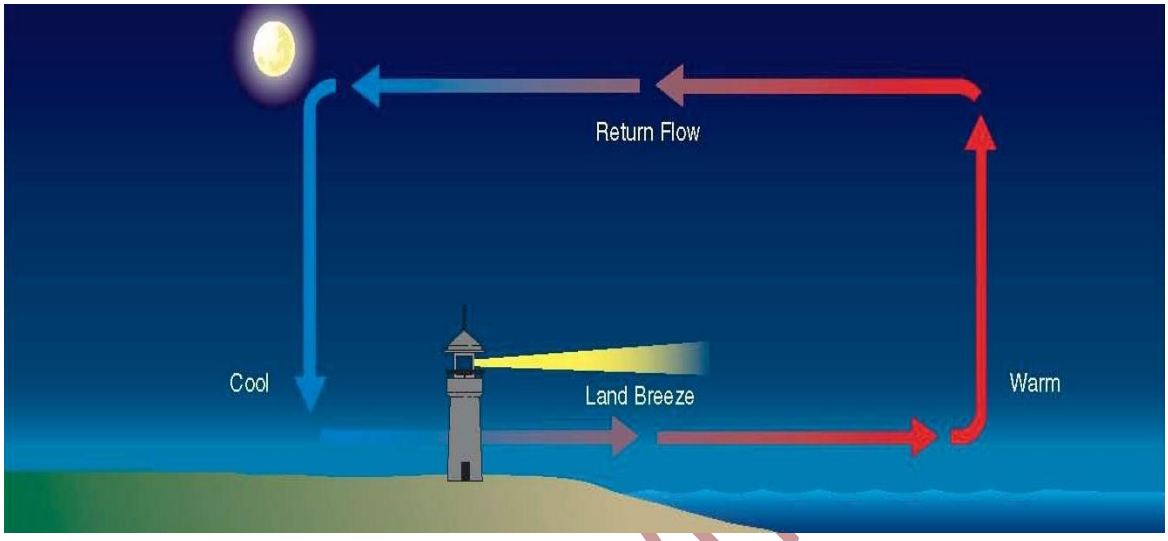
- Apart from variations of temperature, the formation of pressure belts may be explained by dynamic controls arising out of **pressure gradient forces and rotation of the earth (Coriolis force)**

Inter Tropical Convergence Zone

The Inter Tropical Convergence Zone (ITCZ,) is a broad trough of low pressure in equatorial latitudes. This is where the northeast and the southeast trade winds converge. This convergence zone lies more or less parallel to the equator but moves north or south with the apparent movement of the sun.

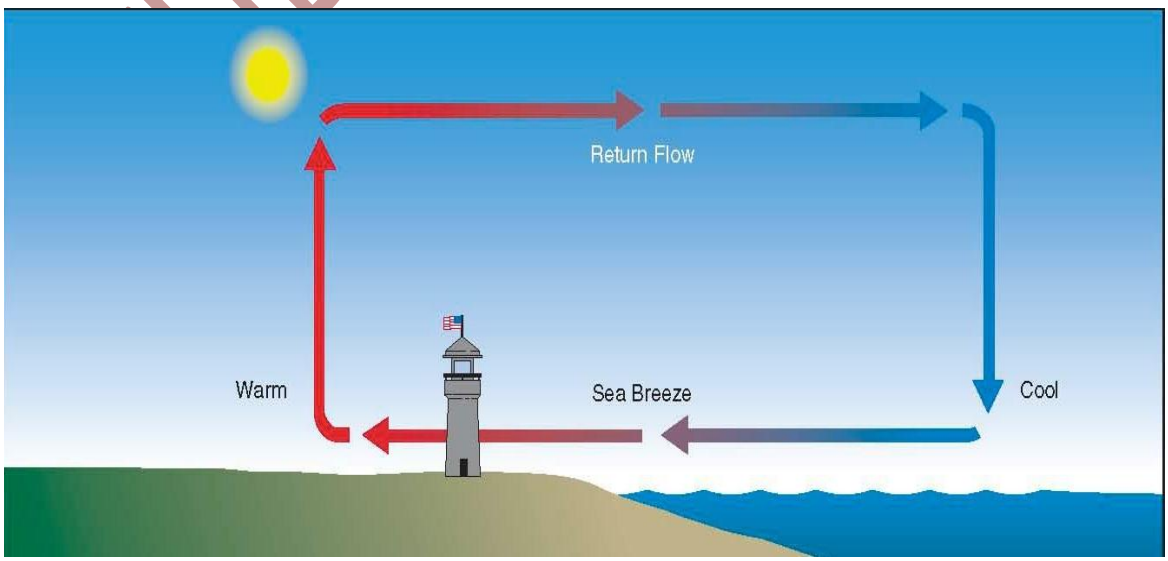
Land Breeze

The movement of local wind system from land to water at late night is called Land Breeze. It is created when the land is cooler than the water such as at night and the surface winds have to be very light.



Sea Breeze

The pressure gradient from sea to land is created and the wind blows from the sea to the land is called as Sea Breeze. It is created when the surface of the land is heated sufficiently to start air rising.



Thunderstorm

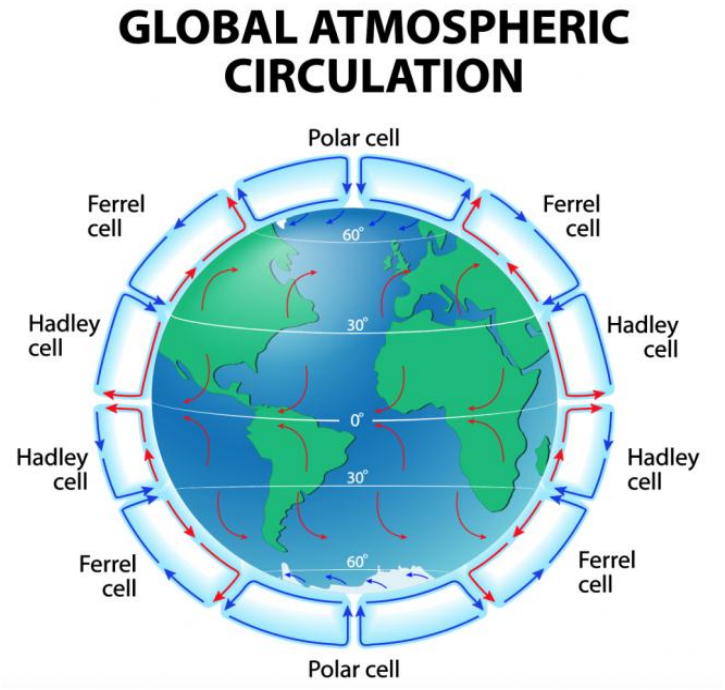
It is a storm resulting from strong rising air currents; heavy rain or hail along with thunder and lightning. It is caused by intense convection on moist hot days.

Tornado

When 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. It is generally occur in middle latitudes.

General Circulation of the Atmosphere

The pattern of the movement of the planetary winds is called the general circulation of the atmosphere



Factors for General Circulation of the Atmosphere

- The pattern of planetary winds largely depends on:
- Latitudinal variation of atmospheric heating
- The emergence of pressure belts
- The migration of belts following the apparent path of the sun
- The distribution of continents and oceans
- The rotation of the earth
- The general circulation of the atmosphere also sets in motion the marine water circulation which affects the climate of the Earth.
- The air at the ITCZ (Inter Tropical Convergence Zone) upsurges because of convection caused by high insolation and low pressure is generated.
- The winds from the tropics join at this low-pressure zone.
- The joined air upsurges along with the convective cell.
- It reaches the top of the troposphere up to an altitude of 14 km. It further moves toward the poles. This causes accumulation of air at about 30o North and South.
- Another reason for sinking is the cooling of air when it reaches 30 degrees North and South latitudes.
- Downward near the land surface, the air flows towards the equator as the easterlies.
- Such circulations from the surface up and vice-versa are called cells.
- This type of cell in the tropics is called the Hadley Cell.
- In the mid-latitudes, the circulation is that of dipping cold air that comes from the poles and the mounting 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.
- These Ferrel cells, Hadley Cell, and polar cell set the configuration for the general circulation of the atmosphere.

General Atmospheric Circulation and its Effects on Oceans

- The general circulation of the atmosphere also influences the oceans.
- Warming and cooling of the Pacific Ocean is most significant in terms of general atmospheric circulation.
- The warm water of the central Pacific Ocean gradually drifts towards the South American coast and substitutes the cool Peruvian current.
- Such presence of warm water off the coast of Peru is known as the El Nino.
- The El Nino is associated with the pressure variations in Australia and Central Pacific.
- This variation in pressure condition over the Pacific is known as the southern oscillation.
- The combined phenomenon of El Nino and southern oscillation is known as ENSO