Atmospheric Circulation and Weather Systems

Atmospheric circulation and weather systems are important concepts for the UPSC exam Geography segment. Questions can be asked from these topics in both the UPSC prelims and the UPSC Mains exams. In this article, you will find relevant notes on this topic for the IAS exam.

Atmospheric Pressure

It is defined as the force exerted by the weight of the air molecules above the earth's surface per unit area. Atmospheric pressure is higher at the surface of the earth due to the gravitational force. The pressure decreases with height and at any elevation, it varies from place to place. This variation is the primary cause of air motion (wind) which moves from high-pressure area to low pressure area.

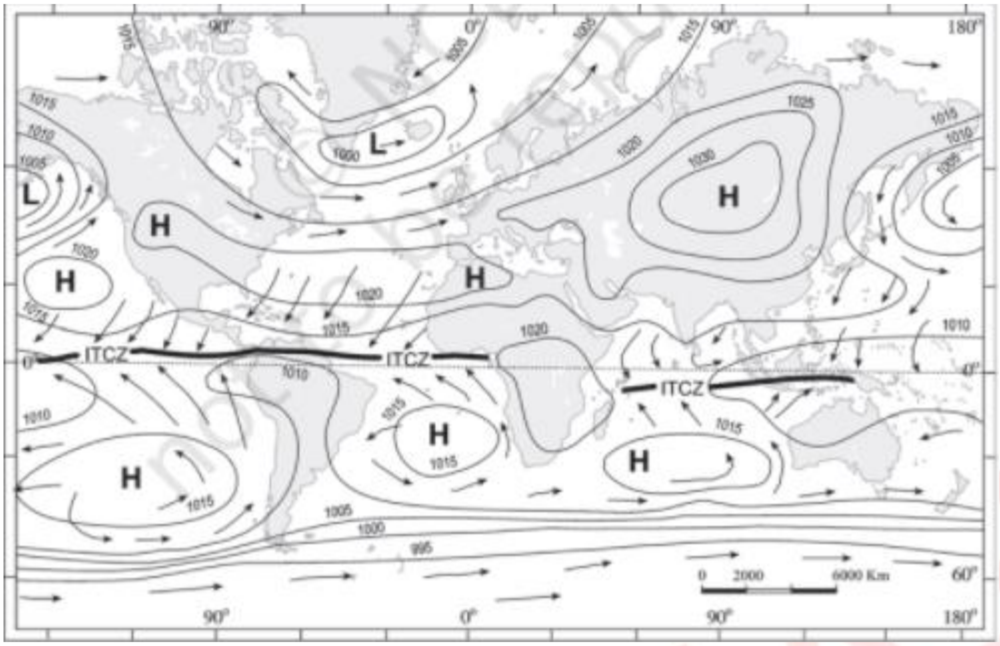
- Atmospheric pressure and temperature are inversely related. With the increase in temperature, the air expands and the number of molecules per unit area decreases which leads to a decrease in pressure. Similarly when the temperature falls, the air contracts and the pressure increases.
- Atmospheric pressure is measured by an instrument called a "Barometer". At sea level, the average atmospheric pressure is 1013.25 mb (millibar).

Vertical Distribution of Atmospheric Pressure

- Atmospheric pressure at the sea level is highest and it rapidly decreases with increasing altitude. There is about 1 mb decrease in pressure for each 10 m increase in elevation.
- The vertical pressure gradient (rate of change of pressure with respect to distance is called pressure gradient) is much stronger than the horizontal pressure gradient. However, we do not experience strong upward winds because of the balancing gravitational force.

Horizontal Distribution of Atmospheric Pressure

- The horizontal distribution of pressure is studied by drawing isobars at constant levels. An isobar is an imaginary line connecting the places of uniform atmospheric pressure reduced to mean sea level.
- Closely spaced isobars indicate a steep pressure gradient while wide spacing implies a gentle pressure gradient.



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- A high-pressure system is enclosed by one or more isobars with the highest pressure in the centre. A low-pressure system is also enclosed by one or more isobars with the lowest pressure in the centre.

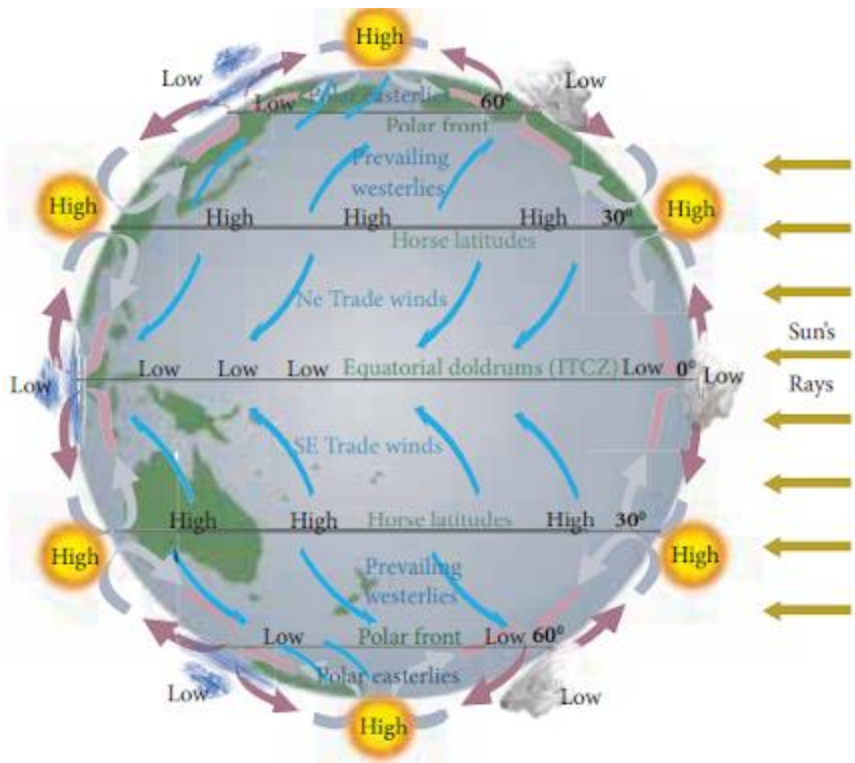
Pressure Belts

These are zones of homogeneous pressure. There are a total of seven pressure belts on the globe.

1. **Equatorial low pressure belt**
    a. Lies between 0°N to 5°N and 0°S to 5°S.
    b. Due to the high temperature over this region, air gets heated, expands, becomes lighter and rises upwards to create a low pressure over this region.
    c. The winds blow from the subtropical high-pressure belt towards the equatorial low-pressure belt. Due to the Coriolis effect, these winds are deflected to the right in the Northern Hemisphere and to the left in the Southern Hemisphere, and are called north-east and south-east trade winds respectively.
    d. The Intertropical Convergence Zone (ITCZ) lies here as the trade winds (north-east and south-east) of the northern and southern hemispheres converge here. ITCZ shifts towards north and south with the apparent movement of the sun.
    e. This region is a belt of calm and is referred to as the “Doldrums”.
2. **Subtropical high pressure belt**
    a. Lies between 30°N to 35°N and 30°S to 35°S.
    b. Over the equatorial region, air rises up and cools when it reaches higher altitudes. The cool air moves towards the poles and collides with the winds coming from the polar region at high altitudes. Being heavy it subsides over the subtropical latitudes which leads to the formation of a high-pressure belt along the subtropical region.

c. The sinking air bifurcates into two branches – one branch towards the equator called trade winds and the other towards poles called westerlies. Westerlies turn towards right and left in the northern hemisphere and southern hemisphere respectively.
d. This belt of high pressure is also called "Horse Latitude". It is said that to avoid slowing down and sinking the ships due to high pressure, the horses were thrown into the sea.

3. **Subpolar low pressure belt**
    a. Lies between 60°N to 65°N and 60°S to 65°S.
    b. The warm westerly winds from the subtropical region move towards the poles and collide with cold polar easterly winds from the polar high pressure region and rise up to form subpolar low pressure belt.
    c. These belts experience stormy weather and cyclonic activity, especially during winter.
4. **Polar high pressure belt**
    a. Lies between 85°N to 90°N and 85°S to 90°S.
    b. The constant low temperature at the poles due to inclined solar radiation and reduced insolation leads to the formation of polar high pressure belts on both poles.



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 summer they move northwards.

- The equatorial low pressure and polar high pressure belts are formed due to high and low temperature respectively. They are called "thermally formed pressure belts".
- The subtropical high and subpolar low pressure belts are formed due to the movement and collision of wind systems. They are called "dynamically formed pressure belts".

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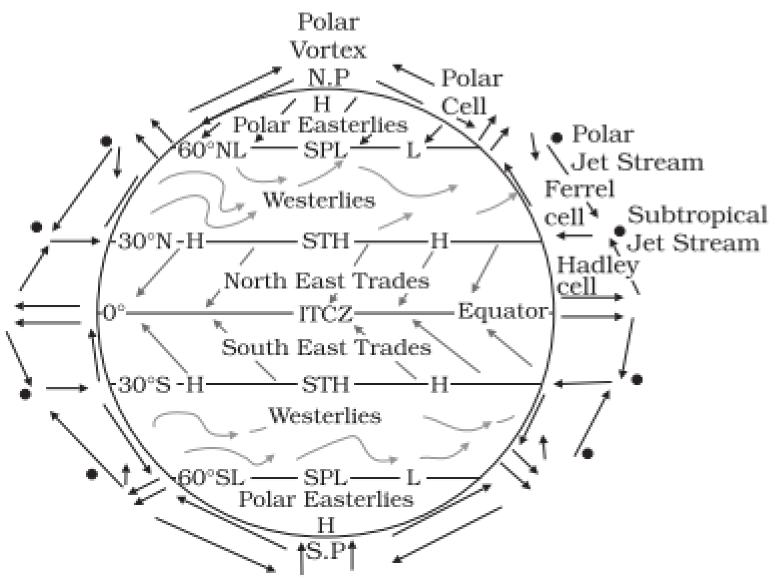
General Circulation of the Atmosphere

The pattern of movement of the planetary winds is called the general circulation of the atmosphere. Three cells set the pattern for the general circulation of the atmosphere. These are – Hadley cell, Ferrel cell and Polar cell.

Hadley Cell

- This model was proposed by George Hadley in 1735.
- The air at the equator (ITCZ – InterTropical Convergence Zone) rises due to high insolation, flows polewards and descends in the subtropics (30°N and S). Down below near the land surface, the air flows towards the equator due to pressure gradient as the easterlies. The easterlies (north-east trade winds and south-east trade winds) converge in the ITCZ. Such a circulation of air gives rise to cells.
- This type of cell formed along with trade winds, equatorial low (ITCZ) and subtropical high pressure belts is called the Hadley cell.



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Ferrel Cell

- This model was proposed by William Ferrel in 1856.
- It is a global atmospheric circulation that features part of the air rising at 60° latitude flowing towards the equator, descending in the sub-tropics and then returning towards the subpolar region.
- At the surface, these winds are called westerlies and the cell is known as the Ferrel cell.

Polar Cell

- It features part of the air rising at 60° latitude that flows towards poles, descends and returns towards the subpolar region.
- The winds blow towards the subpolar region as the polar easterlies and the cell is called the Polar cell.

These cells – Hardley, Ferrel and Polar cells set the pattern for the general circulation of the atmosphere.

Wind Systems

- It is the horizontal movement of air from high pressure zones to low pressure areas to maintain atmospheric equilibrium. Due to the Coriolis force, winds do not flow in a straight path. The direction of the wind is identified by an instrument called a **wind vane**. **Anemometer** is an instrument that measures the speed of the wind.
- Types of winds – Winds are classified into three:
  - Primary winds,
  - Secondary winds and
  - Tertiary winds.

Primary Winds

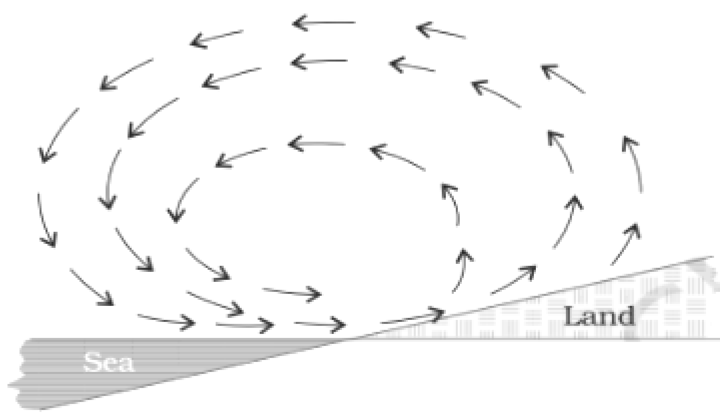
- Primary winds are also called planetary winds, permanent winds (blow constantly throughout the year), global winds, invariable winds and prevailing winds.
- There are three types of primary winds – Trade Winds, Westerlies and Easterlies.
- **Trade winds**
  - These winds flow between 30°N and 30°S latitudes from sub-tropical high pressure belts towards equatorial low pressure belts (in Hadley cell).
  - These trade winds flow towards the equator from the north-east in the northern hemisphere and from the south-east in the southern hemisphere.
  - North-east and south-east trade winds get warm and pick up moisture on their way to the equator. Near the equator, they rise and cause heavy rains.
- **Westerlies**
  - These winds flow between 30°N and 60°N in the northern hemisphere and between 30°S and 60°S in the southern hemisphere (in Ferrel cells). These winds blow from subtropical high pressure towards subpolar low pressure belts.
  - Westerlies blow from south-west to north-east in the northern hemisphere and north-west to south-east in the southern hemisphere.
  - Westerlies are stronger in the southern hemisphere because there are no large landmasses to interrupt them.
- **Easterlies**
  - These winds blow from polar high pressure belts towards subpolar low pressure belts between 90° and 60° latitudes in both the hemispheres (in Polar cells).
  - These polar easterlies blow from north-east to south-west in the northern hemisphere and from south-east to north-west in the southern hemisphere.

Secondary Winds

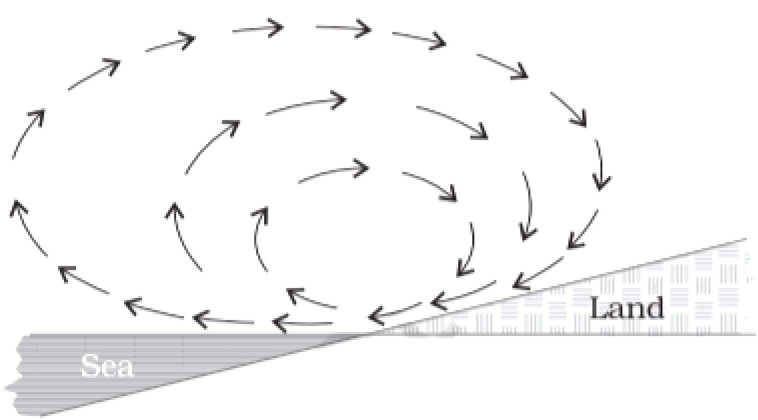
Also called seasonal winds, periodic winds, variable winds and regional winds. Seasonal winds change their direction in different seasons. Monsoons are seasonal winds that are characterised by seasonal reversal of wind direction.

Land and Sea Breezes

During the day, the land heats up faster than water and the air over the land warms and expands leading to the formation of a low pressure zone. At the same time, the air over the ocean is comparatively cool because of water's slower rate of heating and forms a high pressure area. Thus, the pressure gradient from sea to land is created and the wind blows from sea to the land as the sea breeze. In the night, the reversal of condition takes place. The land loses heat faster than the sea and is cooler than the sea. The pressure gradient is developed from the land to the sea and this results in land breeze.



Sea Breeze



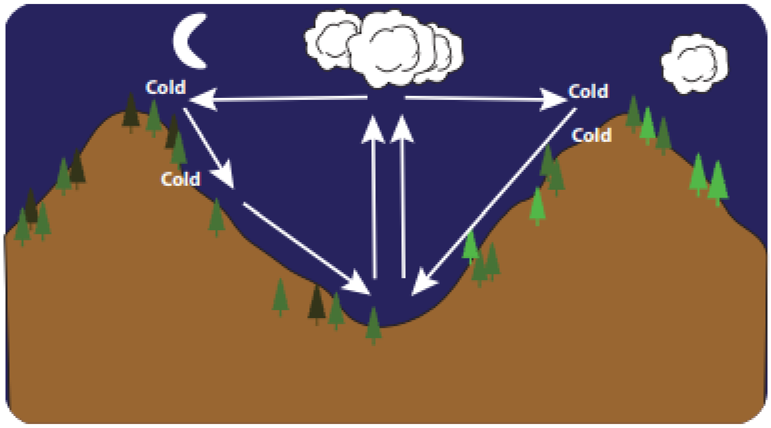
Land Breeze

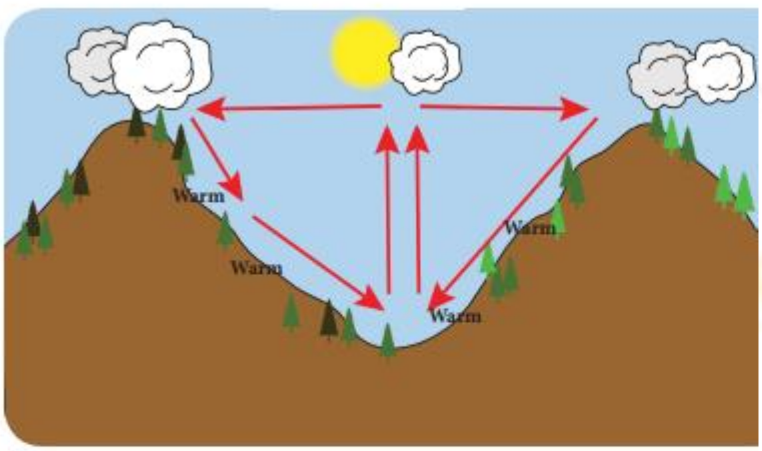
Image source: NCERT

Mountain and Valley Winds

- In mountainous regions, during the day the slopes get heated up and air moves up the slope. To fill the resulting gap, the air from the valley blows up and this wind is known as the valley breeze or Anabatic wind or upslope wind.
- During the night, the slope gets cooled and the dense air descends downhill into the valley. This wind is known as mountain wind or Katabatic wind or downslope wind.

- On the leeward side of the mountain ranges, warm winds may occur. While crossing the mountain ranges, the moisture in these winds condenses and precipitate. The resulting dry winds descend down the leeward side of the slope and get warmed up by the adiabatic process. This warm wind may melt the snow in a short time.





Tertiary Winds

Tertiary winds are formed due to pressure gradients which may develop on a local scale due to differences in the heating and cooling of the earth's surface. Local winds are tertiary winds that blow only during a particular period of the day or year in a small area. Such winds blow locally and are confined to the lowest levels of the troposphere.

North American local winds –

- Chinook – (snow eater) These are warm dry westerly off the Rocky Mountains.
- Blizzard – These are cold winds that blow in Canada, the USA, Siberia, etc.
- Norte – These are strong cold winds that blow along the Gulf of Mexico.
- Santa Ana – These are warm, dry and strong winds that blow out of the Great Basin through the upper Mojave desert to California.

South American local winds –

- Pampero – These are cold winds and blow in Argentina and Uruguay.

- Zonda – These are warm and dry winds, and blow on the eastern slope of the Andes in Argentina and Uruguay.

African winds –

- Sirocco – Also called blood rain as it brings reddish sand along with it from the Sahara desert. It is warm, dry and dusty. Blows in a northerly direction from the Sahara desert and crossing over the Mediterranean Sea, reach southern Europe.
- Khamsin – Dry, hot and sandy wind blows from North Africa to the eastern Mediterranean.
- Harmattan – Also called doctor wind as it makes the weather pleasant. It is a dry northerly wind across central Africa.
- Berg – A hot dry wind blows from the Kalahari high to the coastal low pressure area.

European winds –

- Fohn/Foehn – It is a dry, strong and warm wind that blows along the northern slope of the Alps and Switzerland. The wind helps in melting snow and aids in the ripening of snow. It is a katabatic wind.
- Mistral – It is a cold northerly wind that blows from central France and the Alps to the Mediterranean.
- Levante – It is a moist and rainy wind that blows near the Mediterranean sea and southern France and Spain.
- Bora – It is cold, dry and gusty wind that blows north-easterly from Eastern Europe to northeastern Italy.

Asian winds –

- Karaburan – (Black storm). It is a dusty fast blowing wind that blows in central Asia.
- Buran – In summer, it is hot and dry. During winters, it is an extremely cold wind that blows across eastern Asia.
- Simoom – It is a strong, dry desert wind that blows in the Arabian desert.
- Loo – It is a hot and dry wind that blows over the plains of India and Pakistan.
- Yoma – It is a warm and dry wind that blows in Japan.

Australian winds

- Brickfielder – It is a hot and dry wind that blows in southern Australia.

Image source: SCERT, Tamil Nadu

Air Masses

An air mass is defined as an immense body of air several kilometres in length, breadth and thickness, with little horizontal variation in temperature and moisture. When the air remains over a homogeneous area for a sufficiently long time, it acquires the characteristics of the area. The homogenous regions can be the vast ocean surface or vast plains and plateaus.

- The homogeneous surfaces over which air masses form are called the source regions. The main source regions are the high pressure belts in the subtropics (giving rise to tropical air masses) and around the poles, giving rise to polar air masses. The air masses are classified according to the source regions and there are five major source regions:
    - Warm tropical and subtropical oceans.
    - Subtropical hot deserts.
    - Relatively cold high altitude oceans.
    - Very cold snow-covered continents in high altitudes.
    - Permanently ice-covered continents in the Arctic and Antarctica.
- Accordingly, the following types of air masses are recognised:
    - Maritime tropical (mT) – moist and warm.
    - Continental tropical (cT) – dry and warm.
    - Maritime polar (mP) – moist and cold.
    - Continental polar (cP) – dry and cold.
    - Continental arctic (cA) – dry and cold.

Tropical air masses are warm and polar air masses are cold.

Fronts

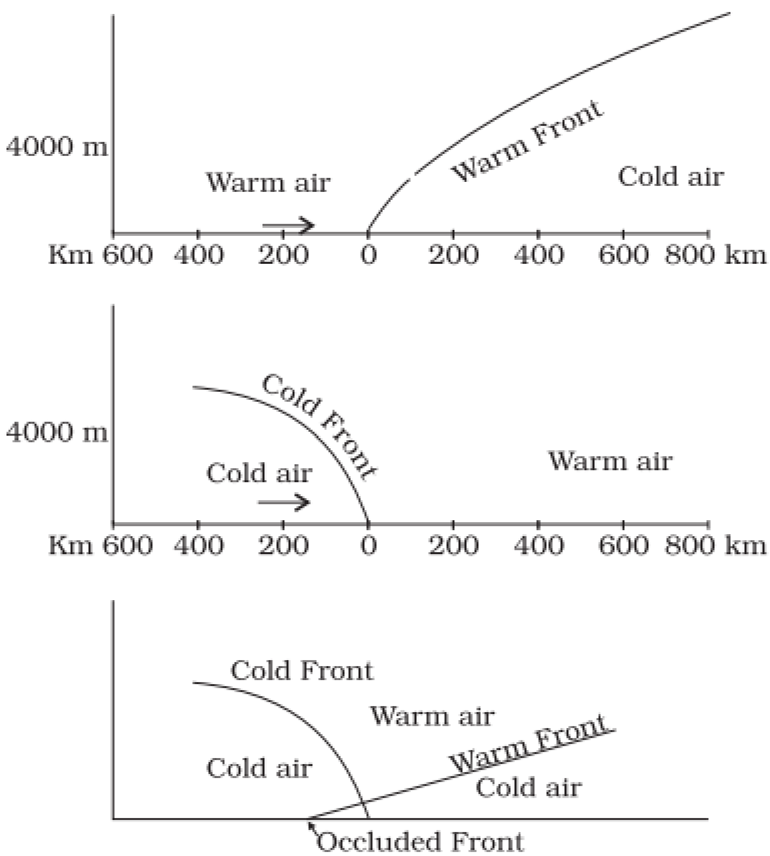
When two different air masses (different physical properties like temperature, humidity, density, etc.) meet, the boundary zone between them is called a front. The fronts occur in middle latitudes (30°-60° N and S) and are characterised by steep gradients in temperature and pressure. They are uncommon in tropical and polar regions.

- The process of formation of fronts is known as **frontogenesis** and dissipation of a front is known as **frontolysis.** Frontogenesis involves the convergence of two distinct air masses and frontolysis involves over riding of one of the air masses by the other.
- Mid-latitude cyclones or temperate cyclones or extratropical cyclones occur due to frontogenesis.

There are four types of fronts –

1. Stationary front -When the front remains stationary, it is called a stationary front. When a warm or cold front stops moving and is unable to push against each other, it results in a stationary front. It brings significant precipitation along the front.

2. Cold front – When the cold air moves towards the warm air mass, its contact zone is called the cold front. Here, cold air mass replaces warm air mass by advancing into it. Cold fronts result in the formation of cumulonimbus clouds with heavy rainfall associated with lightning and thunder.
3. Warm front – When the warm air mass moves towards the cold air mass, the contact zone is a warm front. Here, the active movement of warm air over cold air takes place. Warm fronts result in the formation of stratus and nimbostratus clouds and cover over large areas, leading to moderate to gentle rainfall.
4. Occluded front – This type of front is formed when a cold air mass overtakes a warm air mass and goes underneath it. Occlusion is a process by which the cold front of a rotating low pressure system catches up the warm front, so that the warm air between them is forced upwards. Weather along an occluded front is complex, a mixture of warm front type and cold front type weather. Such fronts are common in western Europe.



Cyclones

The atmospheric disturbances which involve a closed circulation of air around a low pressure at centre and high pressure at the periphery, rotating anti-clockwise in the northern hemisphere and clockwise in the southern hemisphere (due to the Coriolis force) are called “cyclones”.

Cyclones are classified into two types based on the latitudes of their origin-

1. Tropical cyclones
2. Temperate/Extra-tropical cyclones

Tropical cyclones

- Tropical cyclones develop in the region between the tropics of Capricorn and Cancer. These are violent storms that originate over oceans in the tropical areas and move on to the coastal regions bringing large scale destruction caused by violent winds, very heavy rainfall and storm surges. These cyclones are one of the most devastating natural calamities.
- Tropical cyclones are known by different names depending on the regions of the world. They are known as Hurricanes in the Atlantic, Typhoons in the Western Pacific and the South China Sea, Willy-willies in Western Australia and Cyclones in the Indian ocean.

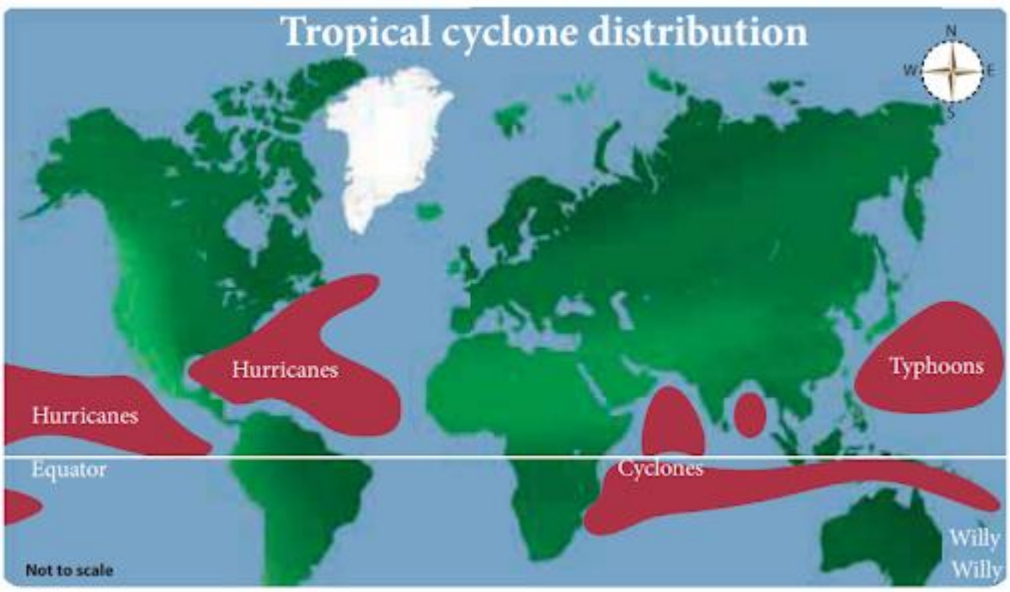
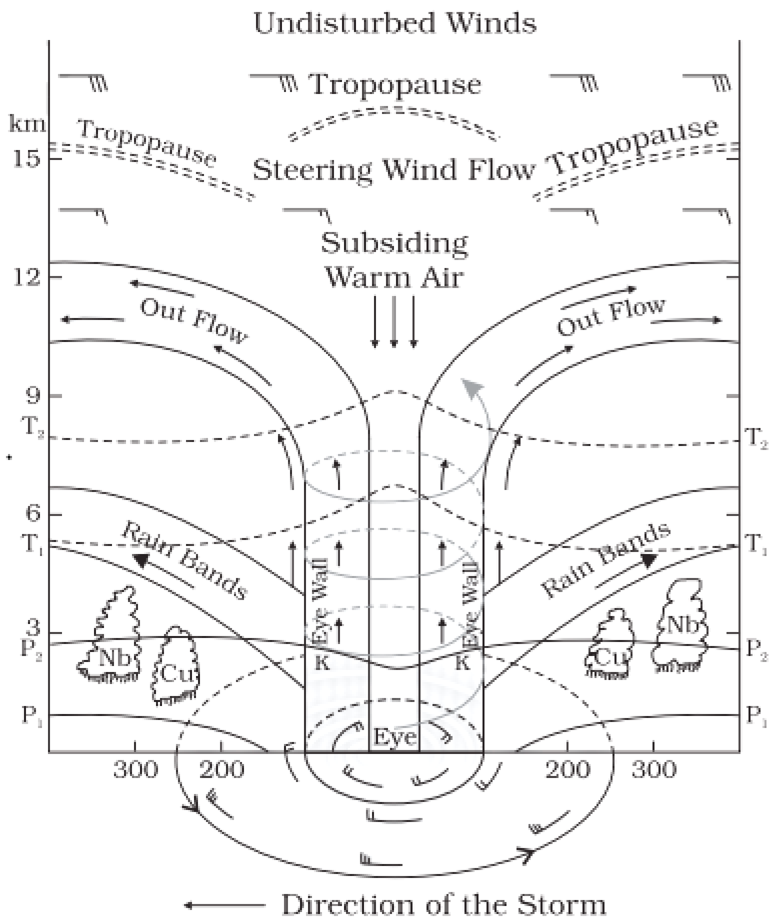


Image source – SCERT, Tamil Nadu

Factors favourable for the formation of tropical cyclones

1. Large sea surface with a temperature greater than 27°C, which is a source of warm and moist air to feed the storm. The condensation of moisture releases enough latent heat of condensation to drive the storm.
2. Presence of the Coriolis force enough to create a cyclonic vortex. The Coriolis force is zero at the equator and it increases with latitudes. Coriolis force at 5°latitude is significant enough to create a storm. About 65% of the cyclonic activity takes place between 10° and 20°(N & S) latitudes.
3. Small variations in the vertical wind speed. Winds that do not vary greatly with height are known as low wind shear. This allows the storm clouds to rise vertically to a high level.
4. Pre-existing weak low pressure area or low level cyclonic circulation. They act as seeds for the cyclones.
5. Upper divergence above the sea level system.



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- The centre of the cyclone where the wind converges and vertically rises is called the "eye". The eye is a calm region with no rainfall, experiences the highest temperature and lowest pressure within the cyclonic system. A mature tropical cyclone is characterised by the strong spirally circulating wind around the centre, called the eye.
- All the wind that is carried upwards loses its moisture and becomes cold and dense. It descends to the surface through the cylindrical eye region and at the edges of the cyclone.
- Continuous supply of moisture is the major driving force behind every cyclone. On reaching the land, the moisture is cut off and the storm dissipates. The place where a tropical cyclone crosses the coast is called the "landfall" of the cyclone.
- Around the eye is the eye wall, the most violent region of the cyclone. The wind reaches maximum velocity in this region, reaching as high as 250 km per hour. Torrential rains occur 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 the 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 lowlands.

- Tropical cyclones mostly move along with the direction of trade winds, so they travel from east to west and make landfall on the eastern coasts of the continents.

Read more on Tropical Cyclones in the linked article.

Temperate Cyclones

- It occurs between 30°-60° latitude in both the hemispheres (in between Tropic of Cancer and Arctic circle in the northern hemisphere and in between Tropic of Capricorn and Antarctic Circle in the southern hemisphere)
- Temperate cyclones are also called extra-tropical cyclones or mid-latitude or frontal cyclones or wave cyclones.
- These cyclones move with the westerlies and are therefore oriented from west to east.
- Unlike tropical cyclones, temperate cyclones form over both land and water. It covers a larger area than tropical cyclones and stays for a longer time.
- Jet streams play an important role in temperate cyclones and also influence their direction, west to east.

Read more on temperate cyclones in the linked article.