Temperate Cyclones (Mid Latitude Cyclone or Extra tropical cyclones or Frontal Cyclones)

Tropical Cyclones

- Tropical cyclones are violent storms that originate over oceans in **tropical areas** and move over to the coastal areas bringing about large scale destruction due to violent winds (squalls), very heavy rainfall (torrential rainfall) and **storm surge**.
- They are irregular wind movements involving **closed circulation** of air around a low pressure center. This closed air circulation (whirling motion) is a result of **rapid upward movement of hot air** which is subjected to Coriolis force. The low pressure at the center is responsible for the wind speeds.

Squall == a sudden violent gust of wind or localized storm, especially one bringing rain, snow, or sleet.

Torrent == a strong and fast-moving stream of water or other liquid.

- The cyclonic wind movements are **anti-clockwise in the northern hemisphere** and **clockwise in the southern hemisphere** (This is due to Coriolis force).
- The cyclones are often characterized by existence of an anticyclone between two cyclones.

Conditions Favourable for Tropical Cyclone Formation

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

Good Source of Latent Heat

- Ocean waters having temperatures of 27° C or more is the source of moisture which feeds the storm. The condensation of moisture releases enough latent heat of condensation to drive the storm.

Why tropical cyclones form mostly on the western margins of the oceans? OR

Why tropical cyclones don't form in the eastern tropical oceans?

- The depth of warm water **(26-27°C)** should extend for **60-70 m** from surface of the ocean/sea, so that deep convection currents within the water do not churn and mix the cooler water below with the warmer water near the surface.
- The above condition occurs only in western tropical oceans because of warm ocean currents (easterly trade winds pushes ocean waters towards west) that flow from east towards west forming a thick layer of water with temperatures greater than 27°C. This supplies enough moisture to the storm.
- The **cold currents** lower the surface temperatures of the eastern parts of the tropical oceans making them unfit for the breeding of cyclonic storms.

[One Exception: During strong El Nino years, strong hurricanes occur in the eastern Pacific. This is due to the accumulation of warm waters in the eastern Pacific due to **weak** Walker Cell]

Why cyclones occur mostly in late summers?

- Whirling motion is enhanced when the doldrums (region within ITCZ) over oceans are farthest from the equator. This happens during the autumnal equinox (August-September). At this time, there are two advantages—the air is overheated and the sun is exactly over the equator.

[Due to high specific heat of water, and mixing, the ocean waters in northern hemisphere attain maximum temperatures in August. (Continents attain maximum temperatures in June-July)]

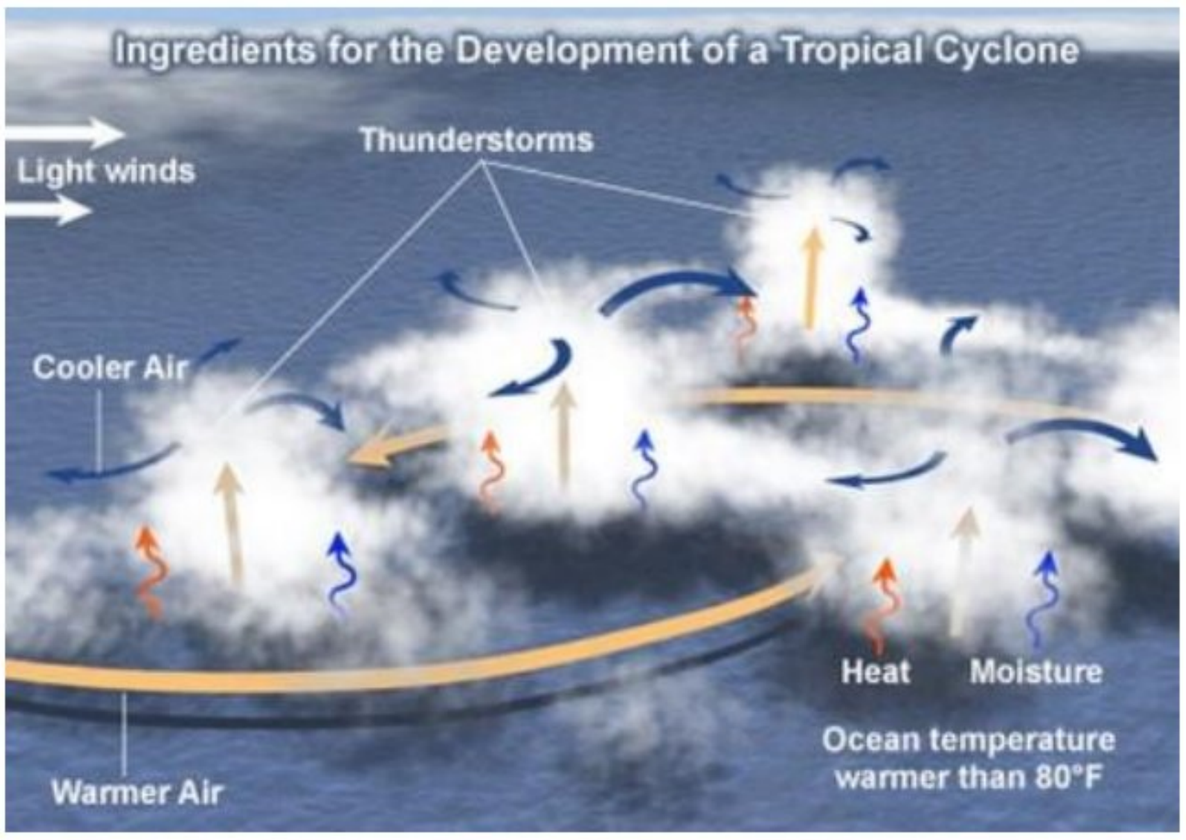
Coriolis Force (f)

- The Coriolis force **is zero at the equator (no cyclones at equator because of zero Coriolis Force)** but it increases with latitude. Coriolis force at **5**° latitude is significant enough to create a storm [cyclonic vortex].

- **About 65 per cent of cyclonic activity occurs between 10° and 20° latitude**.

Low-level Disturbances

- Low-level disturbance (thunderstorms – they are the seeds of cyclones) in the form of easterly wave disturbances in the Inter-Tropical Convergence Zone (ITCZ) should pre-exist.



- **Small local differences** in the temperature of water and of air produce various **low pressure centers** of small size. A weak cyclonic circulation develops around these areas.
- Then, because of the rising warm humid air, a true cyclonic vortex may develop very rapidly. However, only a few of these disturbances develop into cyclones.

[rising of humid air => adiabatic lapse rate => fall in temperature of air => condensation of moisture in air => latent heat of condensation released => air gets more hot and lighter => air is further uplifted => more air comes in to fill the gap => new moisture available for condensation => latent heat of condensation and the cycle repeats]

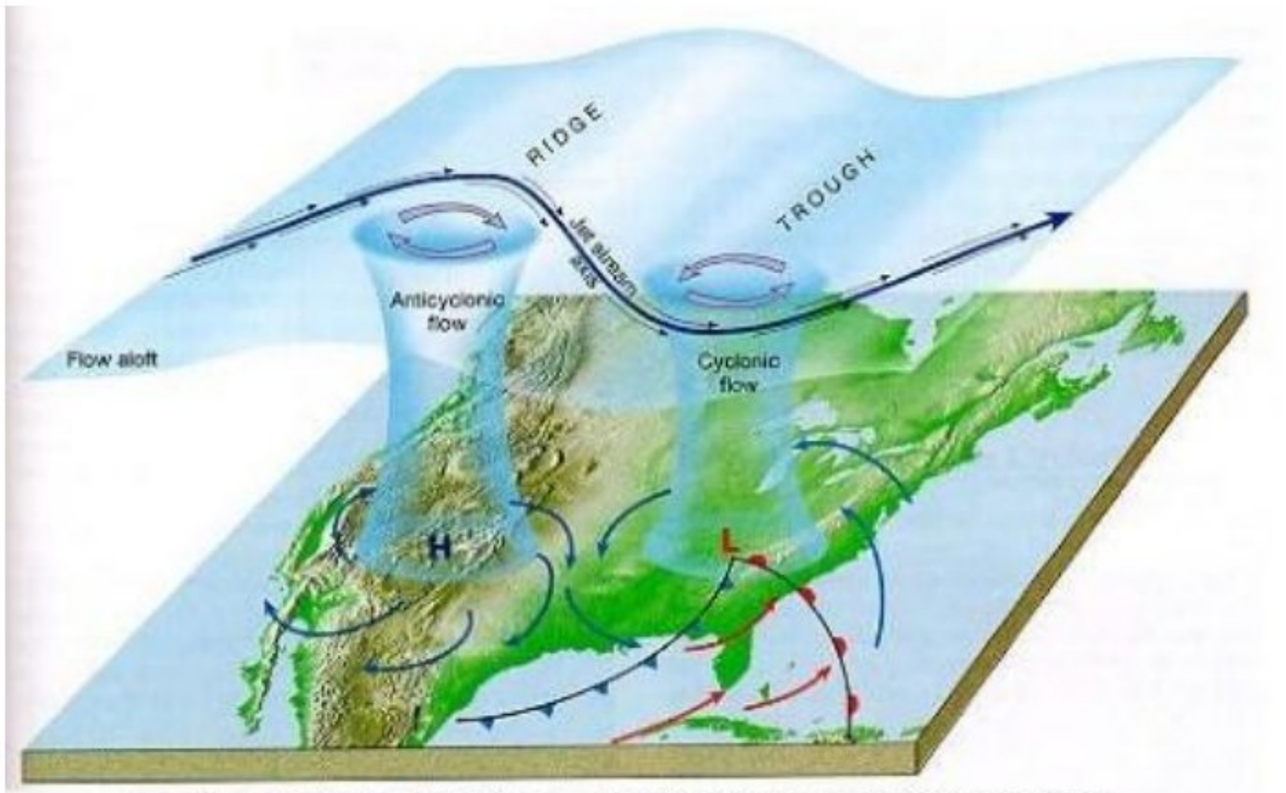
Temperature contrast between air masses

- Trade winds from both the hemispheres meet along inter-tropical front. Temperature contrasts between these air masses must exist when the ITCZ is farthest, from the equator.

- Thus, the convergence of these air masses of different temperatures and the resulting instability are the prerequisites for the origin and growth of violent tropical storms.

Upper Air Disturbance

- The remains of an upper tropospheric cyclone from the Westerlies move deep into the tropical latitude regions. As divergence prevails on the eastern side of the troughs, a rising motion occurs; this leads to the development of thunderstorms.
- Further, these old abandoned troughs (remnants of temperate cyclones) usually have cold cores, suggesting that the environmental lapse rate is steeper and unstable below these troughs. Such instability encourages thunderstorms (child cyclones).



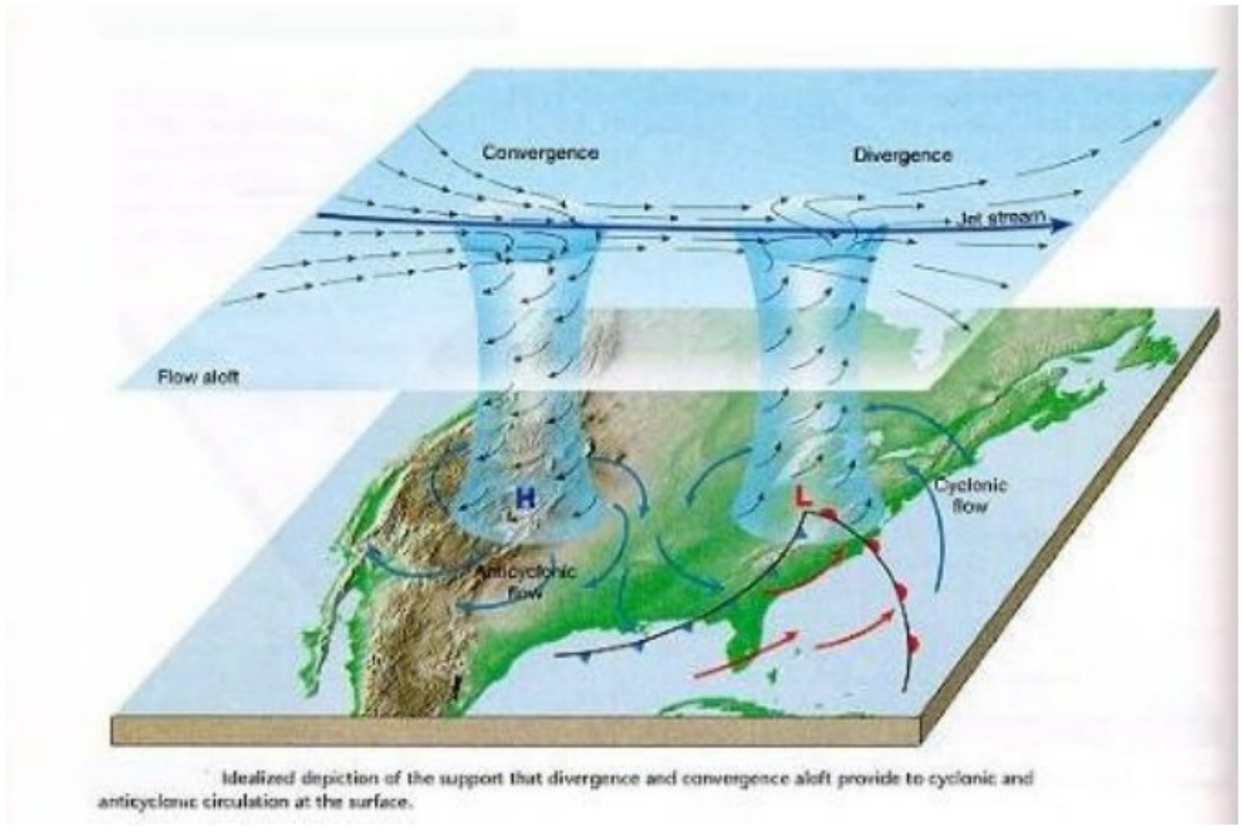
Vorticity provided by flow in the jet stream generates cyclonic flow near a trough and anticyclonic flow adjacent to a ridge.

Wind Shear

- Wind Shear == differences between wind speeds at different heights.
- Tropical cyclones develop when the wind is uniform.
- **Because of weak vertical wind shear, cyclone formation processes are limited to latitude equator ward of the** subtropical jet stream. [Jet streams]
- In the temperate regions, wind shear is high due to westerlies and this inhibits convective cyclone formation.

Upper Tropospheric Divergence

- A well – developed divergence in the upper layers of the atmosphere is necessary so that the rising air currents within the cyclone continue to be pumped out and a low pressure maintained at the center.



Idealized depiction of the support that divergence and convergence aloft provide to cyclonic and anticyclonic circulation at the surface.

Humidity Factor

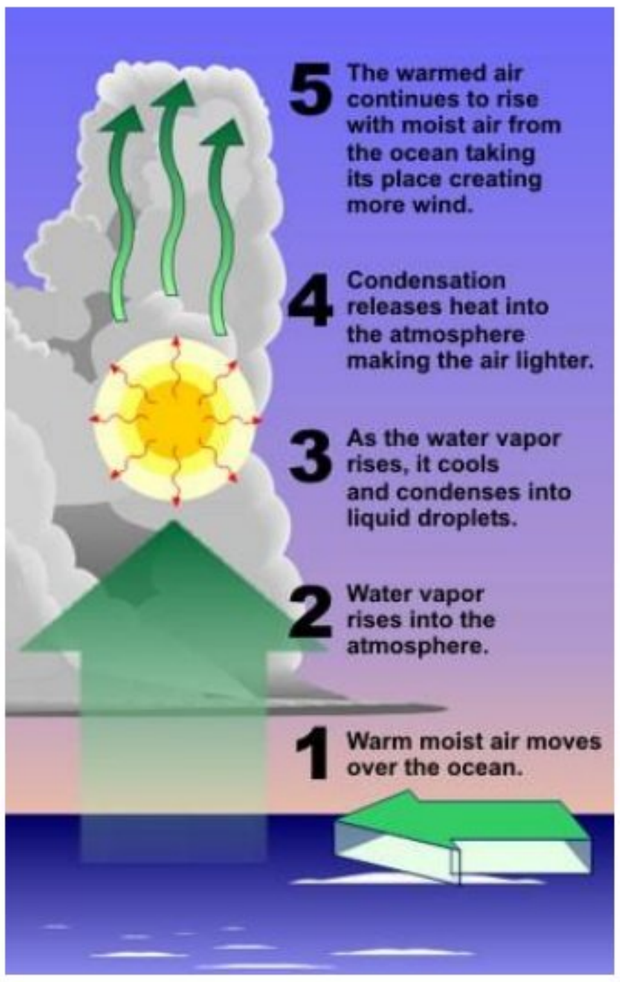
- High humidity (around 50 to 60 per cent) is required in the mid-troposphere, since the presence of moist air leads to the formation of cumulonimbus cloud.
- Such conditions exist over the equatorial **doldrums**, especially in western margins of oceans (this is because of east to west movement of ocean currents), which have great moisture, carrying capacity because the **trade winds** continuously replace the saturated air.

Origin and Development of Tropical Cyclones

- The tropical cyclones have a **thermal origin**, and they develop over tropical seas during late summers (August to mid-November).
- At these locations, the strong local convectional currents acquire a whirling motion because of the Coriolis force.
- After developing, these cyclones advance till they find a weak spot in the trade wind belt.

Origin

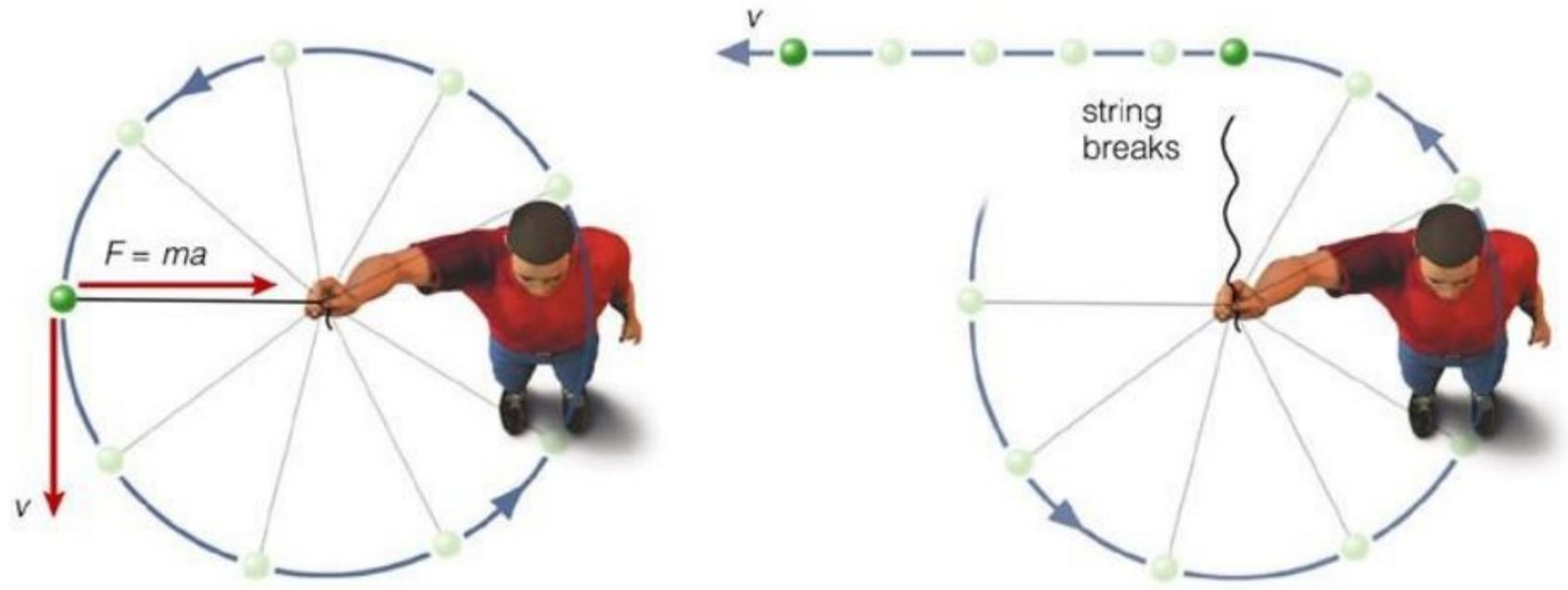
- Under favorable conditions, multiple thunderstorms originate over the oceans. These thunderstorms merge and create an intense low pressure system (wind is warm and lighter).

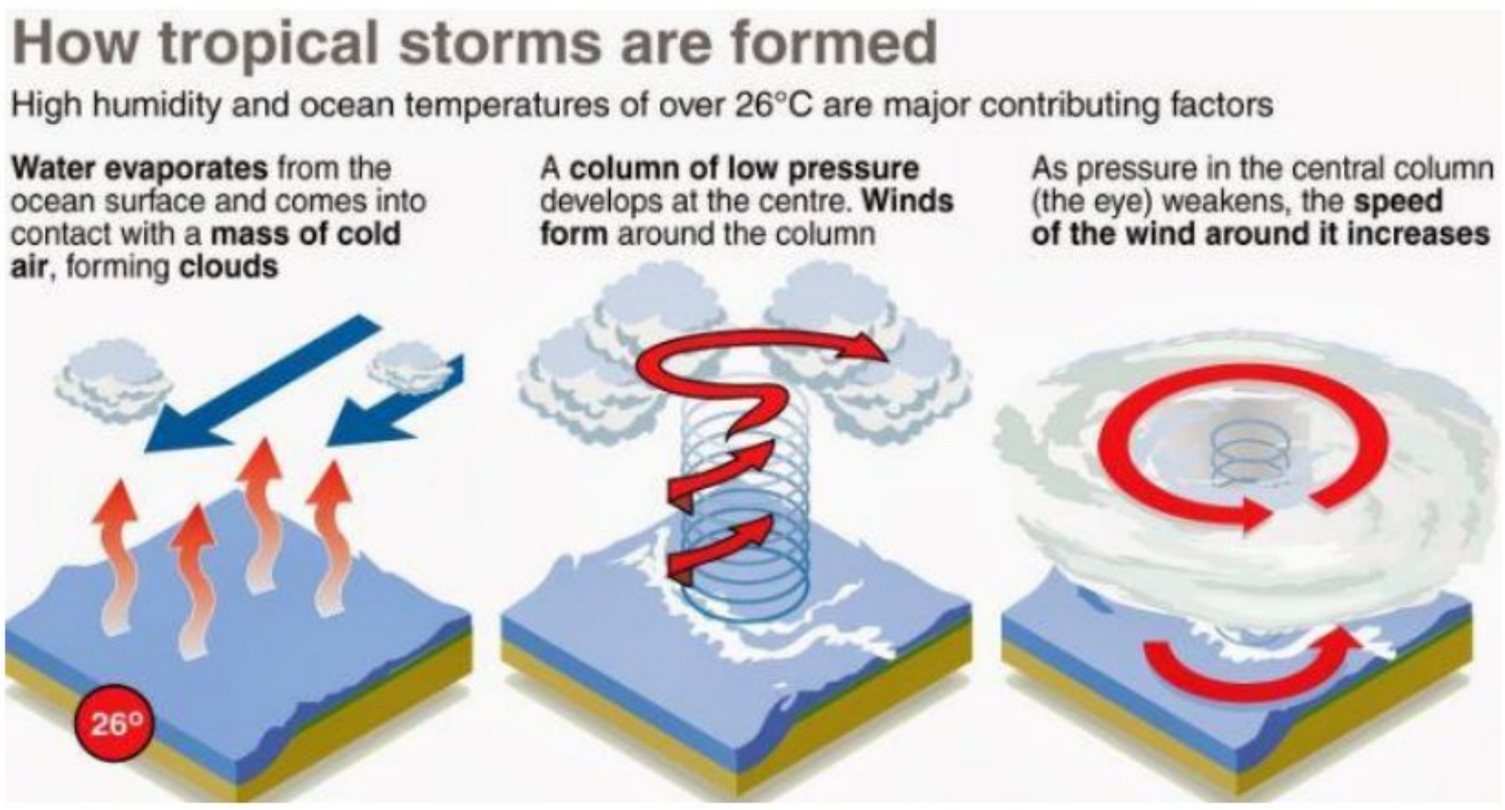


Early stage

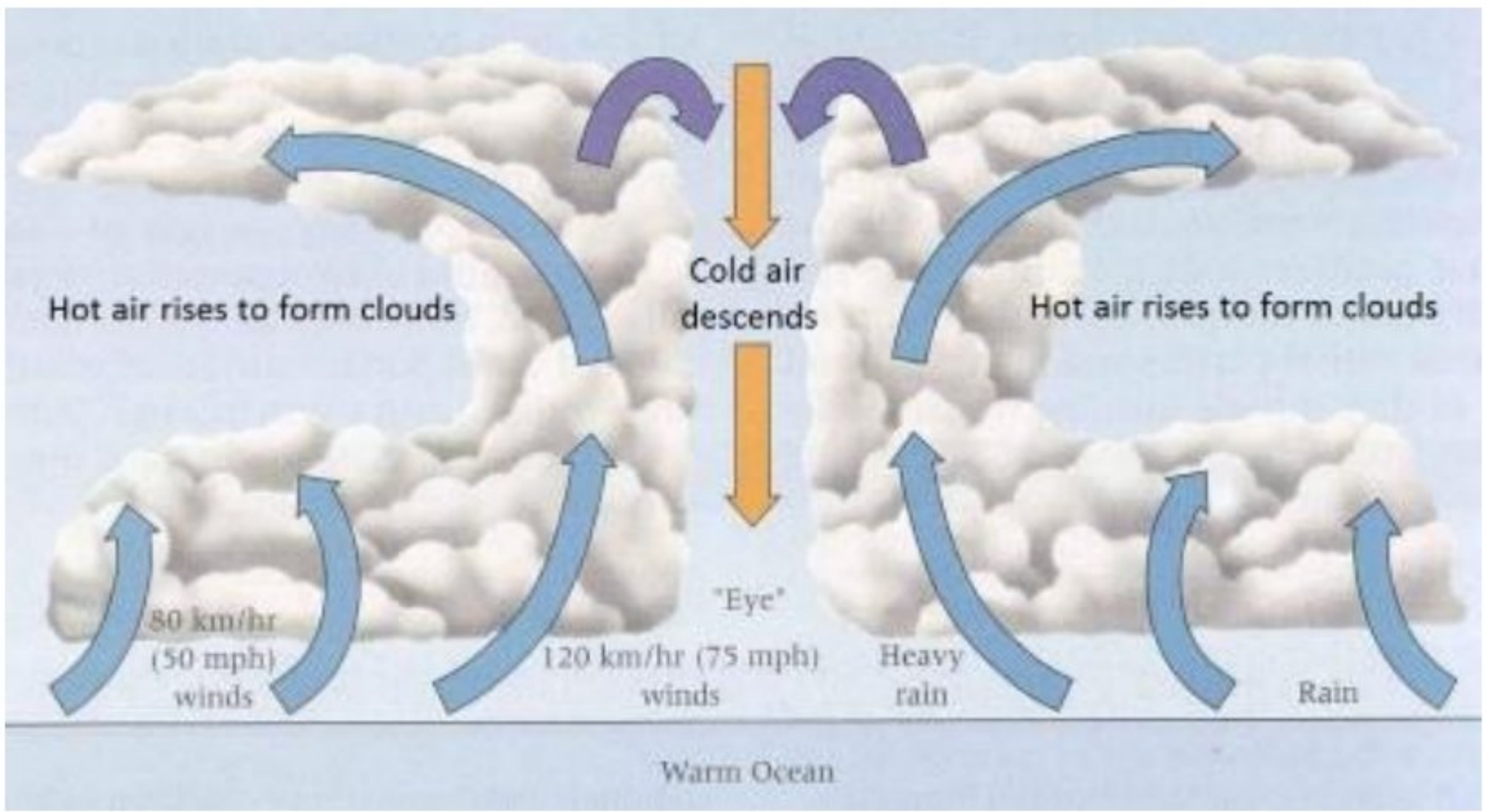
- In the thunderstorm, air is uplifted as it is **warm and light**. At certain height, due to lapse rate and adiabatic lapse rate, the temperature of air falls and moisture in the air undergoes **condensation**.
- Condensation releases latent heat of condensation making the air more warmer. It becomes much lighter and is further uplifted.
- The space is filled by fresh moisture laden air. Condensation occurs in this air and the cycle is repeated as long as the moisture is supplied.
- Due to excess moisture over oceans, the thunderstorm intensifies and sucks in air at much faster rate. The air from surroundings rushes in and undergoes deflection due to **Coriolis force** creating a **cyclonic vortex (spiraling air column. Similar to** tornado**).**

- Due to centripetal acceleration (centripetal force pulling towards the center is countered by an opposing force called centrifugal force), the air in the vortex is forced to form a region of calmness called an **eye** at the center of the cyclone. The inner surface of the vortex forms the **eye wall**, the **most violent region** of the cyclone.





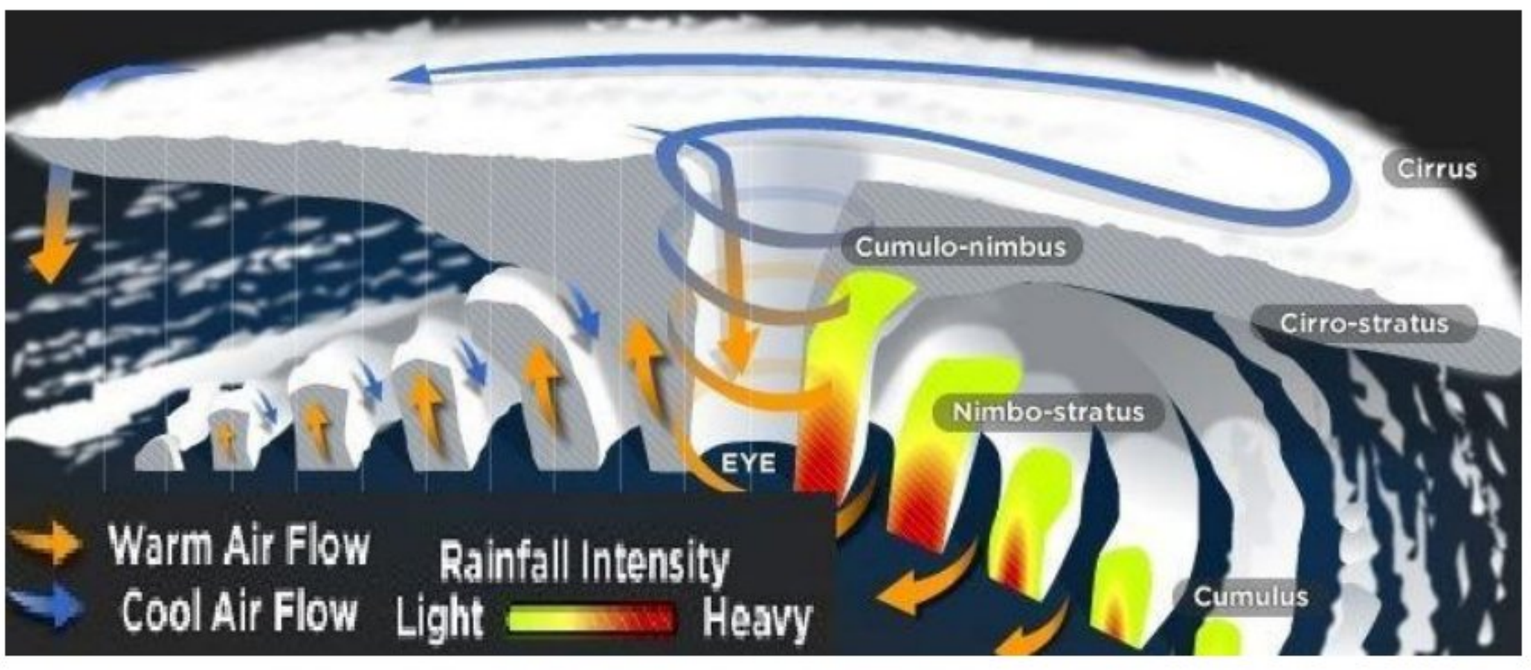
[Eye is created due to tangential force acting on wind that is following a curvy path]



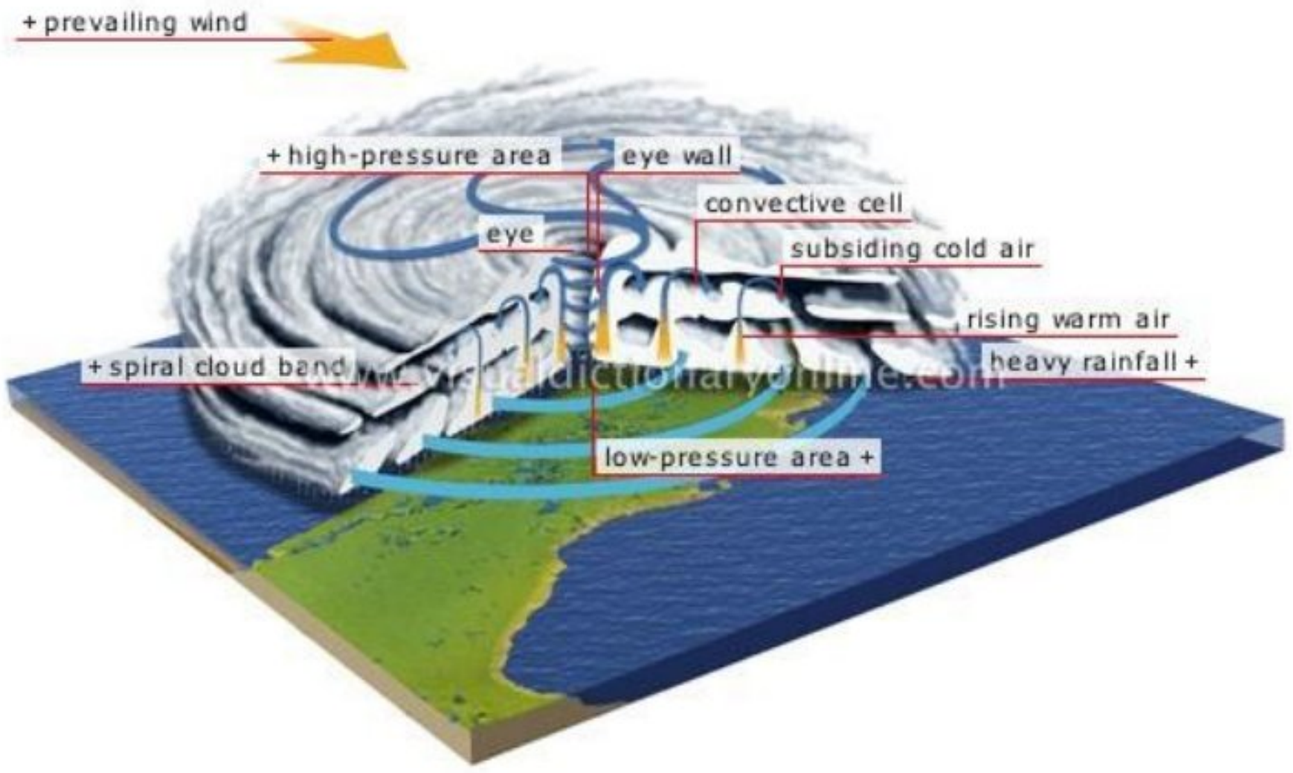
- All the wind that is carried upwards loses its moisture and becomes cold and dense. It descends to the surface through the cylindrical eye region and at the edges of the cyclone.
- Continuous supply of **moisture** from the sea is the major driving force behind every cyclone. On reaching the land the **moisture supply is cut off** and the storm dissipates.
- If ocean can supply more moisture, the storm will reach a mature stage.

Mature stage

- At this stage, the spiraling winds create multiple convective cells with successive calm and violent regions.
- The regions with cumulonimbus cloud (rising limbs of convective cell) formation are called **rain bands** below which intense rainfall occurs.
- The ascending air will lose moisture at some point and descends (subsides) back to surface through the calm regions (descending limbs of convection cell – subsiding air) that exist between two rain bands.
- Cloud formation is dense at the center. The cloud size decreases from center to periphery.
- Rain bands are mostly made up of cumulonimbus clouds. The ones at the periphery are made up of nimbostratus and cumulus clouds.
- The dense overcast at the upper levels of troposphere is due to cirrus clouds which are mostly made up of hexagonal ice crystals.
- The dry air flowing along the central dense overcast descends at the periphery and the eye region.



Structure of a tropical cyclone



Eye

- The "eye" is a roughly circular area of comparatively **light winds and fair weather** found at the center of a severe tropical cyclone.
- There is little or **no precipitation** and sometimes blue sky or stars can be seen.
- The eye is the region of **lowest surface pressure** and warmest temperatures aloft (in the upper levels) – the eye temperature may be 10°C warmer or more at an altitude of 12 km than the surrounding environment, but only 0-2°C warmer at the surface in the tropical cyclone.
- Eyes range in size from 8 km to over 200 km across, but most are approximately 30-60 km in diameter.

Eye wall

- The eye is surrounded by the "eye wall", the roughly circular ring of **deep convection**, which is the area of **highest surface winds** in the tropical cyclone. Eye Wall region also sees the maximum sustained winds i.e. **fastest winds in a cyclone occur along the eye wall region.**

- The eye is composed of air that is slowly sinking and the eye wall has a net upward flow as a result of many moderate – occasionally strong – **updrafts and downdrafts [Explained in 'Thunderstorms'].**
- The eye's warm temperatures are due to compressional warming (adiabatic) of the subsiding air.
- Most soundings taken within the eye show a low-level layer, which is relatively moist, with an inversion above – suggesting that the sinking in the eye **typically does not reach the ocean surface**, but instead only gets to around 1-3 km of the surface.

Spiral bands

- Another feature of tropical cyclones that probably plays a role in **forming and maintaining the eye** is the eye wall convection.
- Convection in tropical cyclones is organized into long, narrow rain bands which are oriented in the same direction as the horizontal wind.
- Because these bands **seem to spiral into the center** of a tropical cyclone, they are called "spiral bands".
- Along these bands, low-level convergence is a maximum, and therefore, upper-level divergence is most pronounced above.
- A direct circulation develops in which warm, moist air converges at the surface, ascends through these bands, **diverges aloft**, and **descends on both sides of the bands**.
- Subsidence is distributed over a wide area on the outside of the rain band but is concentrated in the small inside area.
- As the air subsides, adiabatic warming takes place, and the air dries.
- Because subsidence is concentrated on the inside of the band, the adiabatic warming is stronger inward from the band causing a sharp contrast in pressure falls across the band since warm air is lighter than cold air.
- Because of the pressure falls on the inside, the tangential winds around the tropical cyclone increase due to increased pressure gradient. Eventually, the band moves toward the center and encircles it and the **eye and eye wall form**.
- Thus, the cloud-free eye may be due to a **combination of dynamically forced centrifuging of mass out of the eye into the eye wall and to a forced descent caused by the moist convection of the eye wall.**

Vertical Structure of a Tropical Cyclone

There are three divisions in the vertical structure of tropical cyclones.

- The lowest layer, extending up to 3 km and known as the inflow layer, is responsible for **driving the storm**.
- The middle layer, extending from 3 km to 7 km, is where the **main cyclonic storm** takes place.
- The outflow layer lies above 7 km. The maximum outflow is found at 12 km and above. The movement of air is **anticyclonic** in nature.

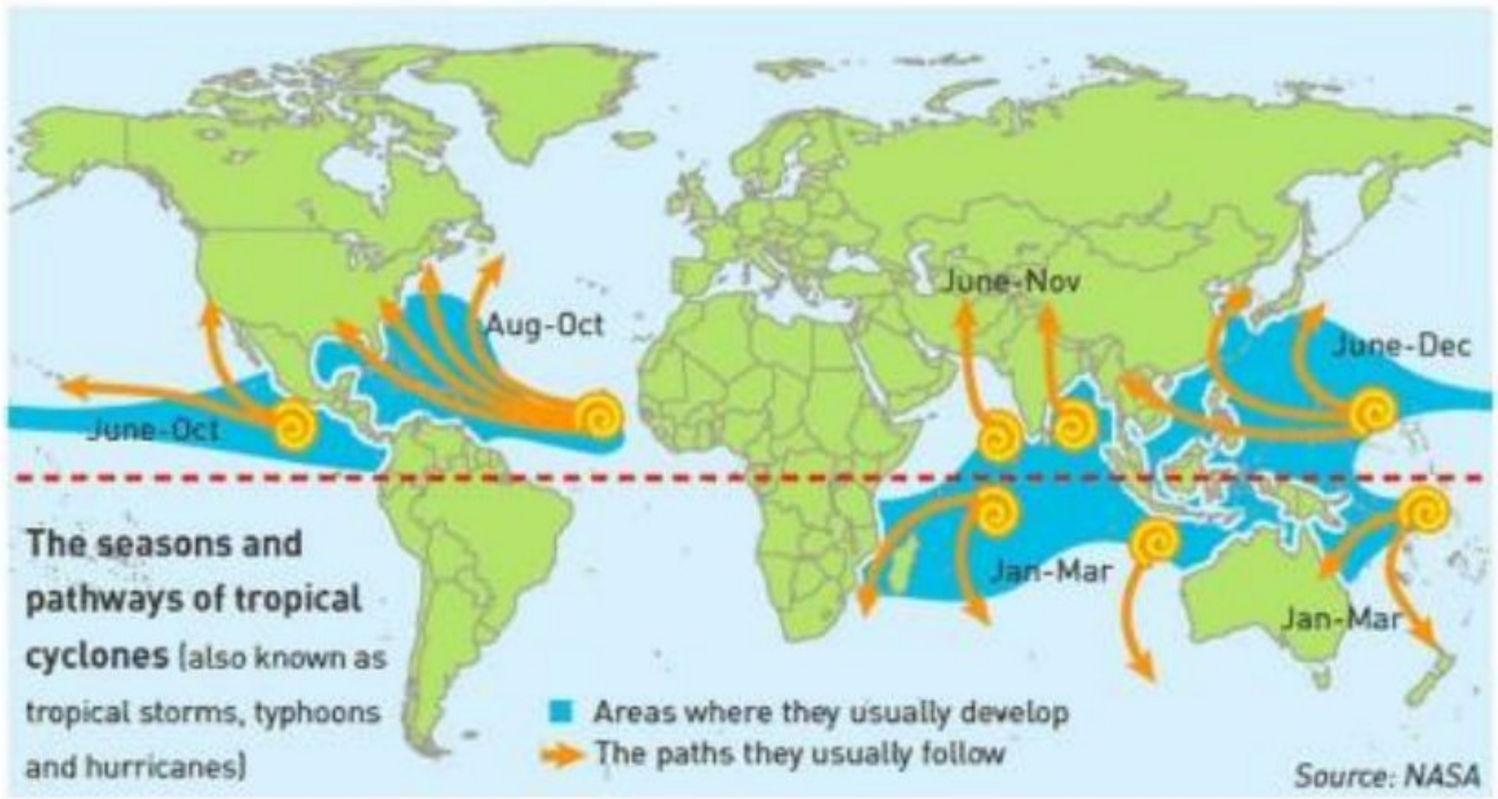
Categories of Tropical Cyclones

Cyclone Category	Wind Speed in Km/h	Damage Capacity
01	120-150	Minimal
02	150-180	Moderate
03	180-210	Extensive
04	210-250	Extreme
05	250 +	Catastrophic

Type of Disturbances	Wind Speed in Km/h
Low Pressure	Less than 31
Depression	31-49
Deep Depression	49-61
Cyclonic Storm	61-88
Severe Cyclonic Storm	88-117
Very Severe Cyclone	118-221
Super Cyclone	More than 221

Category	Australian name	US*	NW Pacific	Arabian Sea /Bay of Bengal
-	Tropical low	Tropical depression	Tropical depression	Depression or severe depression
1	Tropical cyclone	Tropical storm	Tropical storm	Cyclonic storm
2	Tropical cyclone	Tropical storm	Severe tropical storm	Severe cyclonic storm
3	Severe tropical Cyclone	Hurricane	Typhoon	Very severe cyclonic storm
4	Severe tropical cyclone	Hurricane	Typhoon	Very severe cyclonic storm
5	Severe tropical cyclone	Hurricane	Typhoon	Super cyclonic storm

Favorite Breeding Grounds for Tropical Cyclones



- South-east Caribbean region where they are called hurricanes.
- Philippines islands, eastern China and Japan where they are called typhoons.
- Bay of Bengal and Arabian Sea where they are called cyclones.
- Around south-east African coast and Madagascar-Mauritius islands.
- North-west Australia.

Regional names for Tropical Cyclones

Regions	What they are called
Indian Ocean	**Cyclones**
Atlantic	**Hurricanes**
Western Pacific and South China Sea	**Typhoons**
Western Australia	**Willy-willies**

Characteristics of Tropical Cyclones

- The main features of tropical cyclones are as follows.

Size and Shape

- Tropical cyclones have symmetrical **elliptical shapes** (2:3 ratio of length and breadth) with steep pressure gradients. They have a compact size—80 km near center, which may develop up to 300 km to 1500 km.

Wind Velocity and Strength

- Wind velocity, in a tropical cyclone, is more in poleward margins than at center and is more over oceans than over landmasses, which are scattered with physical barriers. The wind velocity may range from nil to 1200 km per hour.

Path of Tropical Cyclones

- These cyclones start with a westward movement, but turn northwards around 20° latitude. They turn further north-eastwards around 25° latitude, and then eastwards around 30° latitude. They then lose energy and subside.
- Tropical cyclones follow a **parabolic path**, their axis being parallel to the isobars.
- Coriolis force or earth's rotation, easterly and westerly winds influence the path of a tropical cyclone.
- Tropical cyclones die at 30° latitude because of cool ocean waters and increasing wind shear due to westerlies.

Path of Tropical Cyclones
a) These cyclones start with a westward movement —- This is because the earth is rotating from west to east and the zone of cyclone formation is under the influence of easterlies.
b) but turn northwards around 20° latitude — Coriolis force deflects the path towards right.
c) They turn further north-eastwards around 25° latitude — Coriolis force deflects it furthur towards the right.
d) and then eastwards around 30° latitude — Because of westerly winds.
e) They then lose energy and subside — Ocean water at 30 ° latitude is not warm enough to sustain a cyclone. Also increasing wind shear due to westerlies doesn't facilitate the formation of cyclonic vortex.

Warning of Tropical Cyclones

- Detection of any unusual phenomena in the weather leading to cyclones has three main parameters: **fall in pressure, increase in wind velocity, and the direction and movement (track) of storm.**
- There are a network of weather stations monitoring pressure fall and wind velocities in all countries of the world, including the Arctic and Antarctic regions.
- The islands attain special significance in this as they facilitate monitoring of these developments.

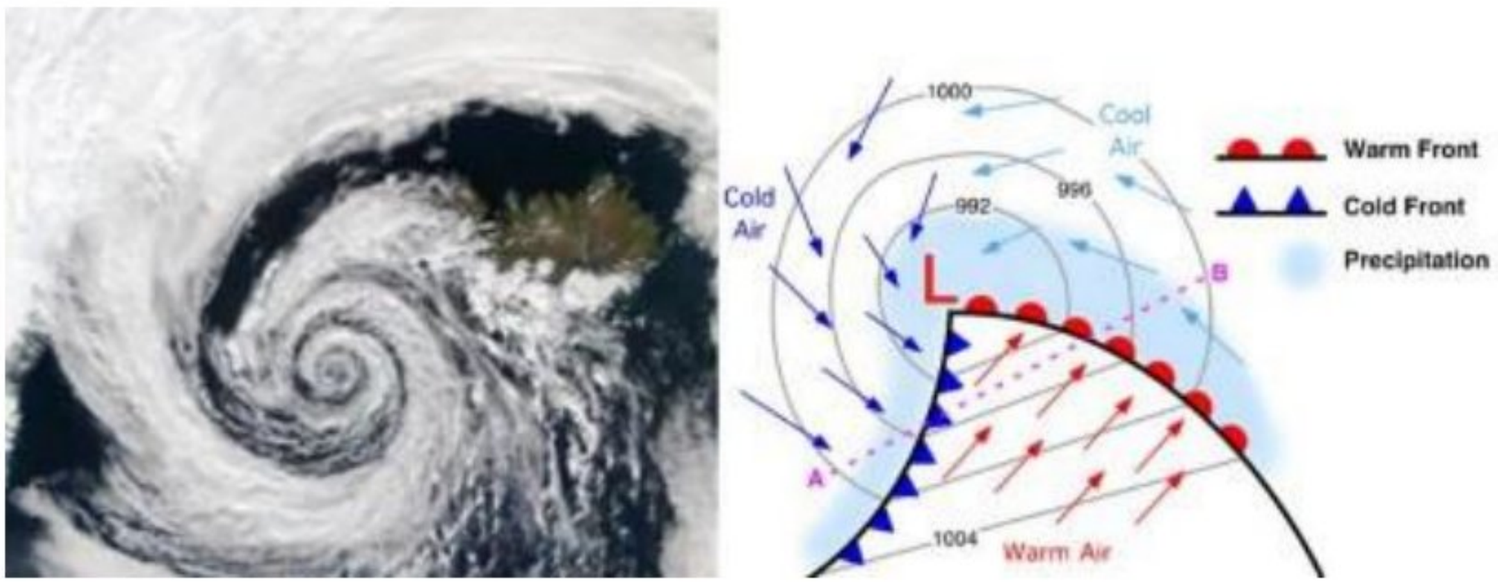
- In India, there are detection radars along both the coasts.
- Monitoring is also done by aircraft which carry a number of instruments including a weather radar.
- Cyclone monitoring by satellites is done through very high resolution radiometers, working in the visual and infra-red regions (for night view) of the spectrum to obtain an image of the cloud cover and its structure.
- Remote sensing by radars, aircraft and satellites helps predict where exactly the cyclone is going to strike. It helps in taking advance steps in the following areas:

1. closing of ports and harbours,
2. suspension of fishing activities,
3. evacuation of population,
4. stocking of food and drinking water, and
5. provision of shelter with sanitation facilities (safety homes).

- Today, it is possible to detect a cyclone right from its genesis in the high seas and follow its course, giving a warning at least 48 hours prior to a cyclone strike.
- However, the predictions of a storm course made only 12 hours in advance do not have a very high rate of precision.

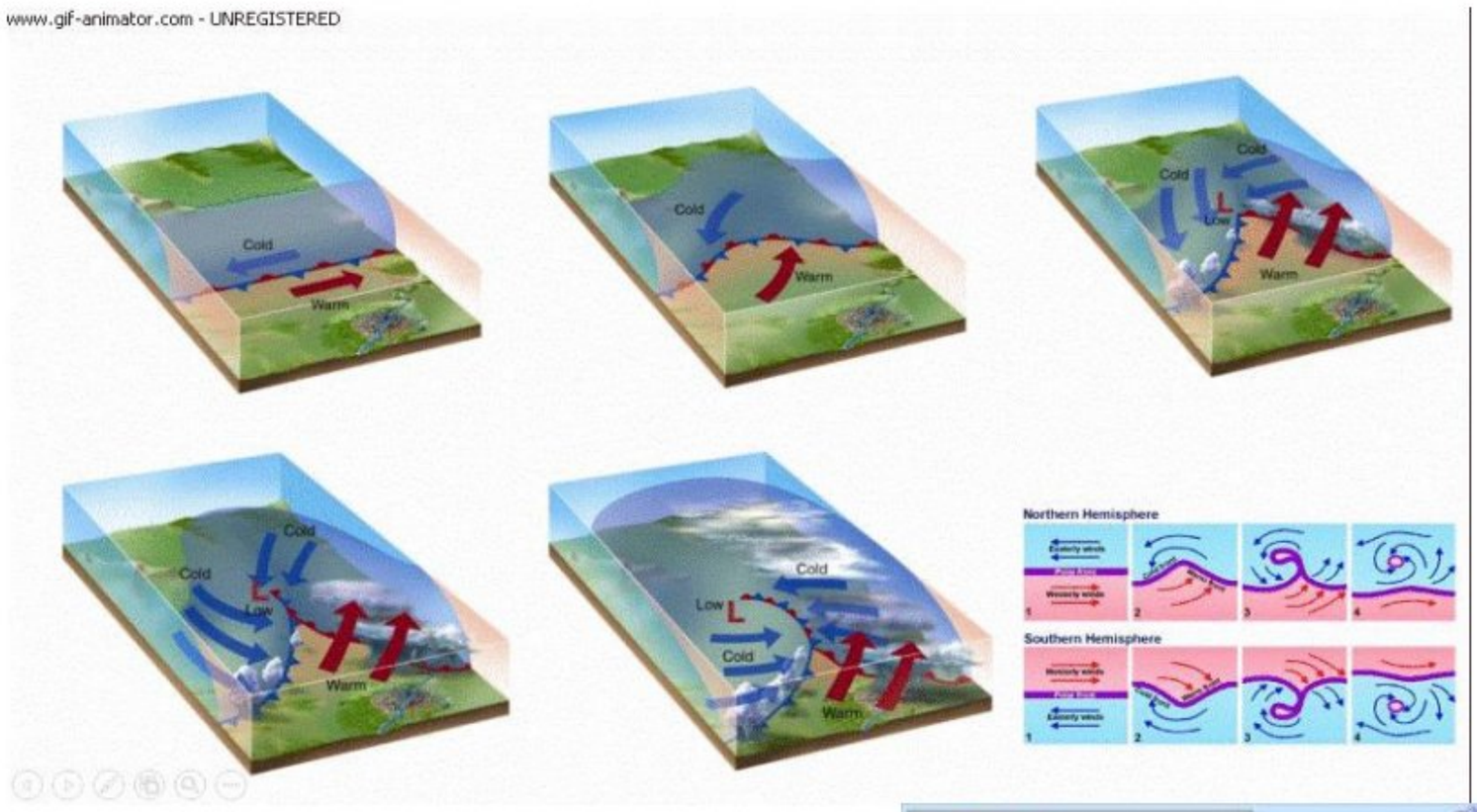
Origin and Development of Temperate Cyclones

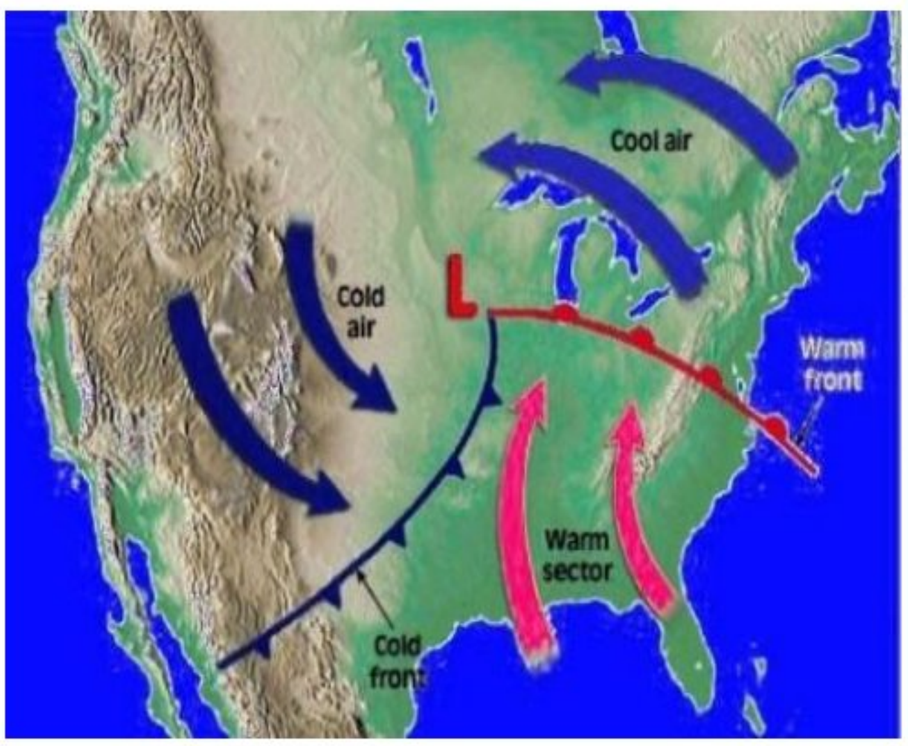
The systems developing in the mid and high latitude **(35° latitude and 65° latitude in both hemispheres)**, beyond the tropics are called the **Temperate Cyclones or Extra Tropical Cyclones or Mid-Latitude Cyclones or Frontal Cyclones or Wave Cyclones.**

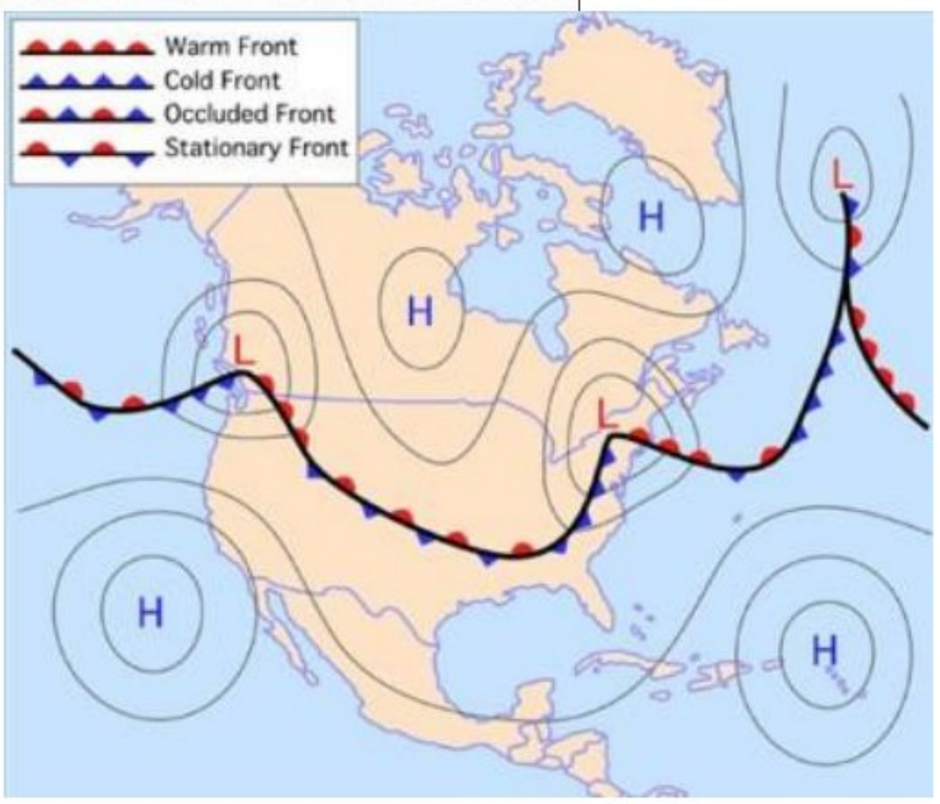


Polar Front Theory

- According to this theory, the warm-humid air masses from the tropics meet the dry-cold air masses from the poles and thus a polar front is formed as a surface of discontinuity.
- Such conditions occur over **sub-tropical high, sub-polar low pressure belts** and along the **Tropopause**.
- The cold air pushes the warm air upwards from underneath. Thus a void is created because of lessening of pressure. The surrounding air rushed in to occupy this void and coupled with the earth's rotation, a cyclone is formed which **advances with the westerlies (Jet Streams).**







- In the northern hemisphere, warm air blows from the south and cold air from the north of the front.
- When the pressure drops along the front, the warm air moves northwards and the cold air move towards south setting in motion an **anticlockwise cyclonic circulation (northern hemisphere). This is due to Coriolis Force.**
- The cyclonic circulation leads to a well-developed extra tropical cyclone, with a warm front and a cold front.
- There are pockets of warm air or warm sector wedged between the forward and the rear cold air or cold sector. The warm air glides over the cold air and a sequence of clouds appear over the sky ahead of the warm front and cause precipitation.
- The cold front approaches the warm air from behind and pushes the warm air up. As a result, cumulus clouds develop along the cold front. The **cold front moves faster** than the warm front ultimately overtaking the warm front. The

warm air is completely lifted up and the front is **occluded (occluded front)** and the cyclone dissipates.

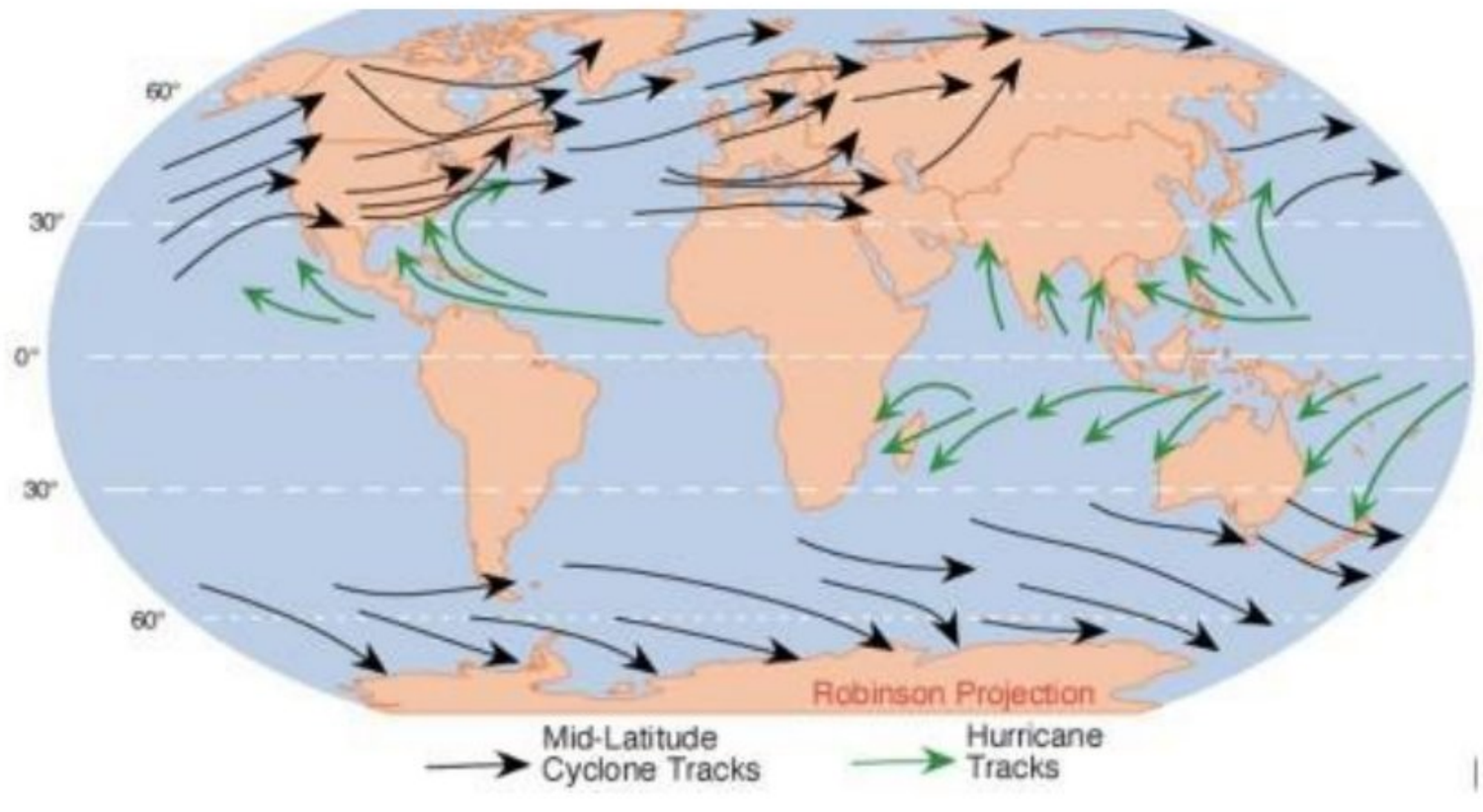
- The processes of wind circulation both at the surface and aloft are closely interlinked.
- So temperate cyclone is intense **frontogenesis** involving mainly **occlusion type front**. (Occluded front explained in detail in previous posts).
- Normally, individual frontal cyclones exist for about 3 to 10 days moving in a generally **west to east direction**.
- Precise movement of this weather system is controlled by the orientation of the polar jet stream in the upper troposphere.

Seasonal Occurrence of Temperate Cyclones

- The temperate cyclones occur mostly in **winter, late autumn and spring**. They are generally associated with rainstorms and cloudy weather.
- During summer, all the paths of temperate cyclones shift northwards and there are only few temperate cyclone over sub-tropics and the warm temperate zone, although a high concentration of storms occurs over Bering Strait, USA and Russian Arctic and sub-Arctic zone.

Distribution of Temperate Cyclones

- USA and Canada – extend over Sierra Nevada, Colorado, Eastern Canadian Rockies and the Great Lakes region,
- the belt extending from Iceland to Barents Sea and continuing over Russia and Siberia,
- winter storms over Baltic Sea,
- Mediterranean basin extending up to Russia and even up to India in winters (called western disturbances) and the Antarctic frontal zone.



Characteristics of Temperate Cyclones

Size and Shape

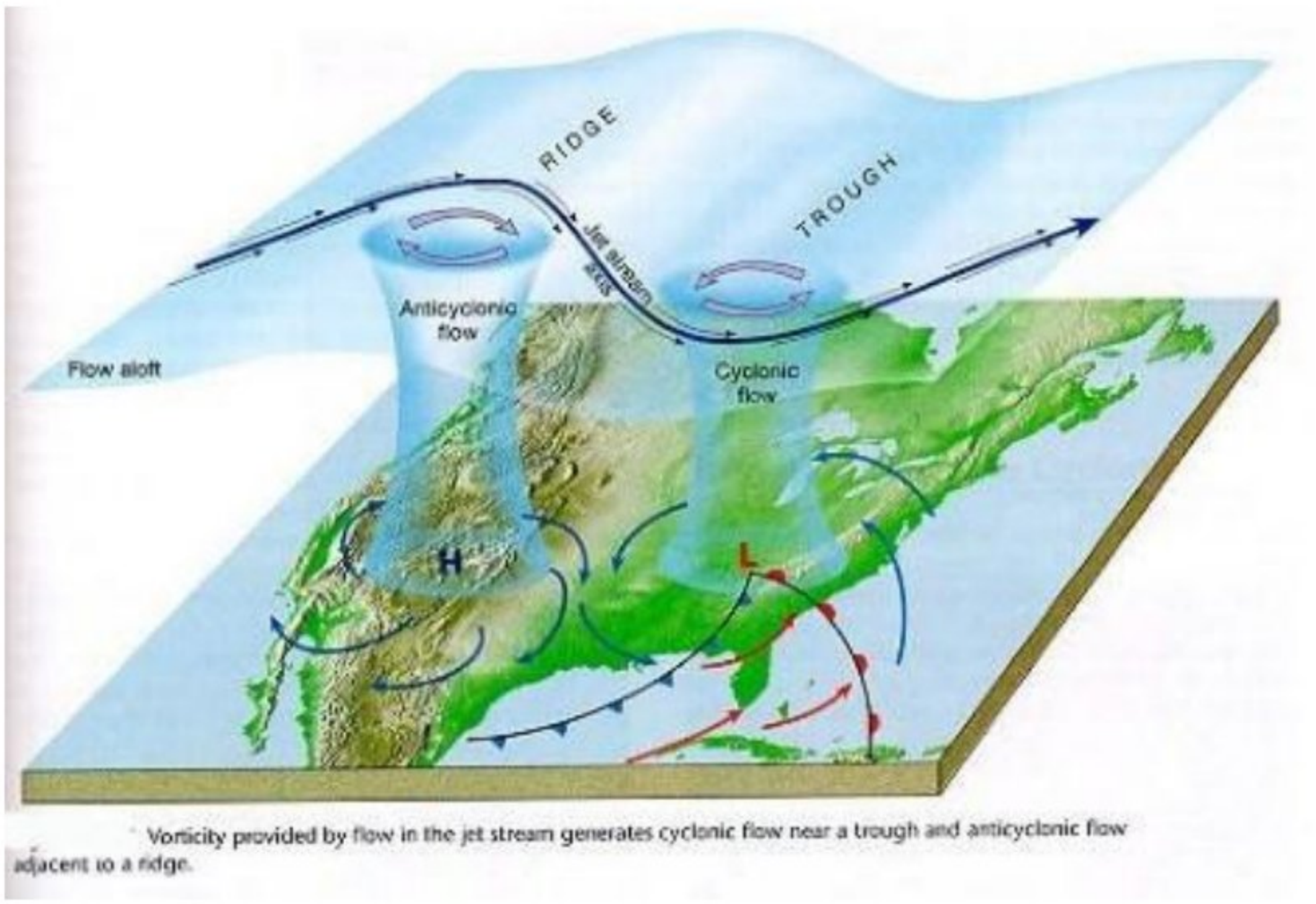
- The temperate cyclones are asymmetrical and shaped like an inverted 'V'.
- They stretch over 500 to 600 km.
- They may spread over 2500 km over North America (**Polar Vortex**).
- They have a height of 8 to 11 km.

Wind Velocity And Strength

- The wind strength is more in eastern and southern portions, more over North America compared to Europe.
- The wind velocity increases with the approach but decreases after the cyclone has passed.

Orientation And Movement

- Jet stream plays a major role in temperate cyclonogeneis.
- Jet streams also influence the path of temperate cyclones.



Vorticity provided by flow in the jet stream generates cyclonic flow near a trough and anticyclonic flow adjacent to a ridge.

- Since these cyclones move with the **westerlies (Jet Streams)**, they are oriented **east-west**.
- If the storm front is east-west, the center moves swiftly eastwards.
- If the storm front is directed northwards, the center moves towards the north, but after two or three days, the pressure difference declines and the cyclone dissipates.
- In case the storm front is directed southwards, the center moves quite deep southwards-even up to the Mediterranean region [sometimes causing the Mediterranean cyclones or **Western Disturbances** (They are very important as they bring rains to North-West India – Punjab, Haryana)].

Structure

- The north-western sector is the cold sector and the north-eastern sector is the warm sector (Because cold air masses in north and warm air masses in south push against each other and rotate anti-clockwise in northern hemisphere).

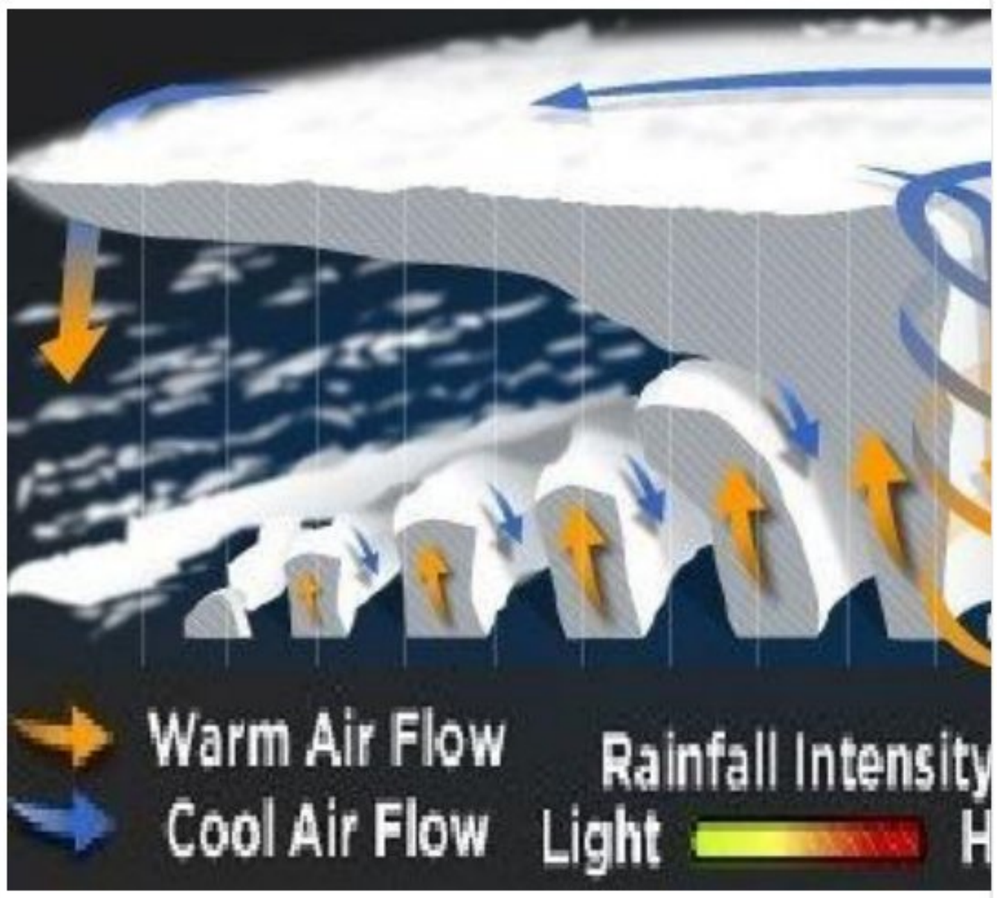
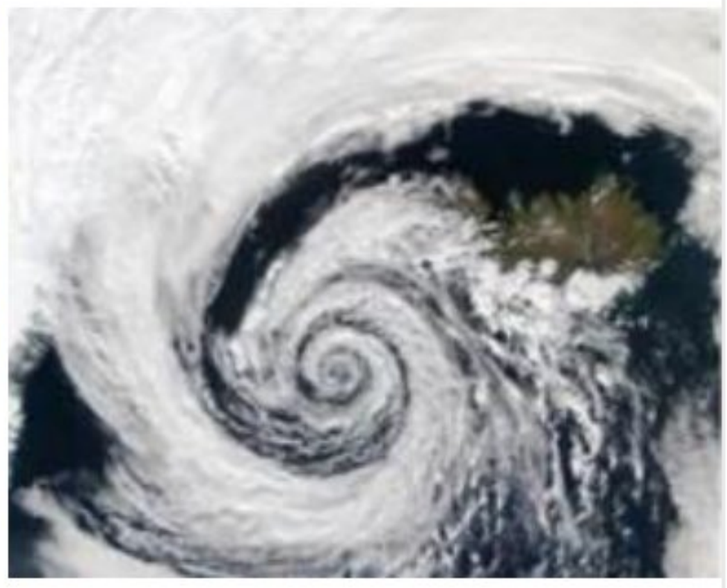
Associated Weather

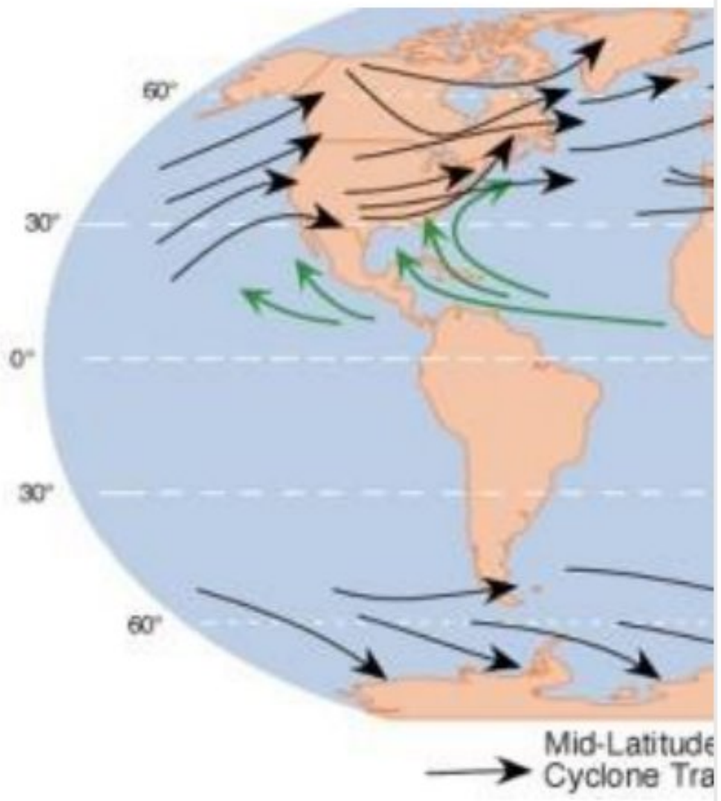
- The approach of a temperate cyclone is marked by fall in temperature, fall in the mercury level, wind shifts and a **halo around the sun and the moon**, and a thin veil of **cirrus clouds.**

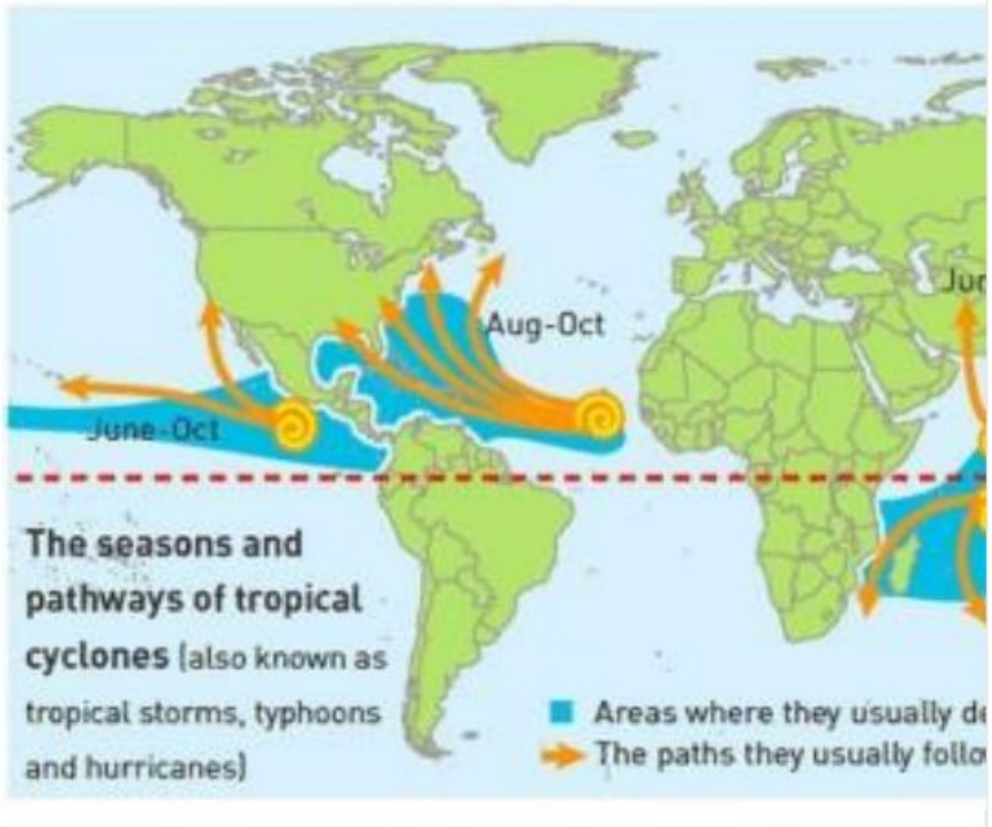
- A light drizzle follows which turns into a heavy downpour. These conditions change with the arrival of the warm front which halts the fall in mercury level and the rising temperature.
- Rainfall stops and clear weather prevails until the cold front of an anticyclonic character arrives which causes a fall in temperature, brings cloudiness and rainfall with thunder. After this, once again clear weather is established.
- The temperate cyclones experience more rainfall when there is slower movement and a marked difference in rainfall and temperature between the front and rear of the cyclone. These cyclones are generally accompanied by anticyclones.

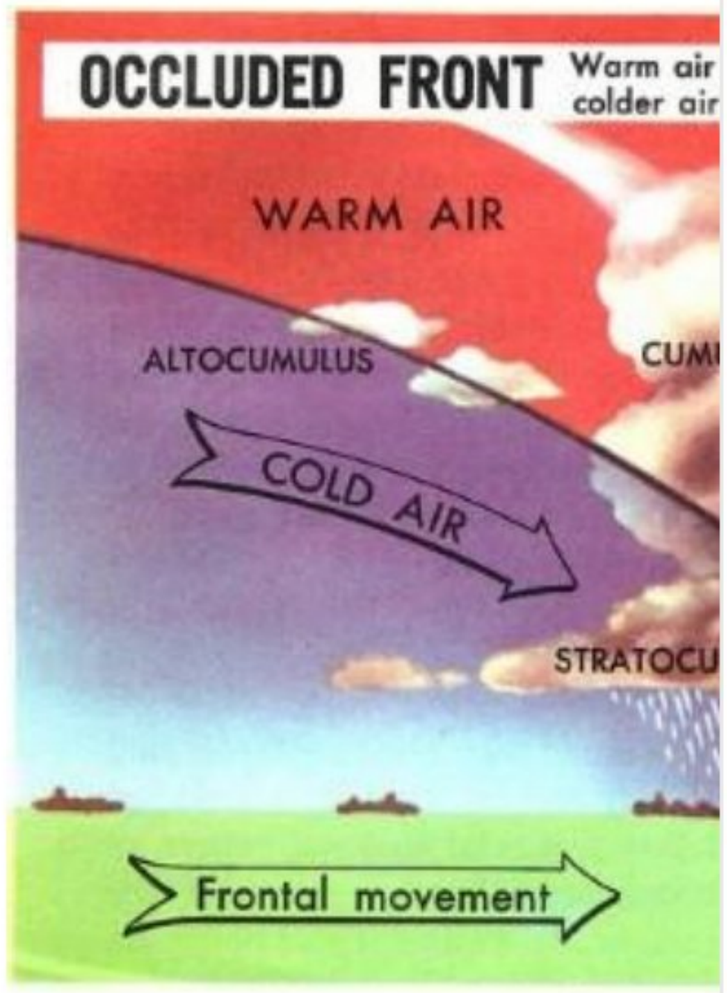
Comparison of Tropical Cyclones & Temperate Cyclones

	Tropical Cyclone	Temperate Cyclone
Origin	**Thermal Origin**	**Dynamic Origin** – Coriolis Force, Movement of air masses.
Latitude	Confined to 10^0 – 30^0 N and S of equator.	Confined to 35^0 – 65^0 N and S of equator. More pronounced in Northern hemisphere due to **greater temperature contrast**.
Frontal system	Absent	The very cyclone formation is due to frontogenesis.[Occluded Front]

Formation	They form only on seas with temperature more than 26-27^0 C. They dissipate on reaching the land.	Can form **both** on land as well as seas
Season	Seasonal: Late summers (Aug – Oct)	Irregular. But few in summers and **more in winters**.
Size	Limited to small area. Typical size: 100 – 500 kms in diameter. Varies with the strength of the cyclone.	They cover a larger area. Typical size: 300 – 2000 kms in diameter. Varies from region to region.
Shape	Elliptical 	Inverted 'V' 
Rainfall	Heavy but does not last beyond a few hours. If the cyclone stays at a place, the rainfall may continue for many days.	In a temperate cyclone, rainfall is slow and continues for many days, sometimes even weeks.
Wind Velocity and	Much greater (100 – 250 kmph)(200 – 1200 kmph in upper troposphere)	Comparatively low. Typical range: 30 – 150 kmph.

destruction	Greater destruction due to **winds, storm surges and torrential rains.**	Less destruction due to winds but more destruction due to **flooding.**
Isobars	Complete circles and the **pressure gradient is steep**	Isobars are usually 'V' shaped and the pressure gradient is low.
Life time	Doesn't last for more than a week	Last for 2-3 weeks.
Path	East – West. Turn North at 20^0 latitude and west at 30^0 latitude. Move away from equator. The movement of Cyclones in Arabian Sea and Bay of Bengal is a little different. Here, these storms are superimposed upon the **monsoon circulation** of the summer months, and they move in northerly direction along with the monsoon currents.	West – East (Westerlies – Jet Streams). Move away from equator. 

		
Temperature distribution	The temperature at the center is almost equally distributed.	All the sectors of the cyclone have different temperatures
Calm region	The center of a tropical cyclone is known as the eye. The wind is calm at the center with no rainfall.	In a temperate cyclone, there is not a single place where winds and rains are inactive.
Driving force	The tropical cyclone derives its energy from the **latent heat of condensation**, and the difference in densities of the air masses does not contribute to the energy of the cyclone.	The energy of a temperate cyclone depends on the **densities of air masses**.
Influence of Jet	The relationship between tropical cyclones and the upper level air-flow is not very clear.	The temperate cyclones, in contrast, have a distinct relationship with upper level air flow (jet streams, Rossby waves etc.)

streams		 Vorticity provided by flow in the jet stream generate adjacent to a ridge.
Clouds	The tropical cyclones exhibit fewer varieties of clouds – cumulonimbus, nimbostratus, etc..	The temperate cyclones show a variety of cloud development at various elevations. 

Surface anti-cyclones	The tropical cyclones are not associated with surface anticyclones and they have a greater destructive capacity.	The temperate cyclones are associated with anticyclones which precede and succeed a cyclone. These cyclones are not very destructive.
Influence on India	Both coasts effected. But east coast is the hot spot.	Bring rains to North – West India. The associated instability is called '**Western Disturbances**'.

- Titbit: In certain instances, two cyclones move toward each other and revolve around one another, with the smaller and less intense one moving more quickly. This phenomenon is called the **Fujlwara effect**.