

# Tropical Cyclone

Dr. Sandip Sagar

## 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 the closed circulation of air around a low-pressure center. This closed air circulation (whirling motion) is a result of rapid upward movement of the 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 the existence of an anticyclone between two cyclones.
- Tropical cyclones occur around the equator at  $5^{\circ}$  –  $30^{\circ}$ , but also have varying names depending upon where in the world they form.
- An average tropical cyclone can travel about 300 to 400 miles a day, or about 3,000 miles before it dies out.

## Conditions Favorable for Tropical Cyclone Formation

1. Large sea surface with a temperature higher than  $27^{\circ}$  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  $27^{\circ}$  C or more is the source of moisture that feeds the storm. The condensation of moisture releases enough latent heat of condensation to drive the storm.
- The depth of warm water ( $26$ - $27^{\circ}$ C) should extend for 60-70 m from the 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 push ocean waters towards the west) that flow from the east towards the 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.

## Coriolis Force (f)

- The Coriolis force is zero at the equator (no cyclones at the 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 percent 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 the 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 hemispheres meet along the 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).
- **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 equatorward of the subtropical jet stream.**
- 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.

## Humidity Factor

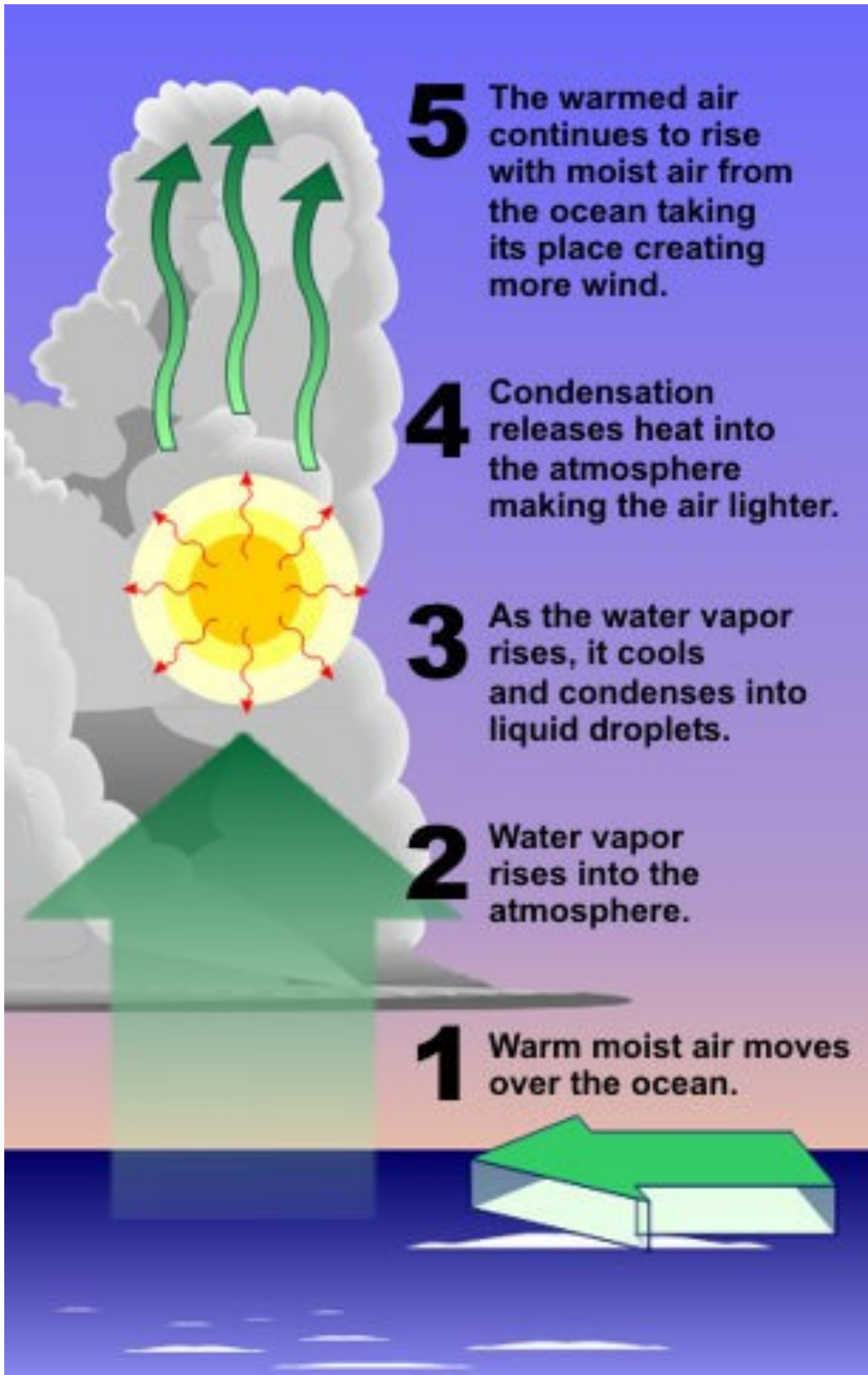
- High humidity (around 50 to 60 percent) is required in the mid-troposphere since the presence of moist air leads to the formation of **cumulonimbus clouds**.
- Such conditions exist over the equatorial **doldrums**, especially in western margins of oceans (this is because of the east to west movement 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

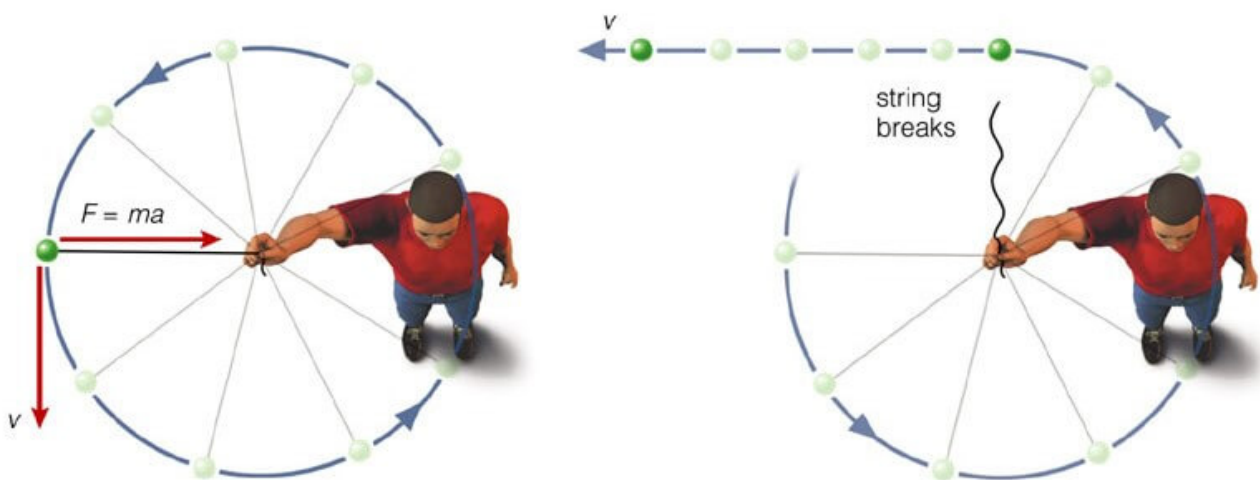
- Under favorable conditions, multiple thunderstorms originate over the oceans. These thunderstorms merge and create an intense low pressure system (wind is warm and lighter).



## Early stage

- In the thunderstorm, the air is uplifted as it is **warm and light**. At a certain height, due to **lapse rate and adiabatic lapse rate**, the temperature of the air falls and moisture in the air undergoes **condensation**.
- Condensation releases **latent heat of condensation** making the air warmer. It becomes much lighter and is further uplifted.
- Space is filled with 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 the air at a 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 a tornado)**.

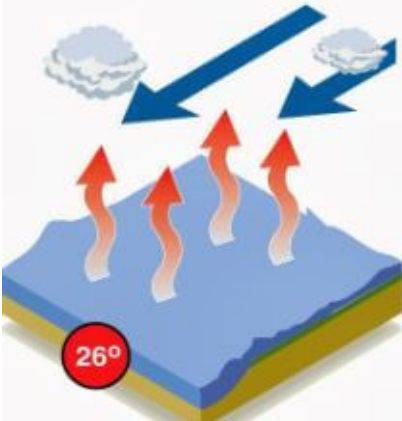
Due to centripetal acceleration (centripetal force pulling towards the center is countered by an opposing force called the centrifugal force), the air in the vortex is forced to form a region of calmness called an **eye** at the center of the cyclone. The inner surface of the vortex forms the **eyewall**,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



# How tropical storms are formed

High humidity and ocean temperatures of over 26°C are major contributing factors

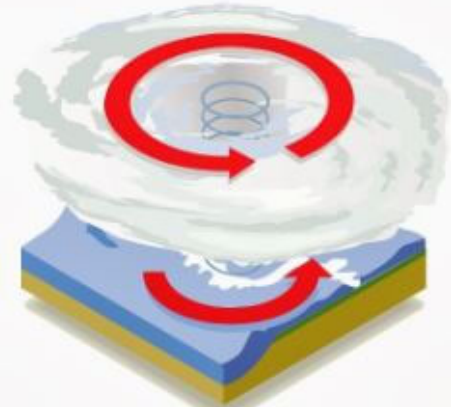
**Water evaporates** from the ocean surface and comes into contact with a **mass of cold air**, forming clouds



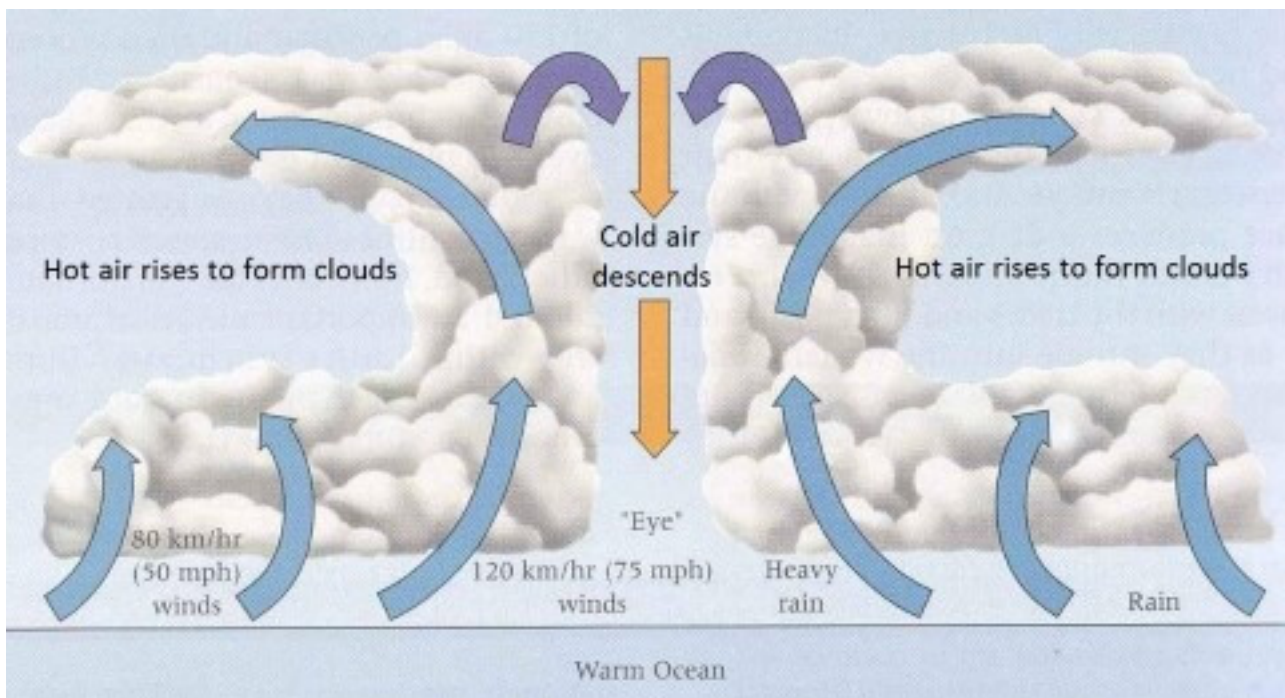
A **column of low pressure** develops at the centre. **Winds form** around the column



As pressure in the central column (the eye) weakens, the **speed of the wind around it increases**



[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.

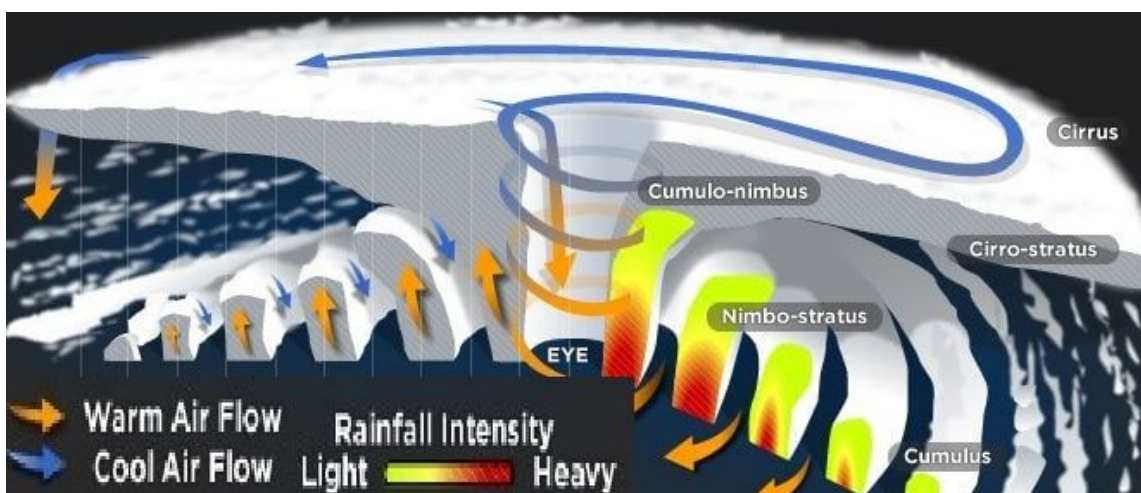
- Continuous supply of **moisture** from the sea is the major driving force behind every cyclone. On reaching the land the **moisture supply is cut off** and the storm dissipates.



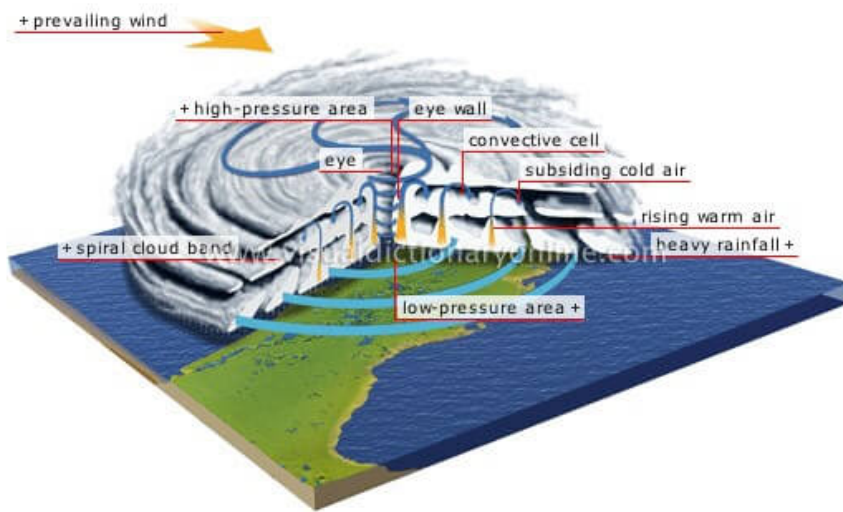
- If ocean can supply more moisture, the storm will reach a mature stage.

## 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 the 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 the 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 the 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

- A mature tropical cyclone is characterized by the **strong spirally circulating wind around the centre which is called the eye.**
- The “eye” is a roughly circular area of comparatively **light winds, clear skies, 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 “eyewall”, the roughly circular ring of **deep convection**, which is the area of **highest surface winds** in the tropical cyclone. The Eye Wall region also sees the maximum sustained winds i.e. **fastest winds in a cyclone occur along the eyewall region.**
- The eye is composed of air that is slowly sinking and the eyewall has a net upward flow as a result of many moderate – occasionally strong
- 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.
- The **wind reaches maximum velocity in this region** and torrential rain occurs here.
- From the eyewall, rain bands may radiate and trains of **cumulus and cumulonimbus clouds may drift into the outer region.**

## Spiral bands

- Another feature of tropical cyclones that probably plays a role in **forming and maintaining the eye** is the eyewall 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 with 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 to fall across the band since warm air is lighter than cold air.
- Because the pressure falls on the inside, the tangential winds around the tropical cyclone increase due to the 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 eyewall and to a forced descent caused by the moist convection of the eyewall**.

## 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

This is the tropical cyclone category system as used by the **Bureau of Meteorology**:

1. **Category one (tropical cyclone)**: A category one cyclone's strongest winds are GALES with typical gusts over open flat land of 90-125kph,
2. **Category two (tropical cyclone)**: A category two cyclone's strongest winds are DESTRUCTIVE winds with typical gusts over open flat land of 125-164kph,
3. **Category three (severe tropical cyclone)**: A category three cyclone's strongest winds are VERY DESTRUCTIVE winds with typical gusts over open flat land of 165-224kph,
4. **Category four (severe tropical cyclone)**: A category four cyclone's strongest winds are VERY DESTRUCTIVE winds with typical gusts over open flat land of 225-279kph,
5. **Category five (severe tropical cyclone)**: A category five cyclone's strongest winds are VERY DESTRUCTIVE winds with typical gusts over open flat land of more than 280kph.



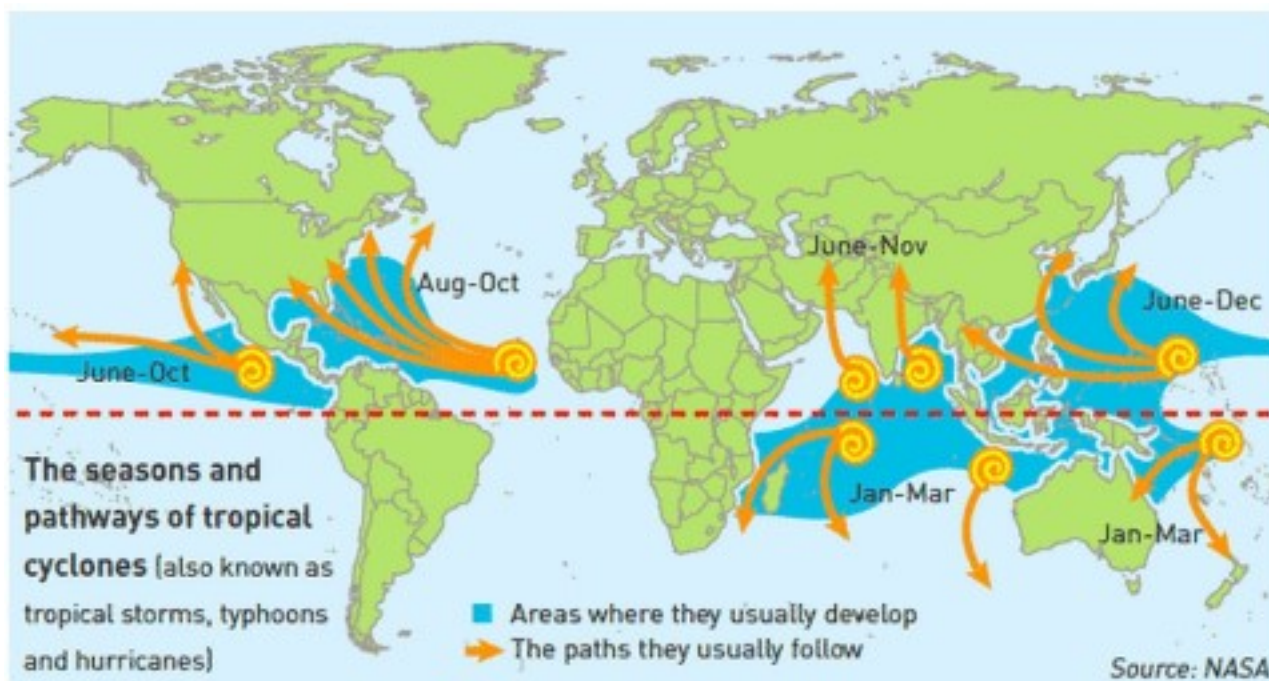
Cyclone Category	Wind Speed in Km/h	Damage Capacity	Type of Disturbances	Wind Speed in Km/h
01	120-150	Minimal	Low Pressure	Less than 31
02	150-180	Moderate	Depression	31-49
03	180-210	Extensive	Deep Depression	49-61
04	210-250	Extreme	Cyclonic Storm	61-88
05	250 +	Catastrophic	Severe Cyclonic Storm	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.
- The **Bay of Bengal and the Arabian Sea** where they are called cyclones.

- Around the **south-east African coast and Madagascar-Mauritius islands.**
- **North-west Australia.**



### Regional names for Tropical Cyclones

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

## 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 moreover 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.

## 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 the storm.**
- There is 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 coasts.**
- **Monitoring is also done by aircraft** which carry a number of instruments including 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 advanced steps in the following areas:
  1. closing of ports and harbors,
  2. suspension of fishing activities,
  3. evacuation of the 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.

## Major Differences between Temperate Cyclone and Tropical Cyclone

<b>Tropical Cyclone</b>	<b>Temperate Cyclone</b>
-------------------------	--------------------------

tropical cyclones, move from east to west.	These cyclones move from west to east
A tropical cyclone has an effect on a comparatively smaller area than a Temperate cyclone.	Temperate cyclone affect a much larger area
The velocity of wind in a tropical cyclone is much higher and it is more damaging.	The velocity of air is comparatively lower
Tropical Cyclone forms only on seas with temperature more than 26-27degree C and dissipate on reaching the land.	Temperate cyclones can be formed on both land and sea
A tropical cyclone doesn't last for more than 7 days	Temperate cyclone can last for a duration of 15 to 20 days