M. Sc | Geography | Unit 1 to 5 | Climatology

Applied Climatology

Presentation By

Dr. P.Siva Kumar, M.Sc., B.Ed., Ph.D.,

Guest Faculty

Department of Geography
Bharathidasan University
Tiruchirappalli - 620 024

Humidity, Condensation, Precipitation and the Air Masses

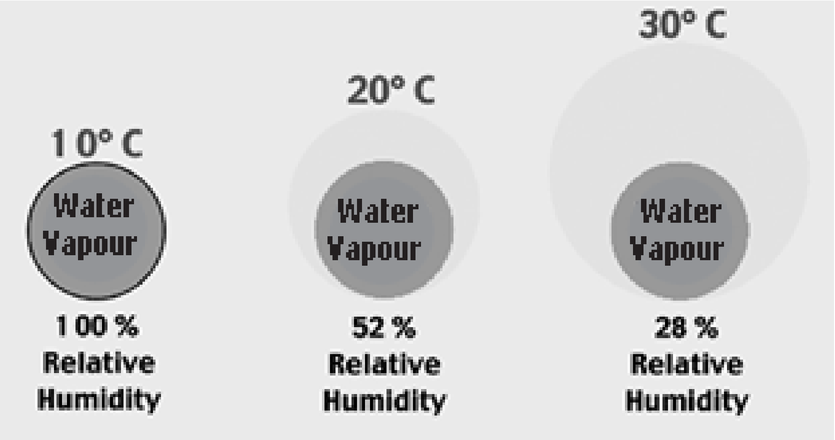
Humidity

Humidity defines the amount of water vapour in the air. The amount of humidity found in air varies because of a number of factors. Two important factors are the **evaporation** and **condensation**.

In our atmosphere, water vapour is converted back into liquid form when air masses lose heat energy and cool. This process is responsible for the development of most of clouds, and also produces the rains that fall to the Earth's surface.

The atmospheric humidity can be expressed in a number of ways.

(i) **Relative Humidity:** It can be simply defined as the amount of water in the air relative to the saturation amount the air can hold at a given temperature, multiplied by 100. Temperature and evaporation are positively related and hence humidity and temperature are also directly positively related. Air with a relative humidity of 50%, contains a half of the water vapour it could hold at a particular temperature.



Relative Humidity and Temperature

The above figure illustrates the concept of Relative Humidity. Relative Humidity (RH) is always expressed as percentage. Suppose an air mass of 1 kg contains 9 gm of water vapours at a given temperature and constant pressure. But 1 kg of an air mass has the capacity to contain 12 gm of water vapours at the same temperature and pressure.

$$RH = 9/12 \times 100 = 75\%$$

There is inverse relationship between air temperature and relative humidity i.e., relative humidity decreases with increasing temperature while it increases with decreasing temperature.

$$\text{Relative Humidity} = \frac{\text{Absolute Humidty}}{\text{Humidity Capacity}}$$

(i) **Specific Humidity:** It is the ratio of mass of water vapours actually present in the air to a unit mass of air including the water vapour (dry air + moisture). It is expressed as grams of water vapour per kg of moist air mass. The amount of water vapour that air can hold depends upon

temperature. Specific humidity at 20°C is 15g per kg. At 30°C, it is 26 g per kg and at -10°C, it is 2 g per kg.

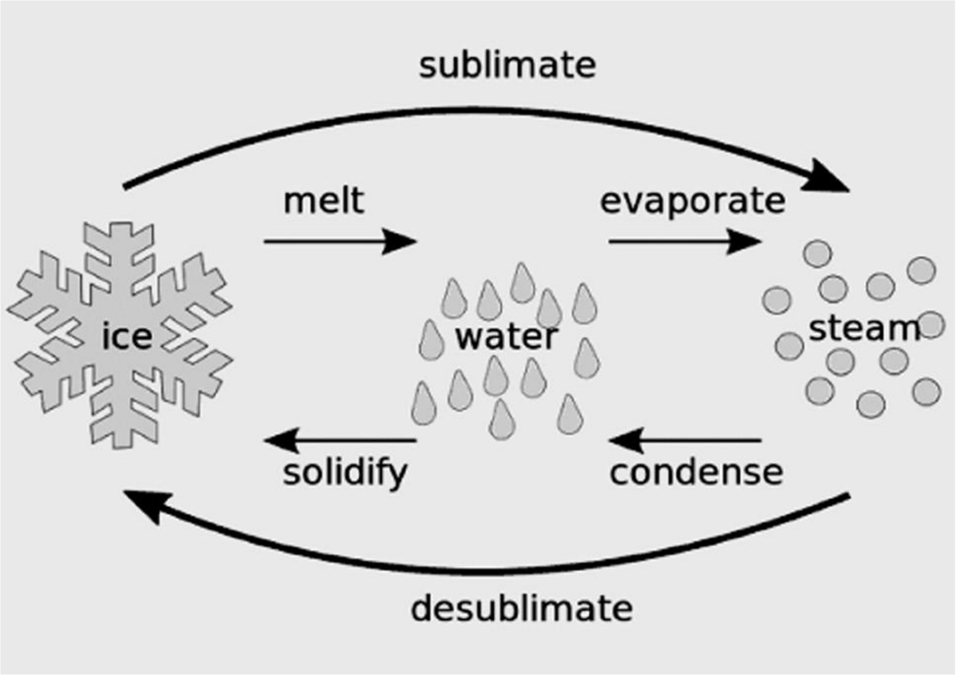
Specific humidity is a constant property of air, therefore, it is frequently used in meteorology. The value of the specific humidity changes only if the amount of water vapours undergoes any change. But it is not affected by the changes in pressure or temperature of air. It is directly proportional to the vapour pressure of air and inversely proportional to the atmospheric pressure.

It decreases from equator to polewards. In arctic, it is 0.2 gm per kg while in equatorial region it is 18 gm per kg.

(i) **Absolute Humidity:** It is defined as the weight of water vapours in a given volume of air. It is expressed as grams of water vapours per cubic meter of air (g m^{-3}). **Absolute humidity is rarely used because it varies with the expansion and contraction of air.** It varies with temperature, even though the amount of water vapours remains constant. Temperature and evapouration are positively related and hence humidity and temperature are also directly positively related.

Condensation

- Condensation is the process by which water vapour in the air is changed into liquid water. Condensation is crucial to the water cycle because it is responsible for the formation of clouds. These clouds may produce precipitation, which is the primary route for water to return to the Earth's surface within the water cycle. Condensation is the opposite of evaporation.
- In free air, condensation results from cooling around very small particles termed as hygroscopic condensation nuclei. Particles of dust, smoke, pollen 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.



Sublimation and Condensation

Dew Point and Frost Point

Associated with relative humidity is dew point (if the dew point is below freezing, it is referred to as the frost point). Dew point is the temperature at which water vapour saturates from an air mass into liquid or solid usually forming rain, snow, frost, or dew. Dew point normally occurs when a mass of air has a relative humidity of 100%. This happens in the atmosphere as a result of cooling through a number of different processes.

Precipitation

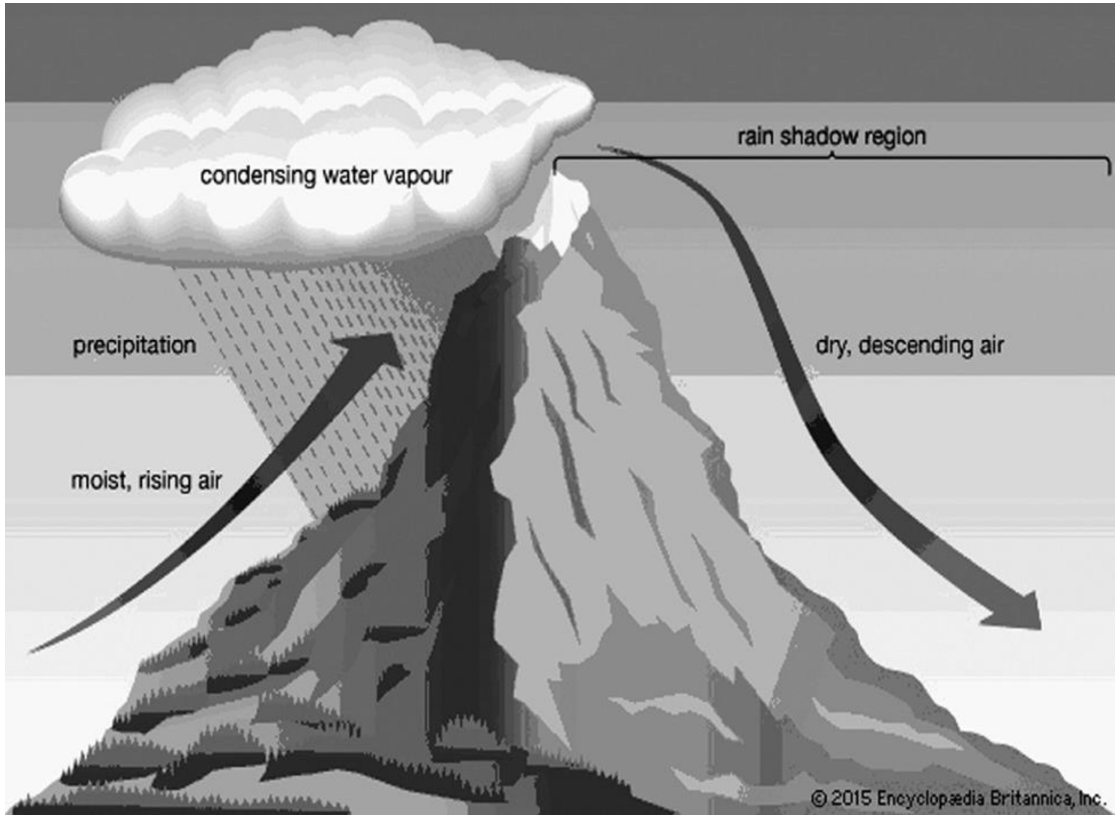
- Precipitation refers to any liquid or solid aqueous deposit that forms in a saturated atmosphere (relative humidity equals 100%), and falls from clouds to the ground surface. It is important to recognize that most clouds do not produce precipitation. In many clouds, water droplets and ice crystals are just too small to overcome the natural updrafts found in the lower atmosphere. As a result, the tiny water droplets and ice crystals remain suspended in the atmosphere until they are converted back into vapour.
- Water droplets and ice crystals can only fall to the Earth's surface if they grow to a size that can overcome updrafts. Conditions for growth can develop in clouds via two different processes: In clouds with temperatures above freezing, turbulent atmospheric mixing can cause droplets to grow through the processes of collision and coalescence. One initial condition, however, must be met for this process to begin-droplet size in the cloud must be variable. This initial condition allows larger and heavier droplets to collide and coalesce with lighter smaller droplets during downdraft periods. If enough atmospheric mixing occurs, the larger droplets can expand by up to 250 times and can become heavy enough to fall to the Earth's surface.
- The other mechanism of precipitation development involves clouds whose temperature is below freezing. In these clouds, large ice crystals grow due to the differences in vapour pressure between ice crystals and supercooled water droplets. Vapour pressure differences between ice and super cooled water cause a net migration of water vapour from water droplets to ice crystals. The ice crystal then absorbs the water vapour, depositing it on their surface. At the same time, the loss of vapour from the water droplets causes them to shrink in size. A necessary initial requirement for this process is the presence of both condensation nuclei and deposition nuclei. While deposition nuclei form ice crystals at temperatures just below zero degrees Celsius, condensation nuclei can remain liquid (super cooled) to temperatures as low as –40° Celsius depending upon size. Because of this phenomenon, cold clouds can contain both ice crystals and super cooled water droplets. The relative proportion of these two types of particles determines whether snow crystals grow to a size to overcome atmospheric updrafts.

Types of Precipitation

(A) Orographic Precipitation

This type of precipitation occurs when the moist air mass rises on the windward side of the mountains. The moist air mass is lighter than the dry air mass, therefore, buoyancy forces push the air mass along the slope of the mountain and cools at the dry adiabatic rate. When cooling is sufficient, air mass becomes saturated and the condensation starts. As a result, lifting condensation level is reached and clouds begin to form. When the mountains act as barrier to the flow of air mass, the air cools adiabatically, as a result, clouds and precipitation occur. This is called orographic precipitation. This type of precipitation occurs on the windward side of the mountains.

- But on the leeward side, there is abrupt decrease in precipitation due to the descending air mass which gets heated at dry adiabatic lapse rate. The descending air mass becomes dry and hot. As a result, the clouds on the leeward side disappear. Therefore, dry areas always exist on the leeward side of the mountains. These are known as *rain shadow areas*. This is due to the reason that moist air prevails on the windward side and warm dry air prevails on the leeward side. In India, south-west monsoon causes heavy rains on the windward slope of Western Ghats, whereas on the leeward side there are extensive rain shadow areas. There is a continuous increase in precipitation on the windward side up to a certain height beyond which the rainfall starts decreasing. This is called the inversion of rainfall.



The Orographic Precipitation

b) Convectional Precipitation

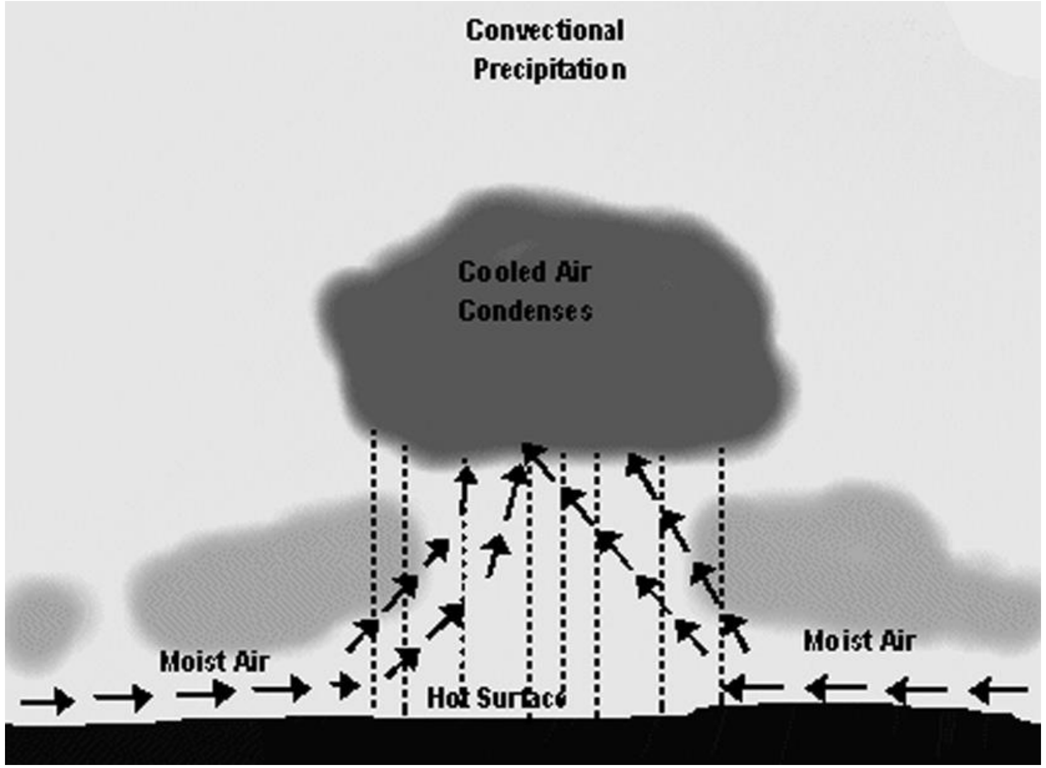
Two conditions are required to cause this type of precipitation:

(i) Intense heating of the ground surface.

(ii) Abundant supply of moisture.

Solar radiation is the main source of heat to produce convection currents in the air. This process starts, when surface is heated unequally. During the day, the air above the bare soil will grow warmer than the air over the adjacent forest. Warm air is less dense as compared to cold air. Convection currents are set up forcing air to rise. The air is cooled adiabatically and its temperature will decrease as it rises. The air mass will continue to rise as long as it remains warmer than its surrounding air.

Rising air mass becomes saturated as it gets cooled adiabatically. Condensation starts and the rising air column becomes a puffy cumulus cloud. If the convection continues strongly, the cloud develops into a dense cumulonimbus cloud. Heavy rainfall is always associated with this type of cloud. Convective type precipitation is a warm weather phenomena. It is generally associated with thunder, lightning and strong surface winds. Sometimes hails are also associated with it.



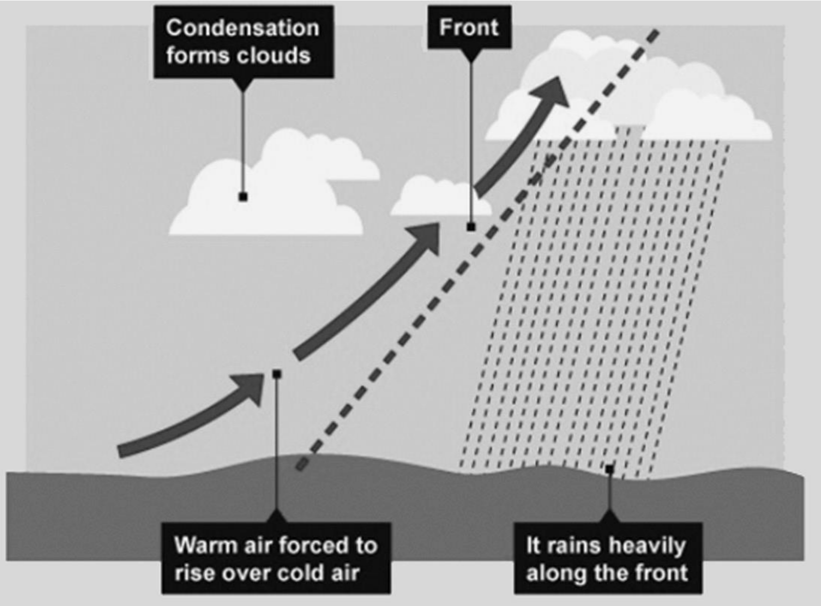
Convectional Precipitation

c) Cyclonic or Frontal Precipitation It occurs when deep and extensive air masses are made to converge and move upwards so that their adiabatic cooling takes place. For this type of precipitation lifting of air mass is required. (Ref. Fig 1. 37)

Cyclonic precipitation can be achieved in two ways

I. When two air masses with different temperature and moisture content meet at a certain angle, the warm and moist air is forced to rise over the heavier cold air mass.

II. When air masses from different directions converge to the centre, some of the air is forced up.



Frontal Precipitation

In the tropical region, there is little difference in the temperature and humidity of the converging air masses. The lifting is almost vertical and is accompanied by convection. In such a condition the convergence provides the initial upward movement of unstable air mass and causes large clouds and heavy showers.

In temperate regions, a zone of contact between warm and cold air mass is called the front. There may be warm or cold front. Frontal precipitation occurs when the warm and moist air gradually rises over the cold air mass. The main cause of this precipitation is the mixing of air along the front. Frontal precipitation along the warm front is in the form of drizzle. It is always widespread and of long duration.

In case of cold front it is always in the form of intense thunder showers and is of very short duration. Frontal precipitation occurs in Europe and North. America. During winter season, cyclonic precipitation occurs in the northern parts of India.

Forms of Precipitation

Rain: It is defined as liquid deposit that falls from the atmosphere to the surface, and has a diameter greater than 0.5 millimetres. The maximum size, of a rain drop is about 5 millimetres. Beyond this size, inter-molecular cohesive forces become too weak to hold the mass of water together as a single drop.

Freezing Rain: This takes place when falling liquid water droplets encounter a surface with a temperature below 0° Celsius. Upon contact with this surface, the rain quickly turns into ice. Another important condition required for freezing rain is that the atmosphere where rain develops must be above freezing. A situation where warm air is found on top of cold air is called as the temperature inversion. Temperature inversions are not the common state of the lower atmosphere. Usually, air temperature decreases with an increase in altitude in the troposphere. In the mid-latitudes, we often find temperature inversions developing along the moving front edge of a cold air mass that is overtaking the warmer air. This condition causes the less dense warm air to be pushedup and over the more dense cold air.

Ice Pellets (or Sleet): These are transparent or translucent spheres of frozen water. They have a diameter smaller than 5 millimetres. This form of precipitation develops first as raindrops in a relatively warm atmosphere where the temperature is above freezing. These raindrops then descend into a colder lower layer of the atmosphere where freezing temperatures occur. In this layer, the cold temperatures cause the raindrops to freeze into ice pellets during their transit to the ground surface. Similar to freezing rain, anair temperature inversion is required for the formation of ice pellets.

’The Ice Pellets’ Precipitation

Snow: It is a type of precipitation common to the mid and high latitudes. Snow develops when water vapour deposits itself (skipping the liquid phase) directly on a six-sided (hexagon) deposition nuclei as a solid crystals, at temperatures below freezing. The unique form of snowflakes occurs because ice crystal growth is most rapid at the six points associated with geometric shape of the deposition nuclei. These points are more directly exposed to the atmosphere and consequently convert more water vapour into ice. Snow is usually generated by frontal lifting associated with mid-latitude cyclones. Snowfall can occur in the fall, winter, and spring months when atmospheric temperatures can drop below freezing. Much of the ground surface of North America can be covered with snow for several months during a typical year.

Precipitation in form of Snow Pellets

Snow Pellets or Graupel: There are spherical white bits of ice that have a diameter less than 5 millimetres. Snow pellets develop when super cooled droplets freeze onto the surface of falling snowflakes. Snow pellets usually fall for only a brief period of time when a precipitation event changes from ice pellets to snow.

The Hail

Hail: It is a type of frozen precipitation that is more than 5 millimetres in diameter. Hailstones often have concentric shells of ice alternating between those with a white cloudy appearance and those that are clear. The cloudy white shells contain partially melted snowflakes that freeze onto the surface of the growing hailstone. The clear shells develop when liquid water freezes to the hailstone surface.

Fogs

Fog is simply a cloud of minute water droplets that exists at the ground level. Fog develops when the air at ground level is cooled enough to cause saturation (relative humidity equals 100%). Meteorologist have a very specific definition to determine if fog exists. This definition suggests that fog is occurring when the visibility of the atmosphere, near the Earth's surface, becomes less than 1 kilometre. Fog can be created through a variety of processes:

Radiation Fog (or Ground Fog): Produced by near surface cooling of the atmosphere due to long wave radiation emissions. This particular type of fog is normally quite shallow and develops during the evening hours. Shortly after sunrise, the radiation fog disappears because of surface heating due to the absorption of the solar radiation.

Upslope Fog: Created when air flows over higher topography. When the air is forced to rise in altitude because of the topographic barrier, it is cooled by the adiabatic expansion. This type of fog is often found formed on the windward slopes of hills or mountains.

Advection Fog: Generated when air flows over a surface with a different temperature. Warm air advection can produce fog if it flows over a cold surface. The contact cooling associated with this process causes saturation to occur in a relatively thin layer of air immediately above the ground surface.

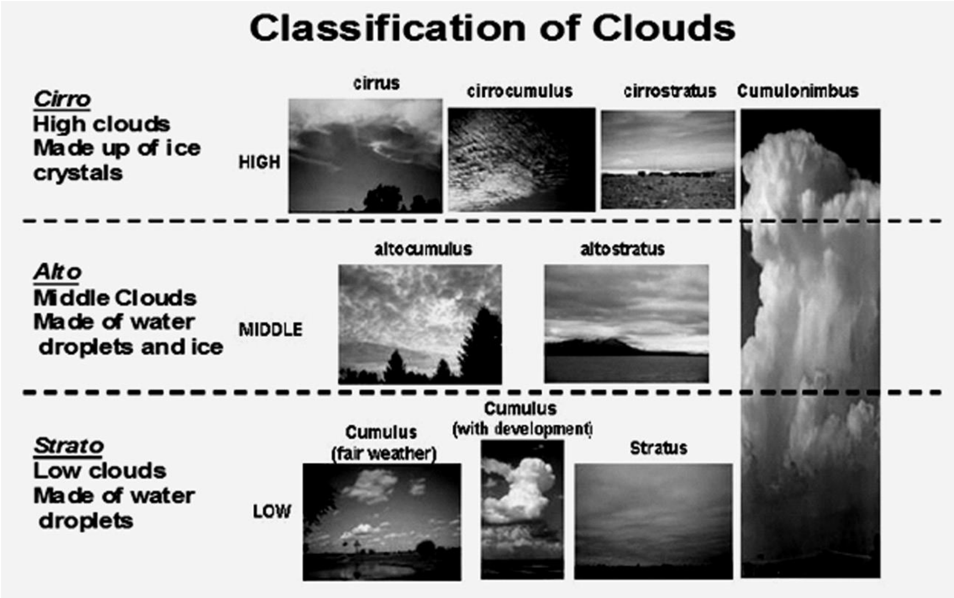
Evaporation Fog: A specific type of advection fog. It occurs when one get cold air advancing over warm water or warm, moist land surfaces. In this situation, fog forms as water from the surface evapourates into the cold air and then saturates. This type of fog can also be called steam fog or sea smoke.

Frontal Fog: it is a type of fog that is associated with weather fronts, particularly warm fronts. In this situation, rain descending into the colder air ahead of the warm front can increase the quantity of water vapour in this atmosphere through evaporation. Fog then forms when the quantity of water in the atmosphere ahead of the front reaches a saturation **(relative humidity equals to 100%).**

Cloud Formation Process

Condensation or deposition of water above the Earth's surface creates clouds. In general, clouds develop in any air mass that becomes saturated (relative humidity becomes 100%). Saturation can occur by way of atmospheric mechanisms that cause the temperature of an air mass to be cooled to its dew point or frost point. These mechanisms or processes can achieve this outcome causing clouds to develop.

1. **Orographic Uplift:** It occurs when air is forced to rise because of the physical presence of elevated land. As the parcel of air rises it cools due to adiabatic expansion at a rate of approximately 10° Celsius per 1000 metres until saturation.
2. **Convectional Lifting:** It is associated with surface heating of the air at the ground surface. If enough heating occurs, the mass of air becomes warmer and lighter than the air in the surrounding environment, and just like a hot air balloon, it begins to rise, expand, and cool. When sufficient cooling has taken place saturation occurs, forming clouds. This process is active in the interior of continents and near the equator forming cumulus clouds and or cumulonimbus clouds (thunderstorms). The rain that is associated with the development of thunderstorm clouds is delivered in large amounts over short periods of time in extremely localized areas.



The Classification of Clouds

3) Convergence or Frontal Lifting: It takes place when two masses of air come together. Generally, the two air masses have different temperature and moisture characteristics. One of the air masses is usually warm and moist, while the other is cold and dry. The leading edge of the latter air mass acts as an inclined wall or front causing the moist warm air to be lifted. The lifting causes the warm moist air mass to cool due to expansion, resulting in saturation. This cloud formation mechanism is common at the mid- latitudes where cyclones form along the polar front and near the equator where the trade winds meet at the inter-tropical convergence zone.

4) Radiative Cooling: This situation occurs when the Sun is no longer supplying the heat to the ground and overlying air with energy derived from solar insolation (e.g., night). Instead, the surface of the Earth now begins to lose energy in the form of longwave radiation which causes the ground and air above it to cool. The clouds that result from this type of cooling take the form of surface fog.

These causes of cloud development do not always act in a singular fashion. It is possible to get combinations of all four types, such as when convection and orographic uplift cause summer afternoon cloud development and showers in the mountains.

Types of Clouds

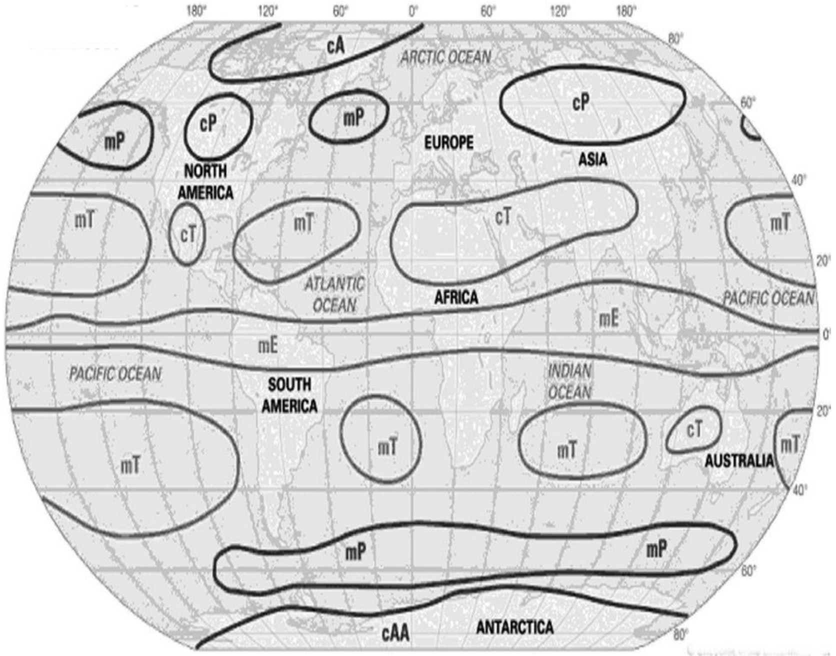
Family	Genus and Main Content	Height (Mts.)	Characteristics
Hight clouds	Cirrus (ice)	5000-13500	High altitude, white, silk like sheen, thin and wispy, often in streaks.
	___ Cirrostratus (ice)	5000-13500	High, whitish like a veil, may cover entire sky.
	Cirrocumulus (usually ice, occasionally mixed)	5000-13500	High, thick, white patches of clouds made up of small ripples.
Medium clouds	Altostratus (usually mixed, occasionally ice)	2000-7000	Middle altitude, greyish or bluish cloud sheets, thin, blanket layer, rain bearing, often distributed over the entire sky.
	Altocumulus (water)	2000-7000	Middle, white or gery, layer of individual cloud masses in geometrical pattern or rounded masses, "mackerel" sky.
	Nimbostratus (water)	900-3000	Middle, dark, dense cloud layer, rain or snow.
Low clouds	(Nimbo means precipitation coming from cloud)	below 450	Low, grey cloud layer may produce drizzle or snow grains.
	Stratus (water)	450-2000	Low, whitish or grey with dark parts, in wave-like layers, usually no rain.
	Stratocumulus (water) e.g. fog	450-2000	Low, deta red clouds with white tufted tops, may bring showers.
	Cumulus (water)		
Clouds with vertical development have up-currents within them		450-2000	Usually low based, tall and towering white and black, bring thunder storms.

Air Masses

- Air masses constitute a large body of air having nearly uniform conditions of temperature and humidity at any given level of altitude. Such a mass has distinct boundaries and may extend hundreds or thousands of kilometres horizontally and sometimes as high as the top of the troposphere (*About 10–18 km above the Earth's surface*).
- An air mass forms whenever the atmosphere remains in contact with a large, relatively uniform land or sea surface for a time sufficiently long to acquire the temperature and moisture properties of that surface. The Earth's major air masses originate in polar or subtropical latitudes. The middle latitudes constitute essentially a zone of modification, interaction, and mixing of the polar and tropical air masses. Air masses are named for the type of surface over which they are formed.
- The nature of air masses is determined by three factors: *the source region, the age, and the modifications that may occur as they move away from their source region across the earth's surface*.The primary classification of air masses is based on the characteristics of the source region, giving *Arctic (A), Polar (P)* or *Tropical air (T),* and on the nature of the surface in the source region: *continental (c)* or *maritime (m)*. In addition, a large variety of secondary types of air masses are defined. For example, equatorial air (E) or Mediterranean air. Sometimes there is a letter (k) or (w) attached to the two-letter initials indicating whether the air is warmer or colder than the surface. The former becomes more stable, and the latter more unstable.

Types of Air Masses

1. **Continental Polar (CP):** Usually formed during the cold period of the year over extensive land areas such as central Asia and northern Canada. They are likely to be stable and characteristically free of condensation forms. When heated or moistened from the ground with strong turbulence, this type of air mass develops limited convective stratocumulus cloud with scattered light rain or snow showers. In summer, strong continental heating rapidly modifies the coolness and dryness of the CP air mass as it moves to lower latitudes.



The Principal Air Masses of The World

2) **Maritime Polar (MP):** Develop over the polar areas of both the Northern and the Southern hemispheres. They generally contain considerably more moisture than the CP air masses. As they move inland in middle and high latitudes, heavy precipitation may occur when the air is forced to ascend mountain slopes or is caught up in cyclonic activity (see cyclone).

3) **The Continental Tropical (CT):** Originates in arid or desert regions in the middle or lower latitudes, principally during the summer season. It is strongly heated in general, but its moisture content is so low that the intense dry convection normally fails to reach the condensation level. Of all the air masses, the cT is the most arid, and it sustains the belt of subtropical deserts worldwide.

4) The Maritime Tropical (MT): These are the most important moisture-bearing and rain- producing air masses throughout the year. In winter it moves poleward and is cooled by the ground surface. Consequently, it is characterized by fog or low stratus or stratocumulus clouds, with drizzle and poor visibility. A steep lapse rate aloft in regions of cyclonic activity ensures the occurrence of heavy frontal and convective rains. In summers, the characteristics of the MT air mass over the oceans and in zones of cyclonic activity are basically the same as in winter. Over warm continental areas, however, the air mass is strongly heated, so that, instead of fog and low stratus clouds, widely scattered and locally heavy afternoon thunderstorms occur.

Effect of Airmass on Local Weather and Climate

- An air mass may sits over its source region for long periods of time, or it may migrate. An air mass on the move begins to transform as it passes over new landscapes, while at the same time retaining enough of its original conditions to alter the local weather. For example, a CP air mass originating from the tundra of northern Canada might push southwards during the winter. It brings frigid temperatures to the central United States, even as it warms up somewhat on its journey across lower latitudes.
- While dry in its source region (CP), air mass often picks up substantial moisture during an early-winter transit of the Great Lakes, allowing it to dump so-called lake effect snow on leeward coasts.
- The climates of most regions worldwide are affected by air masses. For example, maritime-tropical air sourced over warm waters of the Atlantic Ocean, Caribbean Sea and Gulf of Mexico, primarily between 10 and 30 degrees north of latitude, is the main contributor of precipitation for much of North America east of the Rocky Mountains. It's also the cause of the persistent humidity typical of that big region's summer season. Maritime air masses also contribute to a moderating climatic influence on coastal temperatures, as oceans heat up and cool down more slowly and less dramatically than landmasses.

Where polar and tropical air masses meet in the mid-latitudes, prevailing westerly winds funnel along alternating low and high-pressure centres called cyclones and anticyclones, respectively. Stormy cyclones form near the air-mass fronts. Anticyclones represent stable, singular air masses, and are typically larger and more sluggish than cyclones. These may be forces of weather, but their regularity gives them a climatic significance: The mixing of air masses achieved along the alternating warm and cold fronts of a mid-latitude cyclone is part of the process by which the heat of the lower latitudes is transferred polewards

Frontogenesis, Cyclones and Anticyclones

Fronts

When two air masses with different physical properties (*temperature, humidity, density, and pressure and wind direction*) meet, due to the effect of the converging atmospheric circulation, they do not merge readily. The transition zone or the layer of discontinuity so formed between two air masses is a three-dimensional surface, and is called a front. The air masses of different densities don't mix readily and tend to retain their identity as far as the moisture is concerned. The front represents a transition zone between two air masses of different densities.

Condition for Frontogenesis
(Front Formation)

The ideal conditions for a front to occur are temperature contrast, converging air of contrasting characteristics which should be strong enough to move one air mass towards another, along with the Coriolis force. There are three basic situations, which are conducive to Frontogenesis and satisfy the two basic requirements.

(a) The wind flow is cross isothermal and flowing from cold air to warmer air.

(b) The flow must be cross isothermal, resulting in a concentration of isotherms (increased temperature gradient).

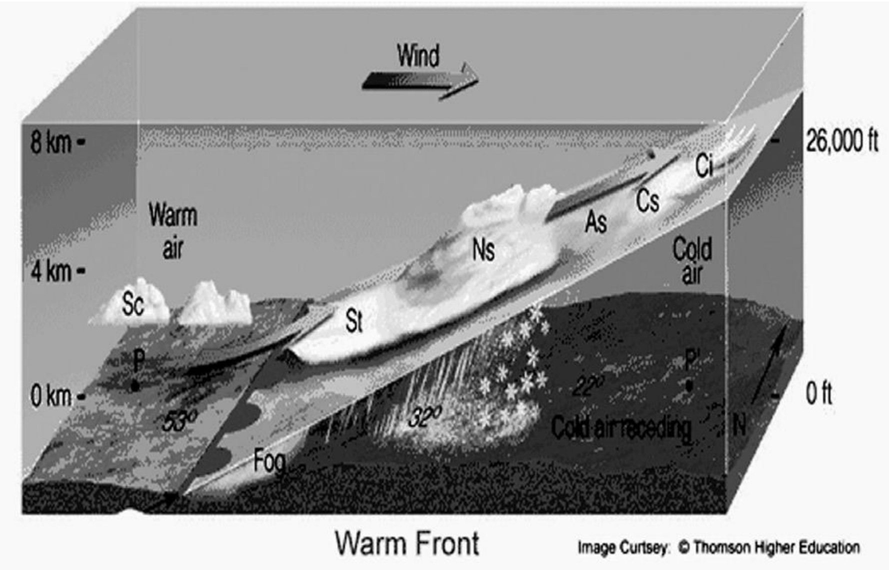
(c) The flow does not have to be perpendicular; however, the more perpendicular the cross isothermal flow, the greater the intensity of Frontogenesis.

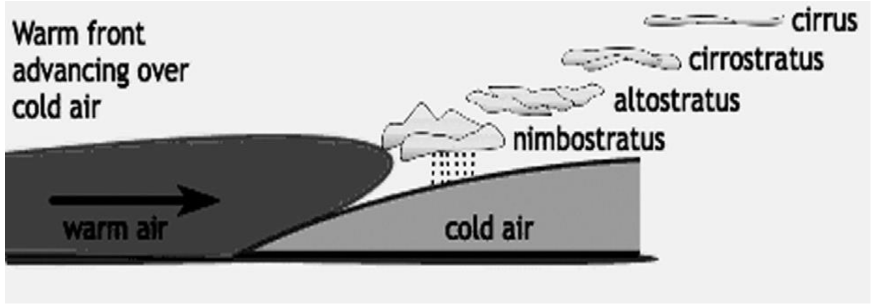
- Just as frontogenesis or front-formation is caused by converging air (for instance, along sub-polar low pressure belts), fron- tolysis or dissipation of front is caused by divergent air (for instance, fronts passing through sub-tropical high pressure belt tend to dissipate).

Difference between Frontogenesis and Frontolysis	
Frontogenesis	**Frontolysis**
• The process of formation of the fronts. • It involves conver- gence of two distinct air masses • In northern hemisphere, Frontogenesis (conver- gence of air masses) happens in anti-clock- wise direction and in southern hemisphere, in clockwise direction. This is due to Coriolis Effect. • Frontogenesis or front- formation is caused by converging air (for instance, along sub- polar low pressure belt).	• The process of dissipation of a front. • Frontolysis is oppo- site of frontogenesis, involves divergence of the air masses. • Frontolysis or dissipation of front is caused by divergent air (for instance, fronts passing through sub-tropical high pressure belt tend to dissipate).

Types of Fronts

1. **Warm Front:** This is gently sloping frontal surface, with a slope gradient between 1:100 and 1:200, along which active movement of warm air over cold air takes place. As the warm air moves up the slope, it condenses and causes precipitation, but, unlike a cold front, the temperature and wind direction changes are gradual. As the warm air moves up the slope, it condenses and causes precipitation, but unlike a cold front, the temperature and wind direction changes are gradual. With the approach, the hierarchy of clouds is — cirrus, stratus and nimbus. Cirrostratus clouds ahead of the warm front create a halo around sun and moon. Such, fronts cause moderate to gentle precipitation over a large area, over several hours. The passage of warm front is marked by rise in temperature, pressure and change in weather.

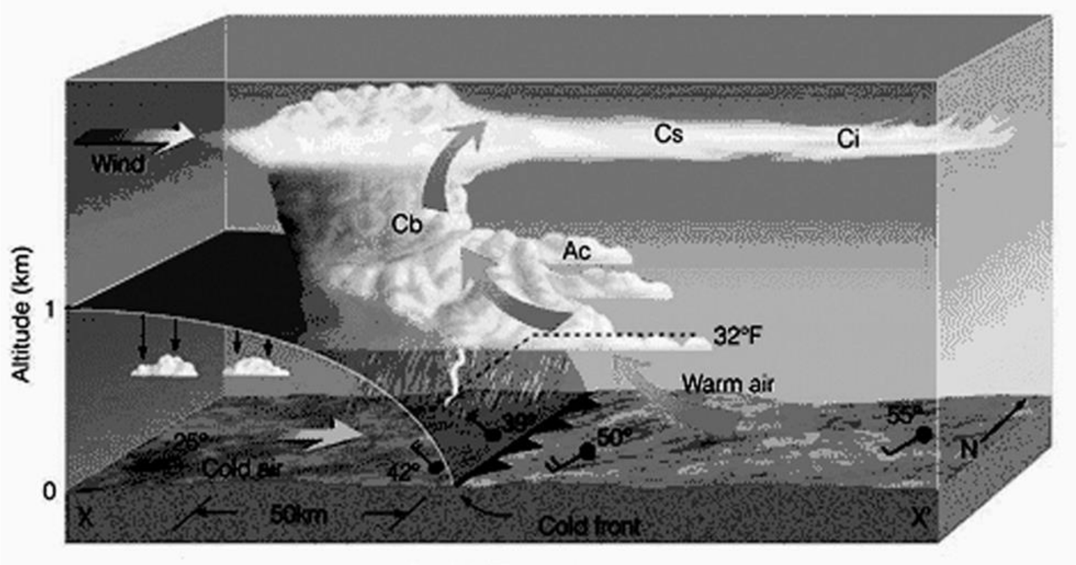


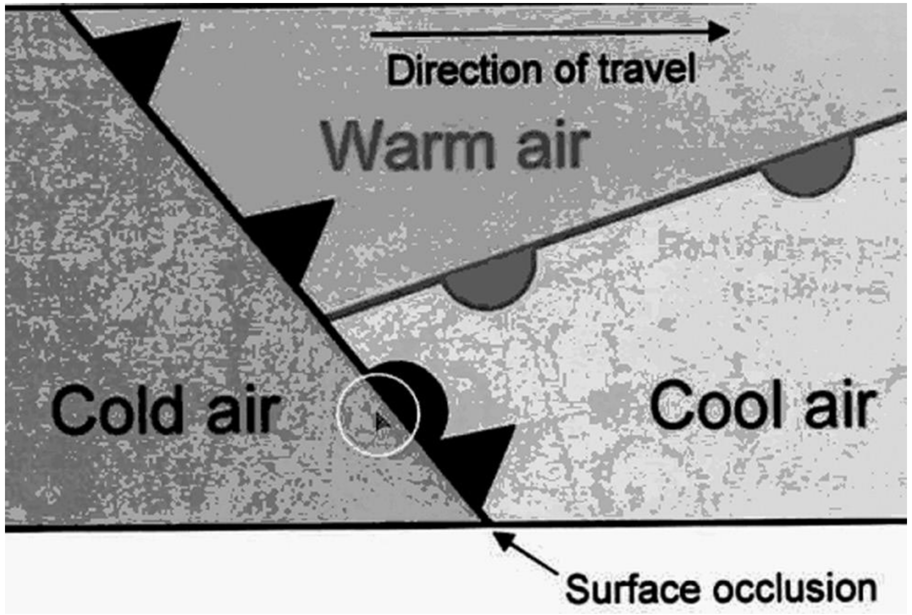


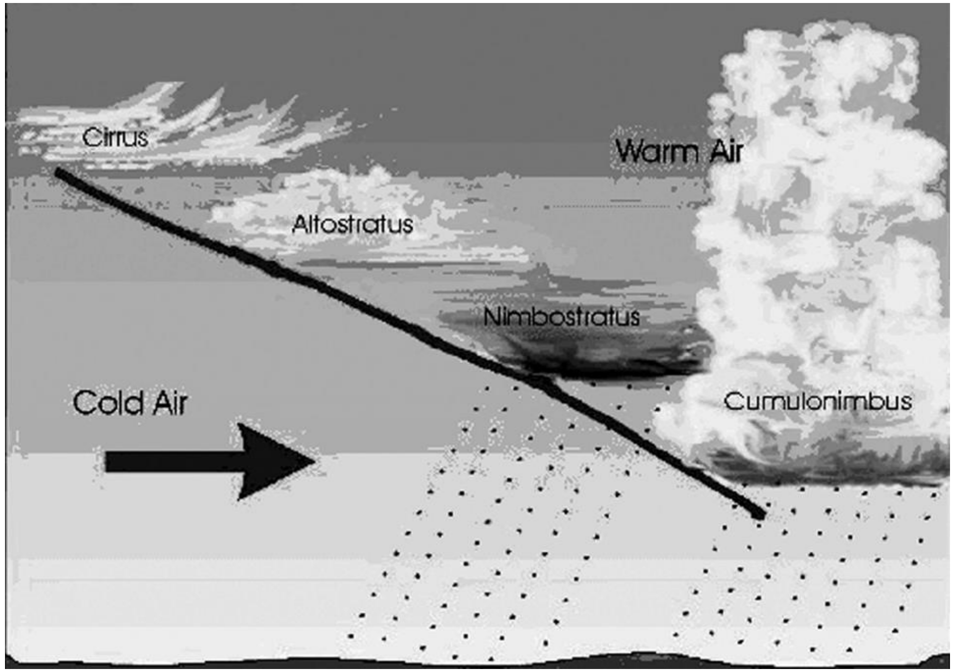
The Warm Air Fronts

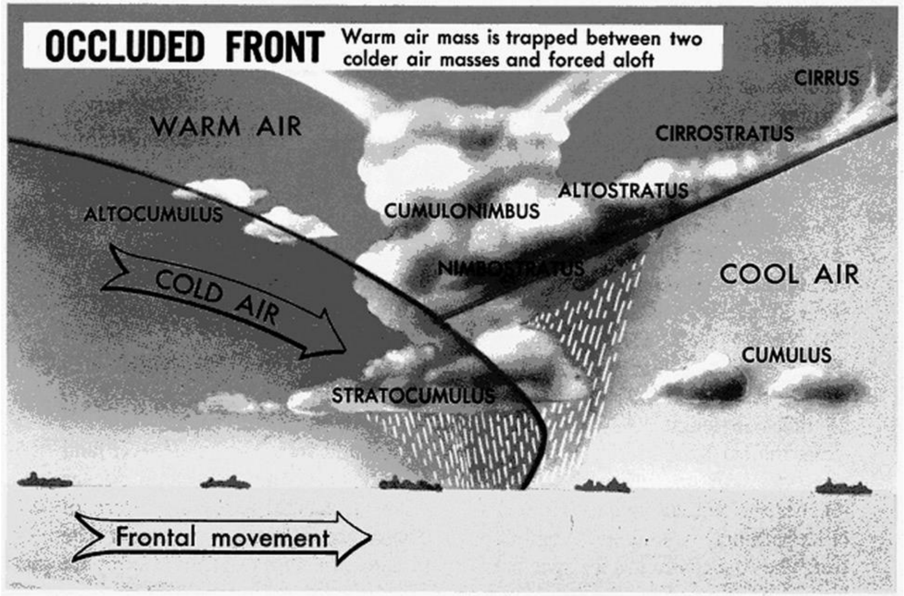
2. Cold Fronts: It is formed when a cold air mass replaces a warm air mass by advancing into it, and lifting it up, or when the pressure gradient is such that the warm air mass retreats and cold air mass advances. Sudden upliftment of warm air due to this the slope will be steep. The cold air mass remains close to the ground and sinks under the less dense warm air mass. As the warm air rises above the cold air, the warm air cools. It soon chills to the temperature at which water vapour in the air condenses into droplets of liquid water. Towering cumulus and cumulonimbus clouds form the drops of water produced by the rapid rise of warm air. Because cold fronts move quickly, they can cause abrupt weather changes. Strong winds and severe thunderstorms are often brought about. The weather along such a front depends on vertical structure of the uplifted air mass, but is generally associated with a narrow band of cloudiness and precipitation. The approach of a cold front is marked by increased wind activity in warm sectors and the appearance of cirrus clouds, followed by lower, denser alto-cumulous and altostratus. At actual front, dark nimbus clouds cause heavy showers. A cold front passes off rapidly, but the weather along it is violent.

3. Occluded Front: At an occluded front, a warm air mass is caught between two cooler air masses. The denser cool air masses move underneath the less dense warm air mass and push it upwards. The two cooler air masses meet in the middle and may mix. The temperature of the air masses meet in the middle and may mix. The temperature near the ground becomes cooler. The warm air mass is cut off, or occluded, from the ground. As the warm air cools and its water vapour condenses, the weather may turn cloudy and rainy or snowy. Thus, a long and backward swinging occluded front is formed which could be a warm front type or cold front type occlusion. Weather along an occluded front is complex a mixture of cold front type and warm front type weather. The formation Mid-latitude cyclones (temperate cyclones or extra-tropical cyclones) involve the formation of occluded front. A combination of clouds formed at cold front and warm front. Warm front clouds and cold front clouds are on opposite side of the occlusion. Such fronts are common in western Europe.





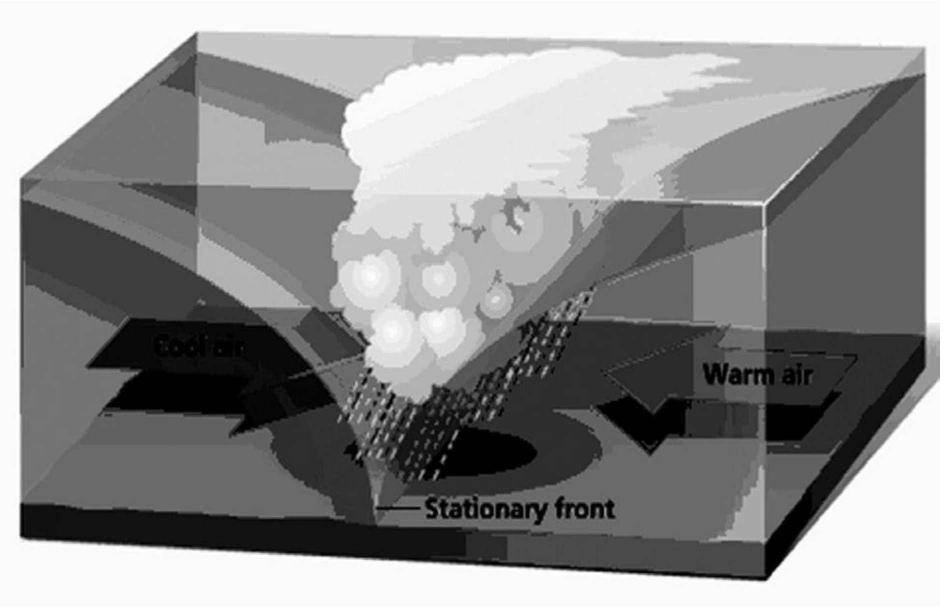


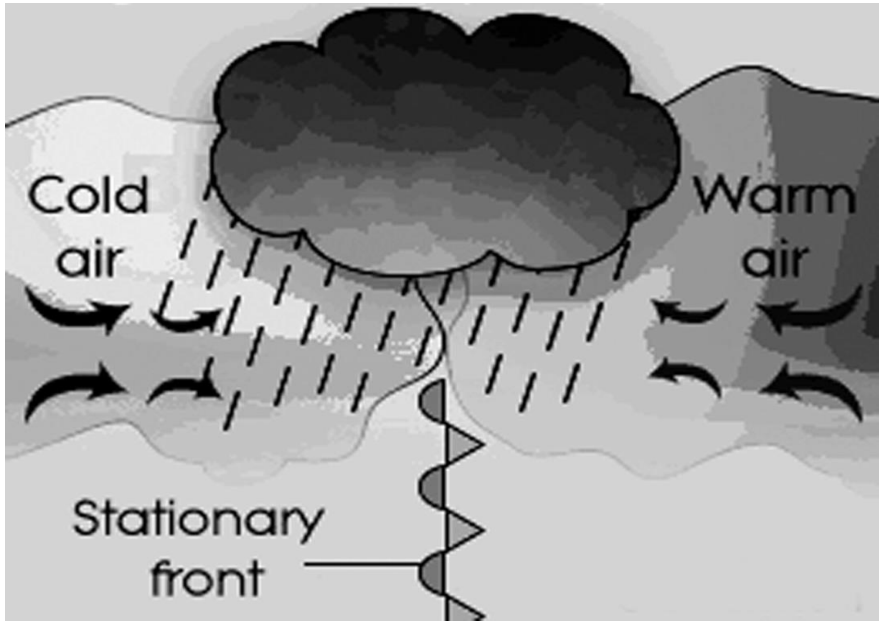


The Cold Air Fronts

The Occluded Fronts

4. Stationary Front: When the surface position of a front does not change, a stationary front is formed.Sometimes cold and warm air masses meet, but neither one has enough force to move the other. The two air masses face each other in a “standoff.” In this case, the front is called a stationary front. Where the warm and cool air meet, water vapour in the warm air condenses into rain, snow, fog, or clouds. A stationary front can remain stalled over an area for many days. In this case, the wind motion on both sides of the front is parallel to the front. Overrunning of warm air, along such a front causes frontal precipitation. Cumulonimbus clouds are formed. Cyclones migrating along a stationary front can dump heavy amounts of precipitation, resulting in significant flooding along the front.





The Stationary Fronts

Importance of Fronts

- Initiation of severe weather conditions and events.
- Temperature and humidity forecasts.
- Cloud and precipitation forecasts.
- Precipitation type forecasts.
- Visibility and sky cover/cloud ceiling.
- Wind speed and direction (particularly important for aviation).
- Upper fronts are linked to clear-air turbulence, which is a major hazard to aircraft.
- Upper fronts and associated tropopause folds are important to stratosphere.
- Troposphere exchange (e.g., ozone depletion and transport issues).

Fronts Around The Globe

The Atlantic Polar Front is formed when maritime tropical air masses meet continental polar air masses. Full development of this front takes place during winter. The Atlantic Arctic Front is formed when the maritime polar air masses meet the air masses developed along the boundary of Arctic source-region. The Mediterranean Front is formed when the cold polar air masses of Europe meet the winter air masses of Africa. Pacific Arctic Fronts are formed along the Rockies-Great Lakes region. These fronts change with seasons.

Cyclones

Cyclones are centres of low pressure surrounded by the closed isobars having increasing pressure outward and closed air circulation from outside towards the central low pressure in such a way that air blows inwards in anticlockwise direction in the northern hemisphere and clockwise in the southern hemisphere. Cyclones are termed as atmospheric disturbances.

Atmospheric and Oceanic Conditions Necessary for a Cyclonic Storm

(i) A warm sea temperature in excess of 26 degrees centigrade to a depth of 60 m, which provides abundant water vapour in the air by evaporation.

(ii) High relative humidity of the atmosphere to a height of above 7,000 m facilitates condensation of water vapour into water droplets and clouds, releases heat energy thereby inducing a drop in pressure.

(iii) Atmospheric instability encourages formation of massive vertical cumulus cloud convection with condensation of rising air over ocean.

(iv) A location of at least 4-5 latitude degrees from the equator allows the influence of the forces due to the earth's rotation to take effect in reducing cyclonic wind circulation around low-pressure centres.

Tropical Cyclones

- Tropical cyclones are compact, circular storms, generally some 320 diameter, whose winds swirl around a central region of low atmospheric pressure. The winds are driven by this low-pressure core and by the rotation of the Earth, which deflects the path of the wind through a phenomenon known as the Coriolis force.
- As a result, tropical cyclones rotate in a counterclockwise (or cyclonic) direction in the Northern Hemisphere and in a clockwise (or anticyclonic) direction in the Southern Hemisphere.
- The wind field of a tropical cyclone may be divided into three regions.

(a) First is a ring-shaped outer region, typically having an outer radius of about 160 km (100 miles) and an inner radius of about 30 to 50 km (20 to 30 miles). In this region the winds increase uniformly in speed toward the center.

(b) Wind speeds attain their maximum value at the second region, the eyewall, which is typically 15 to 30 km (10 to 20 miles) from the center of the storm.

The eyewall in turn surrounds the interior region, called the eye, where wind speeds decreases rapidly and the air is often calm. These main structural regions are described in greater detail below.

Structure of Cyclone

(a) The Eye

- A characteristic feature of tropical cyclones is the eye, a central region of clear skies, warm temperatures, and low atmospheric pressure. Typically, atmospheric pressure at the surface of Earth is about 1,000 milibar.
- At the center of a tropical cyclone, however, it is typically around 960 milibar, and in a very intense "super typhoon" of the western Pacific it may be as low as 880 milibar. In addition to low pressure at the center, there is also a rapid variation of pressure across the storm, with most of the variation occurring near the center. This rapid variation results in a large pressure gradient force, which is responsible for the strong winds present in the eyewall.
- Horizontal winds within the eye, on the other hand, are light. In addition, there is a weak sinking motion, or subsidence, as air is pulled into the eyewall at the surface. As the air subsides, it compresses slightly and warms, so that temperatures at the center of a tropical cyclone are some 5.5 °C higher than in other regions of the storm. Because warmer air can hold more moisture before condensation occurs, the eye of the cyclone is generally free of clouds. Reports of the air inside the eye being "oppressive" or "sultry" are most likely a psychological response to the rapid change from high winds and rain in the eyewall to calm conditions in the eye.

b) The Eyewall

- The most dangerous and destructive part of a tropical cyclone is the eyewall. Here winds are strongest, rainfall is heaviest, and deep convective clouds rise from close to Earth's surface to a height of 15,000 m.
- As noted above, the high winds are driven by rapid changes in atmospheric pressure near the eye, which creates a large pressure gradient force. Winds actually reach their greatest speed at an altitude of about 300 m above the surface. Closer to the surface they are slowed by friction, and higher than 300 m they are weakened by a slackening of the horizontal pressure gradient force. This slackening is related to the temperature structure of the storm. Air is warmer in the core of a tropical cyclone, and this higher temperature causes atmospheric pressure in the center to decrease at a slower rate with height than occurs in the surrounding atmosphere. The lessened contrast in atmospheric pressure with altitude causes the horizontal pressure gradient to weaken with height, which in turn results in a decrease in wind speed.
- Friction at the surface, in addition to lowering wind speeds, causes the wind to turn inward toward the area of lowest pressure. Air flowing into the low-pressure eye cools by expansion and in turn extracts heat and water vapor from the sea surface. Areas of maximum heating have the strongest updrafts, and the eyewall exhibits the greatest vertical wind speeds in the storm—up to 5 to 10 m per second, or 18 to 36 km per hour. While such velocities are much less than those of the horizontal winds, updrafts are vital to the existence of the towering convective clouds embedded in the eyewall. Much of the heavy rainfall associated with tropical cyclones comes from these clouds.

C) Rain bands of Tropical Cyclones

- Along with the deep convective cells (compact regions of vertical air movement) surrounding the eye, there are often secondary cells arranged in bands around the centre. These bands, commonly called rain bands, spiral into the center of the storm. In some cases the rain bands are stationary relative to the center of the moving storm, and in other cases they seem to rotate around the center. The rotating cloud bands often are associated with an apparent wobbling of the storm track.
- If this happens as the tropical cyclone approaches a coastline, there may be large differences between the forecast landfall positions and the actual landfall. As a tropical cyclone makes landfall, surface friction increases, which in turn increases the convergence of airflow into the eyewall and the vertical motion of air occurring there.
- The increased convergence and rising of moisture-laden air is responsible for the torrential rains associated with tropical cyclones, which may be in excess of 250 mm (10 inches) in a 24-hour period. At times a storm may stall, allowing heavy rains to persist over an area for several days. In extreme cases, rainfall totals of 760 mm (30 inches) in a five-day period have been reported.

Dissipation of Tropical Cyclones

- Tropical cyclones dissipate when they can no longer extract sufficient energy from warm ocean water. As discussed above, a tropical cyclone can contribute to its own demise by stirring up deeper, cooler ocean waters. Also, a storm that moves over land will abruptly lose its fuel source and quickly lose intensity.

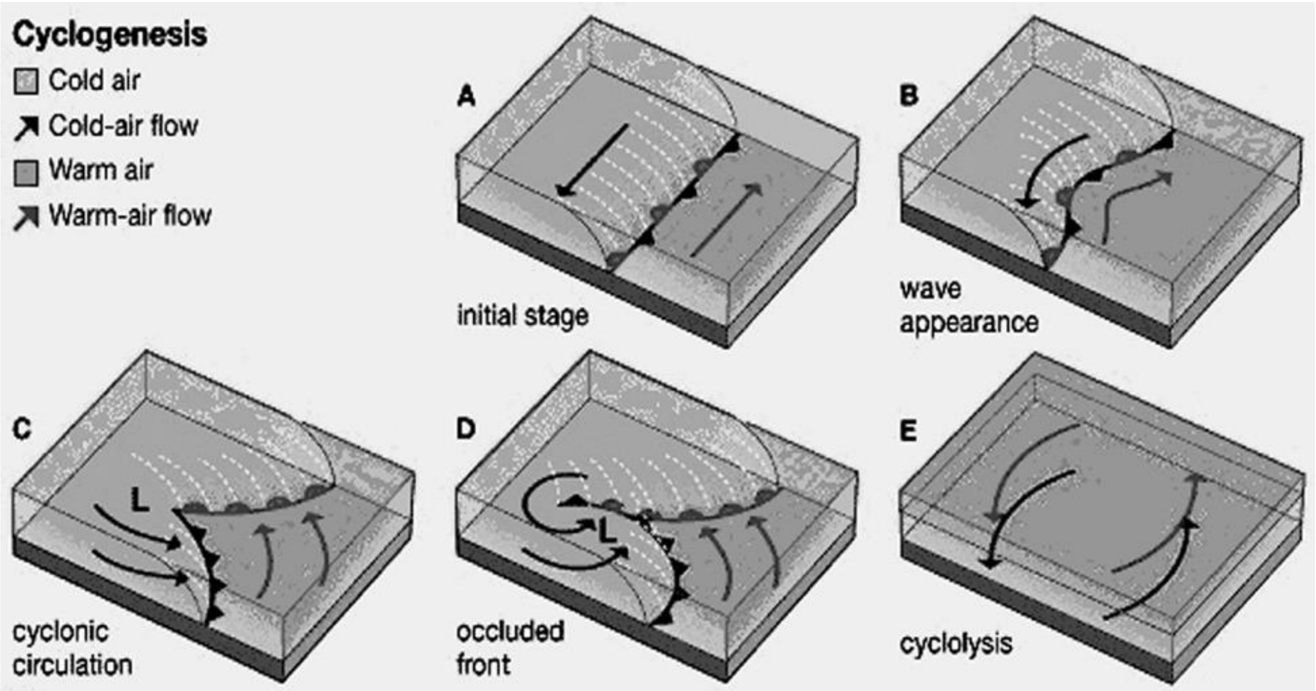
- A tropical cyclone that remains over the ocean and moves into higher latitudes will change its structure and become extra tropical as it encounters the cooler water. The transformation from a tropical to an *extra tropical* cyclone is marked by an increase in the storm's diameter and by a change in shape from circular to *comma-* or *v-shaped* as its rain bands reorganize. An extra tropical cyclone typically has a higher central pressure and consequently has lower wind speeds. Extra tropical cyclones, which are fueled by a north-to-south variation of temperature, weaken and dissipate in a few days.

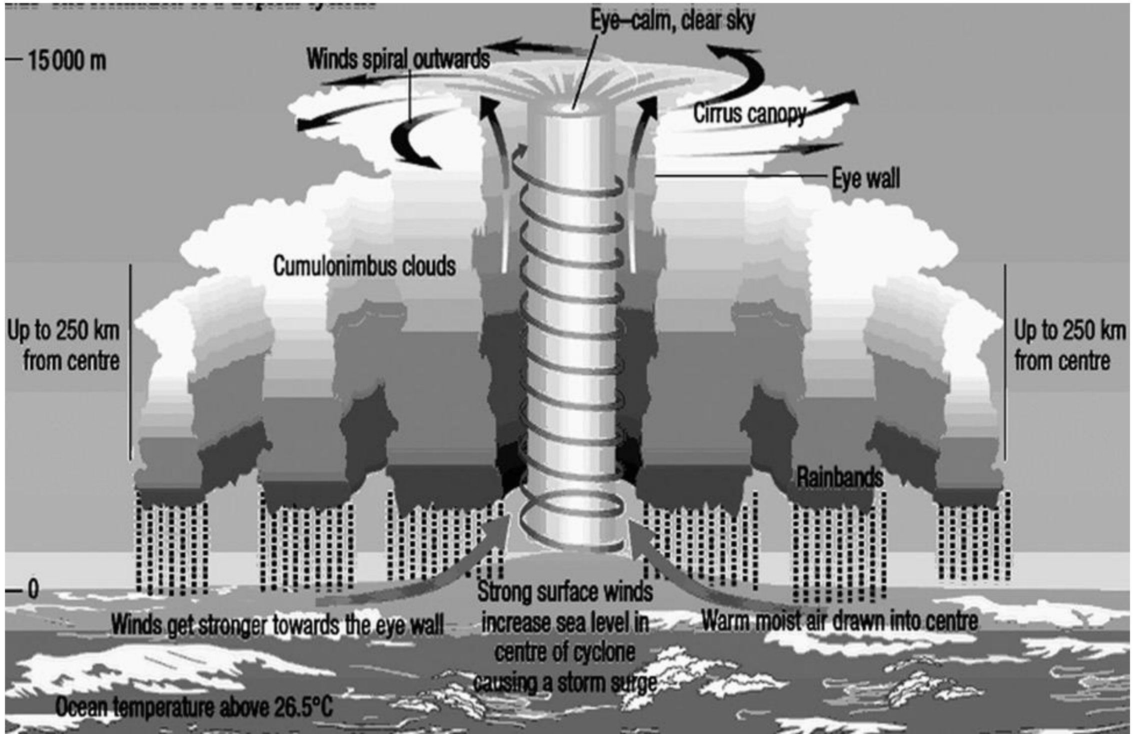
Cyclogenesis

Cyclogenesis is the process of extra tropical cyclone development and intensification. Cyclogenesis is initiated by a disturbance occurring along a stationary or very slow-moving front between cold and warm air. This disturbance distorts the front into the wavelike configuration. As the atmospheric pressure within the disturbance continues to decrease, it assumes the appearance of a cyclone and forces poleward and equatorward movements of warm and cold air, respectively. (Ref. Fig 1. 48)

As the cyclone continues to intensify, the cold dense air streams rapidly equatorward, yielding a cold front with a propagation speed that is often 8 to 15 metres per second or more. At the same time, warm less-dense air moving in a northerly direction blows up over the cold air east of the cyclone to produce a warm front with a typically much slower propagation speed of about 2.5 to 8 metres per second. This difference in propagation speeds between the two fronts allows the cold front to overtake the warm front and produce yet another, more-complicated frontal structure, known as an occluded front. This occlusion process may be followed by further storm intensification; however, the separation of the cyclone from the warm air towards the equator eventually leads to the storm's decay and dissipation in a process called cyclolysis.

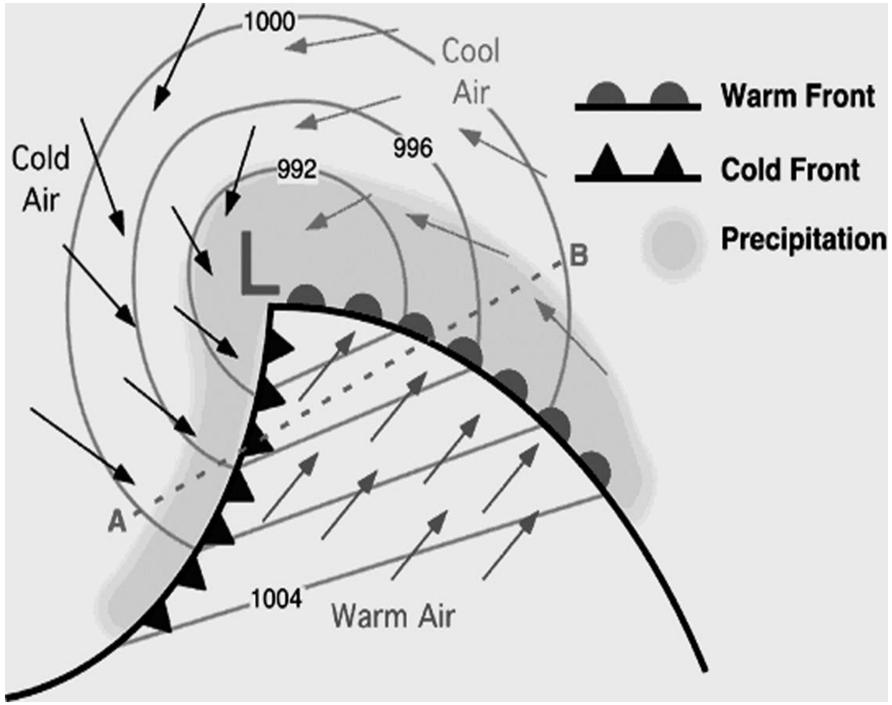
The Cyclogenesis





Temperate Cyclones

- Mid-latitude or frontal cyclones are large traveling atmospheric cyclonic storms up to 2000 kilometres in diameter with centres of low atmospheric pressure. An intense mid- latitude cyclone may have a surface pressure as low as 970 milibar, compared to an average sea-level pressure of 1013 milibar.
- Normally, individual frontal cyclones exist for about 3 to 10 days moving in a generally west to east direction. Frontal cyclones are the dominant weather events of the Earth's mid- latitudes forming along the polar front. Mid- latitude cyclones are the result of the dynamic interaction of warm tropical and cold polar air masses at the polar front. This interaction causes the warm air to be cyclonically lifted vertically into the atmosphere where it combines with colder upper atmosphere air. This process also helps to transport excess energy from the lower latitudes to the higher latitudes.
- The mid-latitude cyclone is rarely motionless and commonly travels about 1200 kilometres in one day. *Its direction of movement is generally eastward*. Precise movement of this weather system is controlled by the orientation of *the polar jet stream in the upper troposphere*. An estimate of future movement of the mid-latitude cyclone can be determined by the winds directly behind the cold front. If the winds are blowing 70 kilometres per hour, the cyclone can be projected to continue its movement along the ground surface at thisvelocity.
- Within the jet stream, localized areas of air outflow can occur because of upper air divergence. Outflow results in the development of an upper air vacuum. To compensate for the vacuum in the upper atmosphere, surface air flows cyclonically upwards into the outflow to replenish lost mass. The process stops and the mid-latitude cyclone dissipates when the upper air vacuum is filled with surface air.



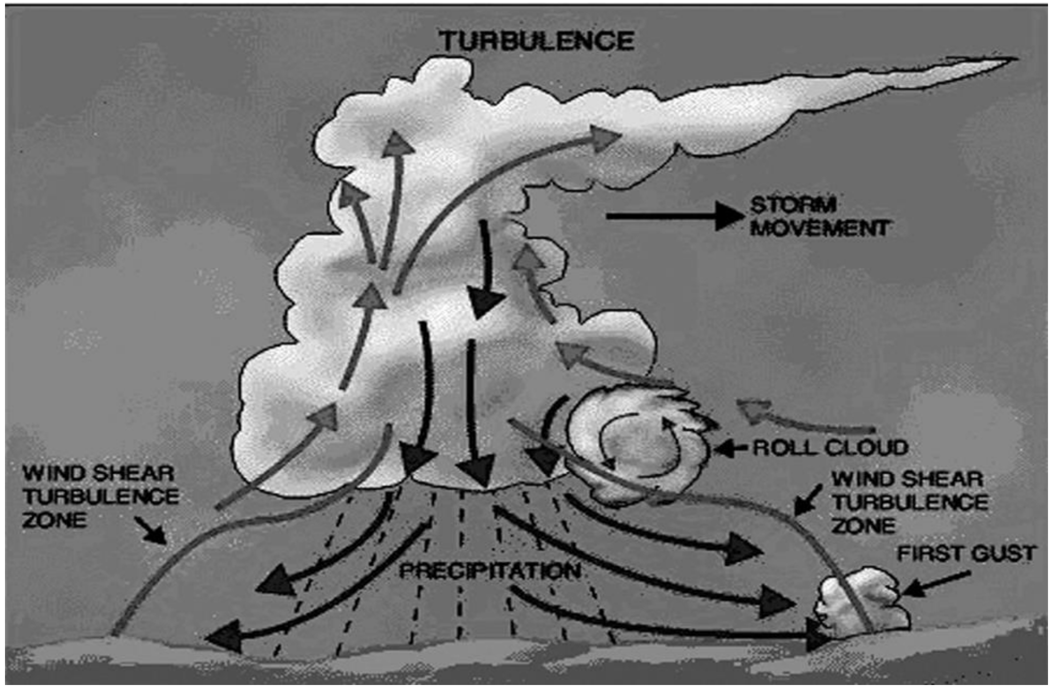
The Temperate Cyclone

Thunderstorms

They are local storms with cumulonimbus clouds with very strong updraft of wind. Similar conditions also leads to cloud bursts. Atmospheric condition which leads to formation of thunderstorms are atmosphere instability, updraft of unstable wind, abundant supply of moisture and thick cloud presence.

Surface happens, making thunderstorms to heating through intense solar insolation hence mostly originate in summer months. Lightning due to electric discharge happens when electric potential difference between two opposite charges become the maximum.

Thundering voice happens due to sudden expansion of air column, caused by intense heat resulting from the lightning strike



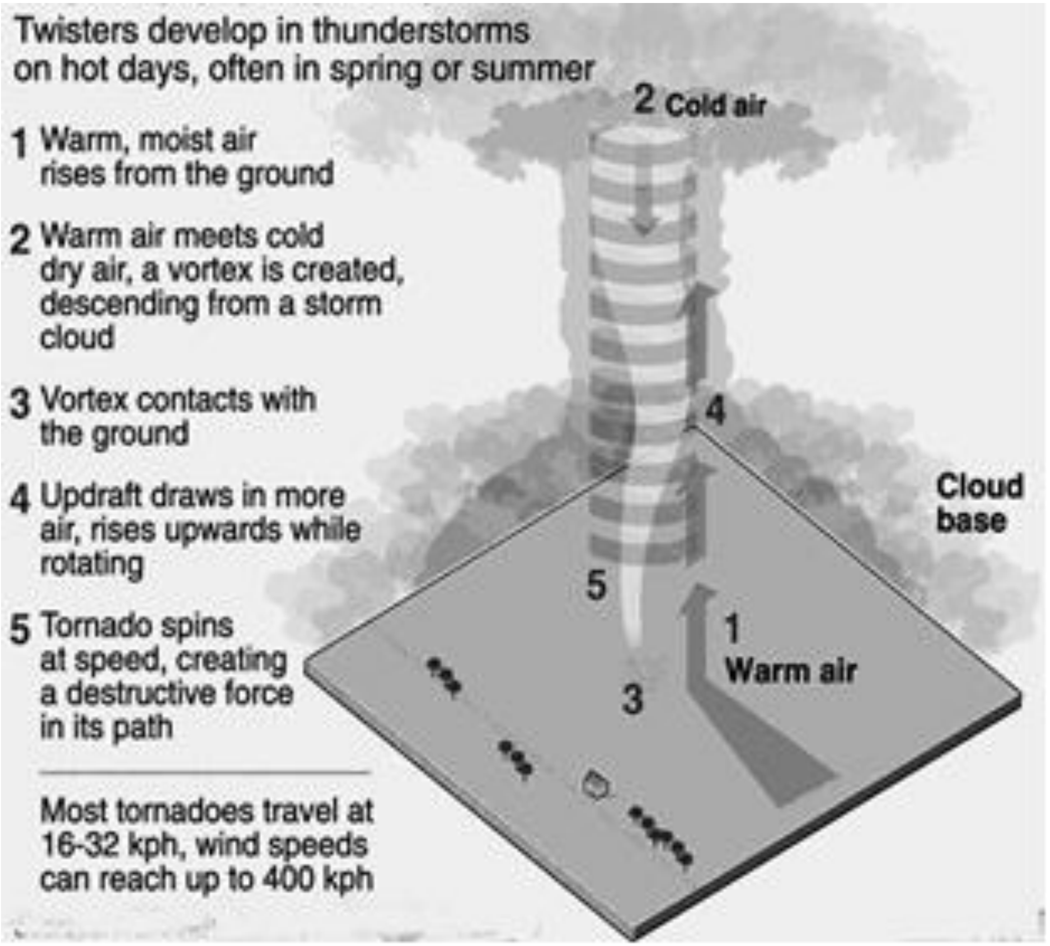
The Cross-section of a Thunderstorm

Typhoon

A typhoon differs from a cyclone or hurricane only on the basis of location. A hurricane is a storm that occurs in the Atlantic Ocean and northeastern Pacific Ocean, a typhoon occurs in the northwestern Pacific Ocean, and a cyclone occurs in the south Pacific or Indian Ocean. There are six main requirements for tropical Cyclogenesis: sufficiently warm sea surface temperatures, atmospheric instability, high humidity in the lower to middle levels of the troposphere, enough Coriolis force to develop a low pressure centre, a pre-existing low level focus or disturbance, and low vertical wind shear.

Tornado

- A tornado is “a violently rotating column of air, in contact with the ground, either pendant from a cumulonimbus cloud or underneath cumulonimbus cloud, and often (but not always) visible as a funnel cloud”.
- For a vortex to be classified as a tornado, it must be in contact with both the ground and the cloud base. They are often referred to as twisters, whirlwinds.
- It has a low-pressure area at the centre around which winds blow counterclockwise in the Northern Hemisphere and clockwise in the Southern hemisphere
- Most tornadoes have wind speeds less than 180 km/h, are about 80 m across, and travel several kilometres before dissipating. The most extreme tornadoes can attain wind speeds of more than 480 km/h are more than 3 km in diameter, and stay on the ground for more than 100 km



Tornado Formation