Module II: Physical Geography

- Cyclones
  - ❖ Cyclones are the **centers of low pressure**.
  - ❖ They are surrounded by **closed isobars having increasing pressure outward.**
  - ❖ The wind circulation is from outside towards the central low pressure.
  - ❖ They rotate **anti-clockwise in the Northern hemisphere** and **clockwise in the southern hemisphere**
  - ❖ The inward flow of air is due to pressure gradient force and the lowest pressure at the center.
  - ❖ Due to Coriolis force, blowing winds are deflected from their paths- rightwards in the **Northern hemisphere and leftward in the Southern hemisphere.**
  - ❖ Types of cyclones
    1. **<u>Extratropical cyclones or Temperate cyclones or wave cyclones</u>**
       - ➢ Temperate cyclones are storm systems emerging in the **mid and high latitudes**, away from the tropics, and They are low-pressure systems with associated cold fronts, warm fronts, and occluded fronts.
       - ➢ 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.**
       - ➢ Characteristics of Temperate Cyclones

         A. <u>Size and Shape</u>

         ➔ 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**

B. <u>Wind Velocity And Strength</u>

- ➔ 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.

C. <u>Orientation And Movement</u>

- ➔ **Jet stream plays a major role in temperate cyclogenesis**.
- ➔ **Jet streams also influence the path of temperate cyclones.**
- ➔ Since these cyclones move with the westerlies **(Jet Streams)**, they are oriented eastwest.
- ➔ 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)]**

D. <u>Structure</u>

- ➔ 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 the northern hemisphere).**

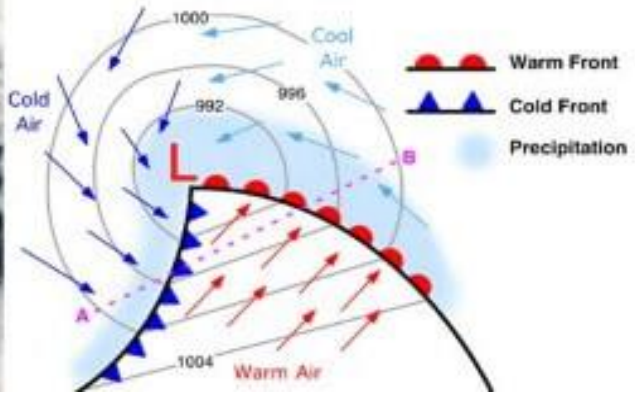
➢ **<u>Polar Front Theory</u>**

- ➔ 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 **subtropical 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 moves towards the south setting in motion an anticlockwise cyclonic circulation (northern hemisphere). **This is due to Coriolis Force.**
- ➔ The cyclonic circulation leads to a well-developed extratropical 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 cyclones are intense frontogenesis involving mainly occlusion type fronts. (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**.
- ➔ The precise movement of this weather system is controlled by the orientation of the polar jet stream in the upper troposphere.

➢ **<u>Distribution of Temperate Cyclones</u>**

- ➔ **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.**



2. 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.**
- 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 ° – 30 °,** 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**

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

➔ **Temperature contrast between air masses**

- ★ **Trade winds from both hemispheres meet along the intertropical 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 sores, suggesting that the environmental lapse rate is steeper and unstable below these troughs. Such instability encourages thunderstorms (child cyclones).

➔ 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 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

➢ **Characteristics of Tropical Cyclones**

➔ **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 the 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.**

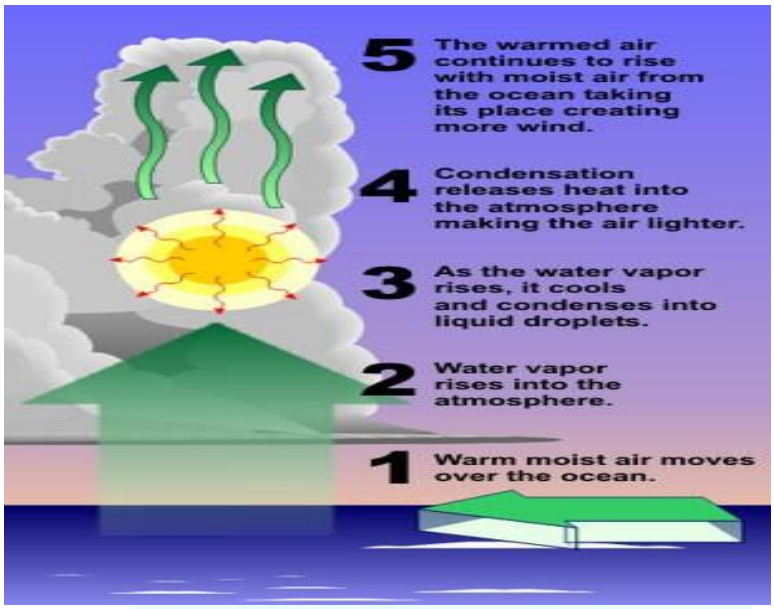
★ Coriolis force or earth's rotation, easterly and westerly winds influence the path of a tropical cyclone.

★ Tropical cyclones die at **30° latitude** because of cool ocean waters and increasing wind shear due to **westerlie.**

➢ **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)**.

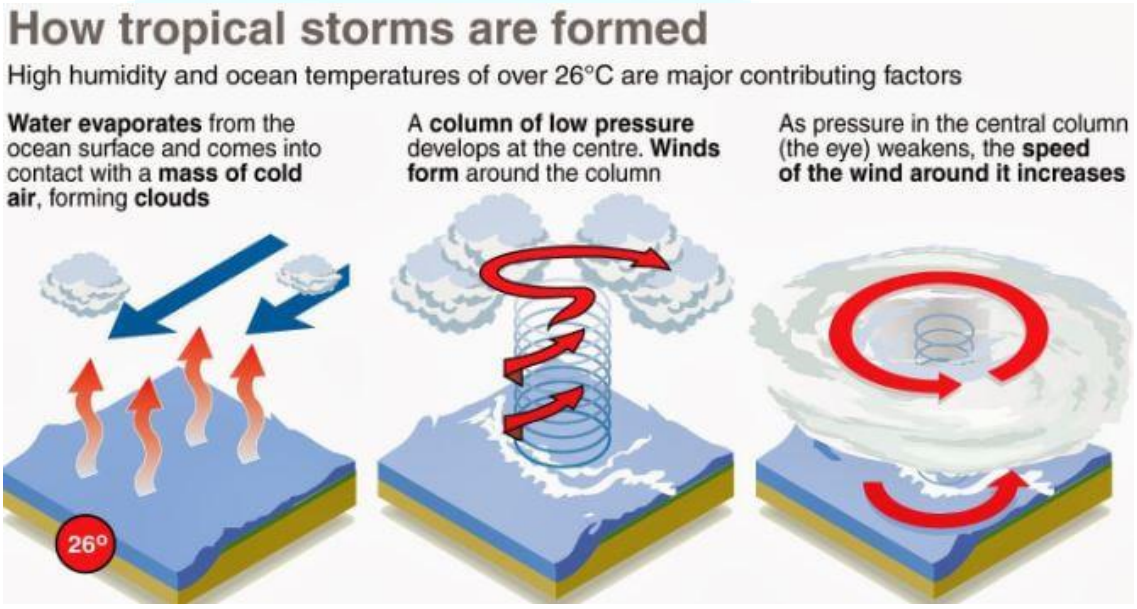
➔ Due to centripetal acceleration (centripetal force pulling towards the center is countered by an opposing force

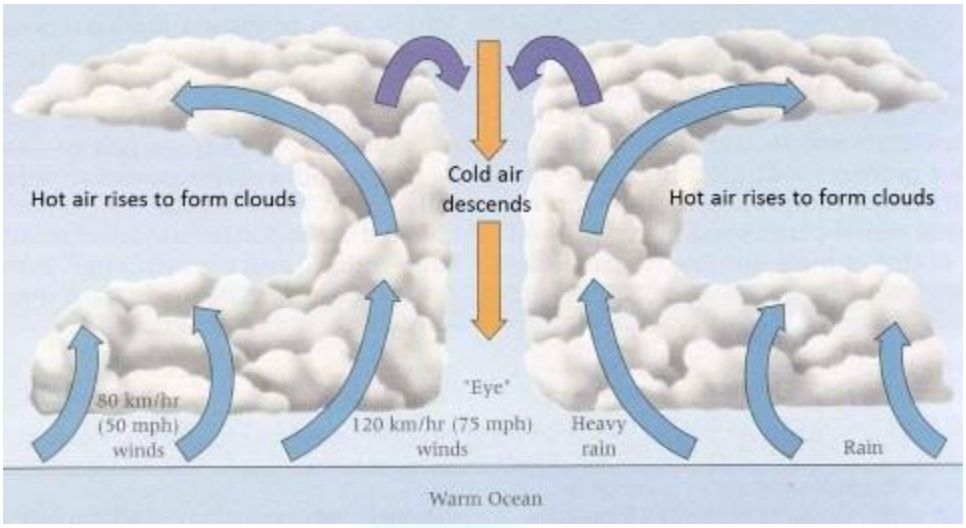
called the centrifugal force), the air in the vortex is forced to form a region of calmness called an **eye at the center of the cyclone**. The inner surface of the vortex forms the eyewall, the most violent region of the cyclone.

➔ 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 the 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 descend (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 center 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 skies 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**

- ★ 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.

➢ **<u>Categories of Tropical Cyclones</u>**

➔ Category one (tropical cyclone): A category one cyclone's strongest winds are GALES with typical gusts over open flat land of **90-125kph,**

- ➔ Category two (tropical cyclone): A category two cyclone's strongest winds are **DESTRUCTIVE** winds with typical gusts over open flat land of **125-164kph,**
- ➔ 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,**
- ➔ 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,**
- ➔ 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
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

➢ **<u>Favorite Breeding Grounds for Tropical Cyclones</u>**

- ➔ **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**

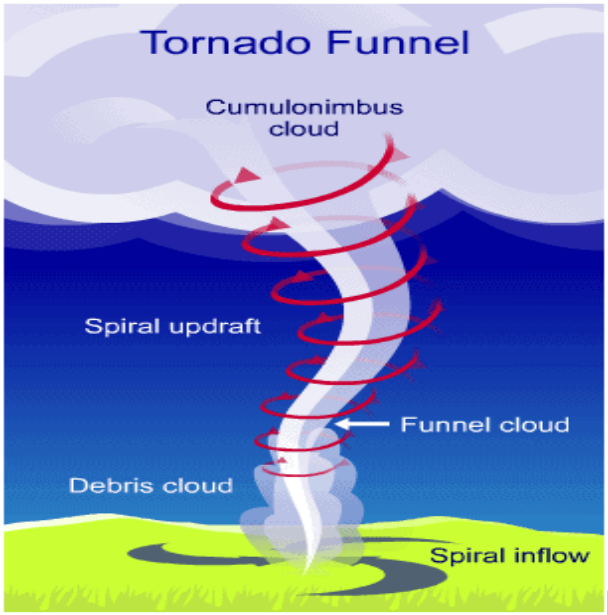
Regions	What they are called
Indian Ocean	Cyclones
Atlantic	Hurricanes
Western Pacific and South China Sea	Typhoons
Western Australia	Willy-willies

❖ **Major Differences between Temperate Cyclone and Tropical Cyclone**

Tropical Cyclone	Temperate Cyclone
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 **26-27 degree 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**

- Tornado
  - ❖ A tornado is a **violently rotating column of air that extends from a thunderstorm to the ground**. It is a vortex of rapidly moving air.
  - ❖ A tornado forms when changes in wind speed and direction create a **horizontal spinning effect within a storm cell**. This effect is then tipped vertically by rising air moving up through the thunderclouds.
  - ❖ Winds within the tornado funnel may exceed **500kmph.**
  - ❖ High-velocity winds cause most of the damage associated with these weather events.
  - ❖ Tornadoes also cause damage through air pressure reductions.
  - ❖ The air pressure at the tornado center is approximately 800 millibars (average sea-level pressure is 1013 millibars) and many human-made structures collapse outward when subject to pressure drops of this magnitude



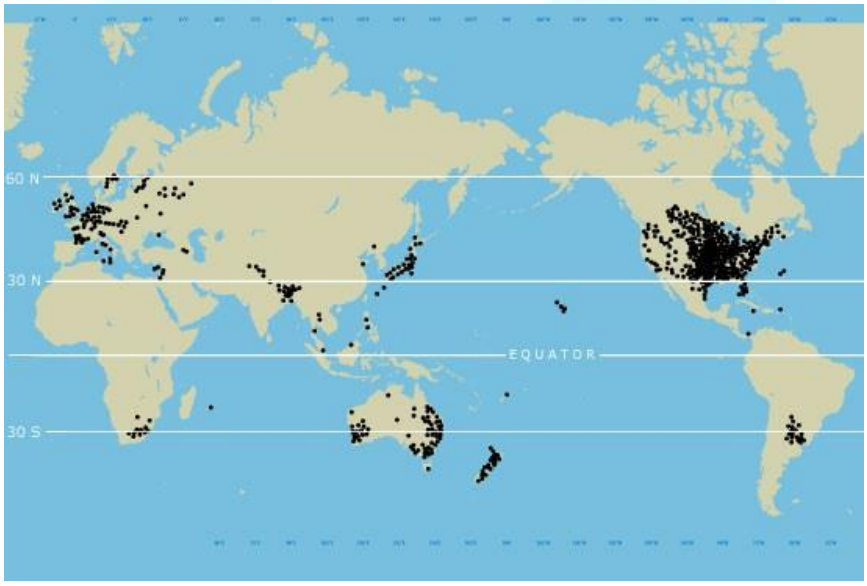
❖ Origin of Tornado

- ➢ **Tornado formation typically needs four ingredients: shear, lift, instability, and moisture.**
- ➢ Wind shear is the most important factor that plays into the creation of tornadoes. When there is wind shear, sometimes these winds begin to roll into a horizontal column of air.
- ➢ Once you get a strong updraft of air being transported from the ground to the atmosphere, that column of air becomes vertical. That is when a storm usually develops in this scenario.
- ➢ As the storm develops, it turns into a supercell thunderstorm much of the time.
- ➢ These supercell thunderstorms are separate, discrete cells that are not part of a line of storms. Also, supercells are storms that rotate and spin. With both the vertical, rotating column of air and the supercell thunderstorm together, that may bring down a tornado from the storm cloud
- ➢ **Tornadoes are most common in spring and least common in winter.**

- ➢ Spring and fall experience peaks of activity as those are the seasons when **stronger winds, wind shear, and atmospheric instability are present. Tornado occurrence is highly dependent on the time of day, because of solar heating.**

❖ **Distribution of tornadoes**

- ➢ Rare in polar regions and infrequent at **latitudes higher than 50° N and 50° S.**
- ➢ **The temperate and tropical regions are the most prone to thunderstorms.**
- ➢ Tornadoes have been reported on all continents except Antarctica.
- ➢ The United States has the most violent tornadoes.
- ➢ Canada reports the second largest number of tornadoes.
- ➢ In the **Indian subcontinent**, **Bangladesh is the most prone country to tornadoes.**
- ➢ At any moment there are approximately **1,800 thunderstorms in progress throughout the world.**



❖ **Differences between Tornado and cyclone**

	Tornado	**Cyclone**

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Definition	A tornado is a rotating column of air ranging in width from a few yards to more than a mile and whirling at destructively high speeds, usually accompanied by a funnel-shaped downward extension of a cumulonimbus cloud. Winds **40-300+ mph.**	A cyclone is an atmospheric system of rapidly circulating air massed about a low-pressure center, usually accompanied by stormy, often destructive weather. Storms that begin in the Southern Pacific are called cyclones
Rotation	**Clockwise in the southern hemisphere and counterclockwise in the northern hemisphere**	**Clockwise in the southern hemisphere and counterclockwise in the northern hemisphere.**
Forms of precipitation	rain	Rain, sleet, and hail
Frequency	The **United States** records about **1200 tornadoes per year,** whereas the Netherlands records the highest number of tornadoes per area compared to other countries. Tornadoes occur commonly in spring and the fall season and are less common in winters	**10-14** per year
Location	Tornadoes have been	Southern Pacific

	spotted in all continents **except Antarctica**	Ocean, Indian Ocean. **Cyclones in the northwest Pacific that reach (exceed) 74 mph are "typhoons".**
Occurrence	Places where cold and warm fronts converge. Can be just almost anywhere.	warm areas

- Anticyclones
  - **Anticyclones are centers of high pressure**.
  - They are surrounded by **closed isobars having decreasing pressure outward.**
  - The circulation is from central high pressure towards the periphery in such a way that air blows outwards in a **clockwise direction in the Northern hemisphere and anticlockwise direction in the southern hemisphere.**
  - Due to Coriolis force, blowing winds are deflected from their paths to the right in the **Northern hemisphere and left in the Southern** hemisphere, that's how it gets circular with a flowing system.
  - The difference of pressure between the center and periphery of anticyclone ranges between **10 to 20 mb and sometimes higher.**
  - They are much larger in size and area than temperate cyclones as the diameter is **75% larger than that of temperate cyclones. Temperate anticyclones are so extensive that a single anticyclone can cover nearly half of the USA.**
  - **The track is highly variable and unpredictable.**
  - They move very sluggishly and sometimes they become stationary over a particular place for 4 days. **The average velocity of an anticyclone is 30 to 50 km per hour**.

- Anticyclones originated due to the descent of either **polar cold air mass or warm tropical air mass.**
- These anticyclones are high-pressure systems and are more common in subtropical high-pressure belts and polar high-pressure belts where the air is sinking from the upper troposphere to the lower troposphere but are practically absent in equatorial regions.
- The formation of anticyclonic conditions at polar high-pressure belts is a thermal phenomenon as these bills are thermally direct whereas the **formation of anticyclonic conditions at subtropical high-pressure belts is a dynamic phenomenon as these bills are thermally indirect.**
- A**nticyclones tend to produce fairly uniform weather.**
- Whence descend from above at the center and the weather becomes clear and rainless because the descending wind brings atmospheric stability.
- **The weather of Canada, USA and northern Eurasia is mostly affected by anticyclones.**
- **Types of anticyclones**
  - **Cold anticyclones or thermal anticyclones**
    - They are formed above the **Polar Regions** due to the sinking of air.
    - Post subsidence of air outflows from the polar region in an easterly and southeasterly direction.
  - **Warm anticyclones or dynamic anticyclones**
    - They are formed above warm subtropical regions due to the sinking of air from the upper troposphere to the lower troposphere and consequent divergence of air.
  - **Blocking anticyclones**
    - These developed due to obstruction in the air circulation in the upper troposphere that develops over mid-latitudes and

are called blocking because they obstruct the flow of temperate cyclones in **mid-latitudes.**

- Monsoons
  - A monsoon **(from the Arabic mawsim, which means "season")** is a seasonal change in the direction of the prevailing, or strongest, winds of a region.
  - Monsoons cause wet and dry seasons throughout much of the tropics.
  - Monsoons are most often associated with the Indian Ocean.
  - Generally, across the world, the monsoons are experienced in the tropical area roughly **between 20° N and 20° S.**
  - The climate of India is described as the **'monsoon' type.**
  - **In Asia, this type of climate is found mainly in the south and the southeast.**
- Air masses
  - It is defined as a **large body of air having little horizontal variation in temperature and moisture.**
  - The air masses have a relatively uniform distribution of vertical gradients in their physical properties like **temperature, pressure, and humidity.**
  - Air masses form an integral part of the global planetary wind system. Therefore, they are associated with one or other wind belts.
  - They extend from the surface to the lower stratosphere and are across thousands of kilometers.
  - **<u>Conditions for the formation of Air masses</u>**
    - Source region should be extensive with **gentle, divergent air circulation (slightly at high pressure).**
    - Areas with high pressure but little pressure difference or pressure gradient are ideal source regions.
    - There are no major source regions in the mid-latitudes as these regions are dominated by cyclonic and other disturbances.

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❖ Conditions for the origin of Air masses

- ➢ **Homogeneous Surface**
- ➢ **Isotropic surface**
- ➢ **Lack of turbulence in the air**
- ➢ **Lack of convection in air**
- ➢ **Subsiding air with high pressure**
- ➢ **Atmospheric stability**
- ➢ **Kinetic energy of wind and friction**

❖ Classification of Air Masses

Nature of Surface

1. Continental
2. Marine

Source region

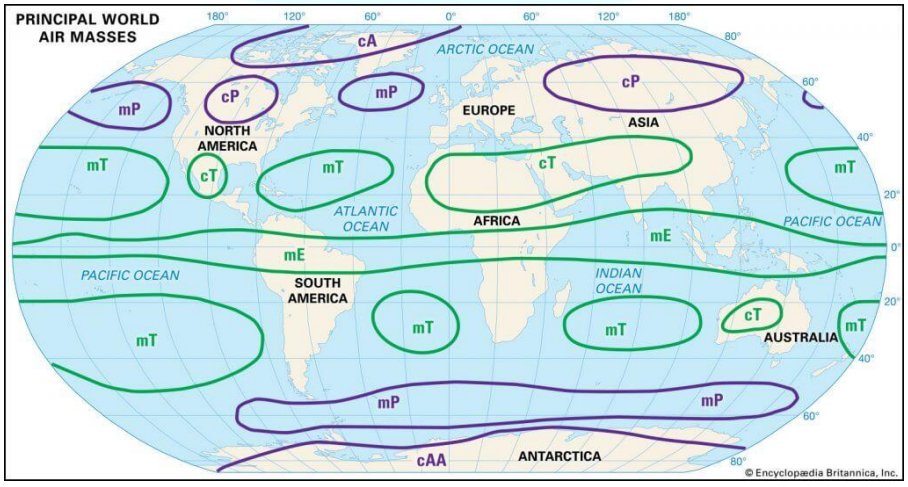
1. Polar
2. Tropical

Temperature

1. Cold
2. Warm

Atmospheric conditions

1. Stable
2. Unstable



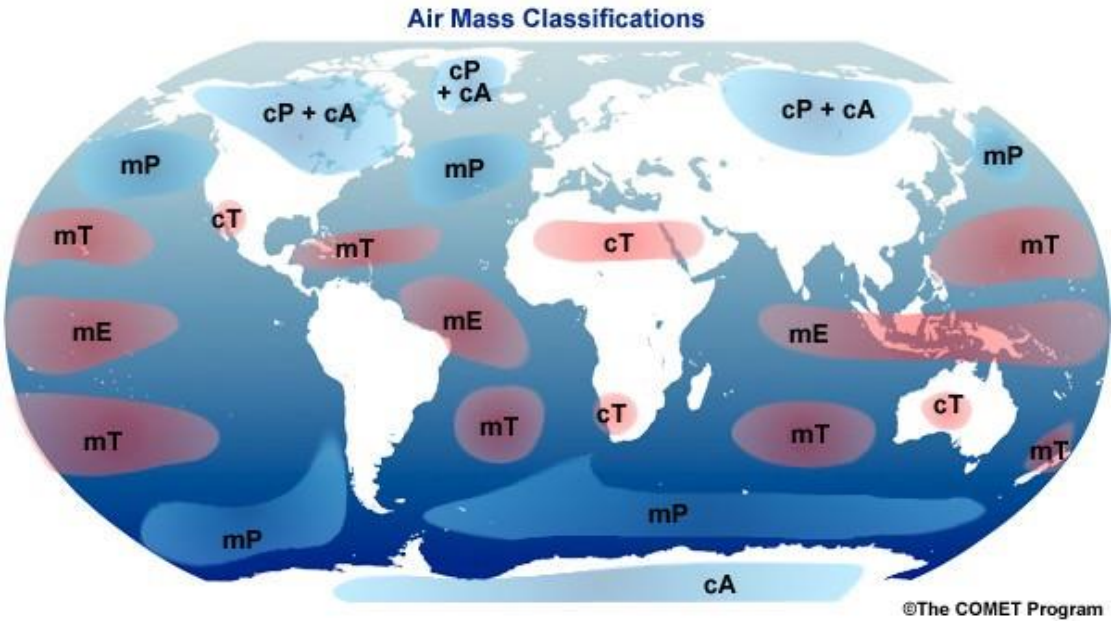
❖ Air masses based on Source Regions

There are five major source regions. These are

1. Warm tropical and subtropical oceans;
2. The subtropical hot deserts;
3. The relatively cold high latitude oceans;
4. The very cold snow-covered continents in high latitudes;
5. Permanently ice-covered continents in the Arctic and Antarctica.

Accordingly, the following types of air masses are recognized

1. Maritime tropical (mT);
2. Continental tropical (cT);
3. Maritime polar (mP);
4. Continental polar (cP);
5. Continental arctic (cA).



- **Cold Air Mass**
  - ➢ A cold air mass is one that is colder than the underlying surface and is associated with instability and atmospheric turbulence. (because of moisture and very low temperature)
  - ➢ Cold source regions (polar air masses)
    1. Arctic Ocean – cold and moist
    2. Siberia – cold and dry
    3. Northern Canada – cold and dry

4. Southern Ocean – cold and moist

❖ **Warm Air Mass**

➢ A warm air mass is one that is warmer than the underlying surface and is associated with stable weather conditions.

➢ Warm source regions (tropical air masses)

1. Sahara Desert – warm and dry
2. Tropical Oceans – warm and moist

❖ **Continental Polar Air Masses (CP)**

➢ Source regions of these air masses are the **Arctic basin, northern North America, Eurasia, and Antarctica.**

➢ These air masses are characterized by **dry, cold, and stable conditions.**

➢ The weather during winter is frigid, clear, and stable.

➢ During summer, the weather is less stable with the lesser prevalence of anticyclonic winds, warmer landmasses, and lesser snow.

❖ **Maritime Polar Air Masses (MP)**

➢ The source region of these air masses are the oceans between **40° and 60° latitudes.**

➢ These are actually those continental polar air masses that have moved over the warmer oceans, got heated up, and have collected moisture.

➢ The conditions over the source regions are cool, moist, and unstable. These are the regions which cannot lie stagnant for long.

➢ The weather during winters is characterized by high humidity, overcast skies, and occasional fog and precipitation.

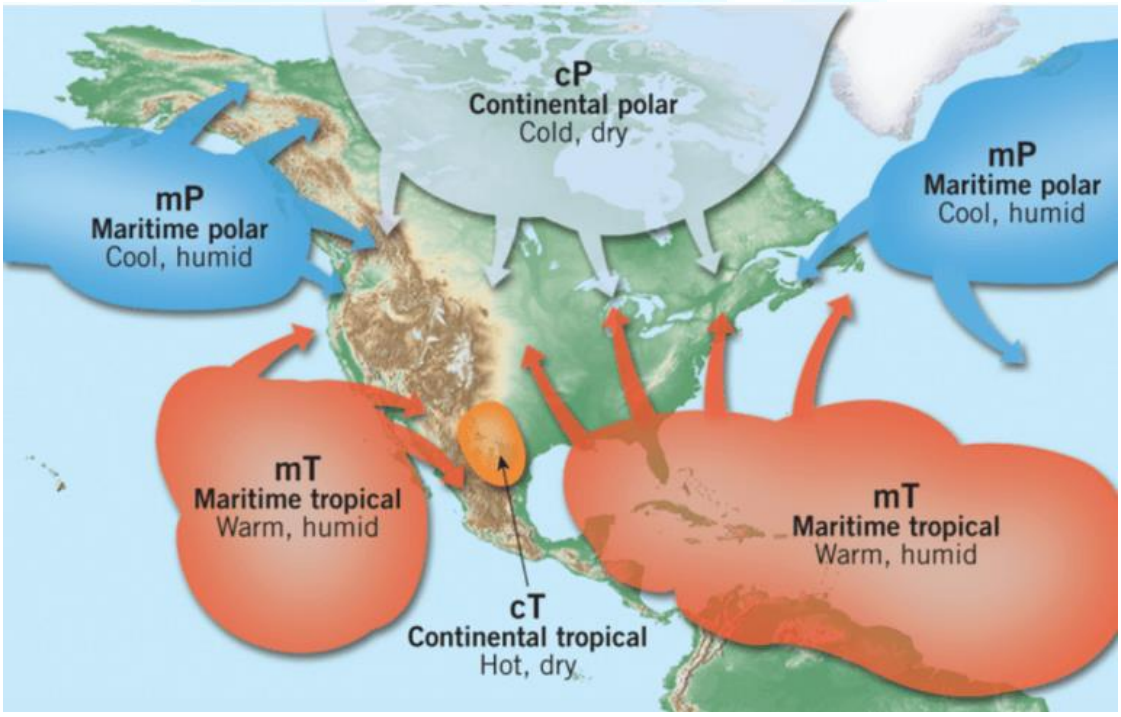
➢ **During summer, the weather is clear, fair, and stable**

❖ **Continental Tropical Air Masses (CT)**

- ➢ The source-regions of the air masses include tropical and subtropical deserts of **Sahara in Africa, and of West Asia and Australia.**
- ➢ These air masses are dry, hot and stable and do not extend beyond the source.
- ➢ **They are dry throughout the year.**

❖ **<u>Maritime Tropical Air Masses (MT)</u>**

- ➢ The source regions of these air masses include the oceans in tropics and sub-tropics such as the **Mexican Gulf, the Pacific, and the Atlantic oceans.**
- ➢ **These air masses are warm, humid, and unstable**.
- ➢ The weather during winter has mild temperatures, overcast skies with fog.
- ➢ During summer, the weather is characterized by high **temperatures, high humidity, cumulus clouds, and convectional rainfall.**



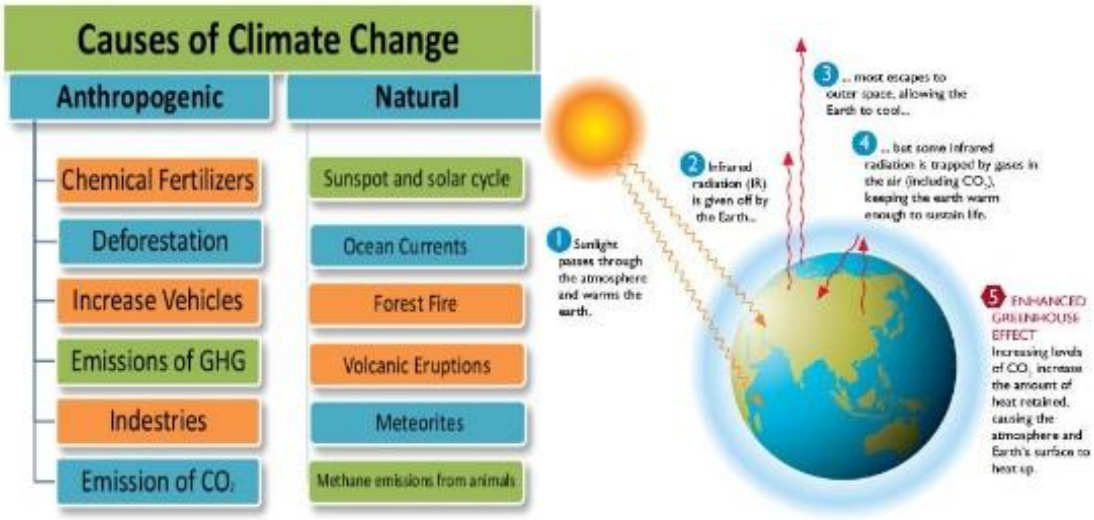
- Ocean atmospheric interactions

- ❖ Ocean–atmosphere interaction commonly refers to the **exchange of energy at the interface of the ocean and atmosphere.**
- ❖ However, besides energy, there is also exchange of mass including that of fresh water (precipitation, runoff, melting of sea ice, evaporation) and of inert and sparingly soluble gasses in seawater [e.g., **oxygen (O_2),methane (CH_4), nitrous oxide (N_2O), carbon dioxide (CO_2)]**, which are quite significant even if they seem small on a unit area basis because of the extent of the ocean surface.
- ❖ The energy exchange usually takes the form of exchange of heat **(sensible heat)**, moisture **(latent heat)**, and momentum **(wind stress)** at the overlapping boundary of the atmosphere and the ocean.
- ❖ The exchange of **heat, moisture, and momentum** are represented usually as fluxes, which are defined as the rate of exchange of energy per unit surface area of ocean–atmosphere interface
- ❖ So the wind stress is the flux of horizontal momentum imparted by the atmospheric wind to the ocean
- ❖ Similarly the latent heat flux refers to the rate at which energy associated with phase change occurs from the ocean to the atmosphere
- ❖ Likewise the sensible **heat flux refers to exchange of heat (other than that due to phase change of water) by conduction and/or convection**
- ❖ There is also heat flux from precipitation, which comes about as a result of the difference in temperature of the raindrops and the ocean surface
- ❖ The heat flux from precipitation could become important in a relatively wet climate.

- Climate change
  - ❖ Climate change includes both **global warming driven by human-induced emissions of greenhouse gasses and the resulting large-scale shifts in weather patterns.**

- Climate Change is a **periodic modification of Earth's climate brought about due to the changes in the atmosphere** as well as the **interactions between the atmosphere and various other geological, chemical, biological and geographical factors within the Earth's system.**
- **Climate change can make weather patterns less predictable.**
- These unforeseen weather patterns can make it difficult to maintain and grow crops, making agriculture-dependent countries like India vulnerable.
- Climate change can make weather patterns less predictable. These unforeseen weather patterns can make it difficult to maintain and grow crops, making agriculture-dependent countries like India vulnerable.
- It is also causing damaging weather events like more frequent and intense hurricanes, floods, cyclones, flooding etc.
- Due to the rising temperature caused by climate change, the ice in the polar regions is melting at an accelerated rate, causing sea levels to rise. This is damaging the coastlines due to the increased flooding and erosion.
- The cause of the current rapid climate change is due to human activities and threatening the very survival of humankind
- The largest driver of warming is the emission of gasses that create a greenhouse effect, of which more than **90% are carbon dioxide (CO2) and methane**
- Fossil fuel burning **(coal, oil, and natural gas)** for energy consumption is the main source of these emissions, with additional contributions from agriculture, deforestation, and manufacturing.
- Temperature rise is accelerated or tempered by climate feedbacks, such as loss of sunlight-reflecting snow and ice cover, increased water vapor (a greenhouse gas itself), and changes to land and ocean carbon sinks.

- Temperature rise on land is about twice the global average increase, leading to desert expansion and more common heat waves and wildfires
- Temperature rise is also amplified in the **Arctic**, where it has contributed to melting permafrost, glacial retreat and **sea ice loss.**
- Warmer temperatures are increasing rates of evaporation, causing more intense storms and weather extremes
- Climate change threatens people with **food insecurity, water scarcity, flooding, infectious diseases, extreme heat, economic losses, and displacement.**
- **Factors that cause climate change**



➢ **Natural Factors**

➔ **Continental Drift**

★ The present-day continents were not the same prior to **200 million years.**

★ They have formed millions of years ago when the landmass began to drift apart due to plate displacement.

★ This movement had an impact on climate change due to the change in the landmass's physical features and

position and the change in water bodies' position like the change in the follow of ocean currents and winds.

- ★ **The drifting of the landmass continues today.**
- ★ The Himalayan range is rising approximately **1 millimeter** every year as the Indian landmass is moving towards the **Asian landmass.**

➔ Variation of the Earth's orbit

- ★ The **Earth's orbit has an impact on the sunlight's seasonal distribution that is reaching the Earth's surface.**A slight change in the Earth's orbit can lead to variation in distribution across the world.
- ★ There are very few changes to the average sunshine. However, it causes a high impact on the geographical and seasonal distribution.
- ★ There are three types of orbital variations – variations in Earth's eccentricity, variations in the tilt angle of the Earth's axis of rotation and precession of Earth's axis.
- ★ These together can cause **Milankovitch cycles**, which have a huge impact on climate and are well-known for their connection to the glacial and interglacial periods.
- ★ **The Intergovernmental Panel on Climate Change** finding showed that the Milankovitch cycles had influenced the behavior of ice formation

➔ Plate tectonics

- ★ Due to the change in the temperature in the core of the Earth, the mantle plumes and convection currents forced the Earth's Plates to adjust leading to the rearrangement of the Earth Plate.
- ★ This can influence the global and local patterns of climate and atmosphere.The oceans' geometry is determined by the continents' position.

- ★ Therefore, the position of the continents influences the pattern of the ocean.
- ★ The location of the sea also plays a crucial role in controlling the transfer of heat and moisture across the globe and determines the global climate.
- ★ The recent example of the tectonic control on ocean circulation is the formation of the Isthmus of Panama about **5 million years** ago, leading to the prevention of direct mixing of the **Atlantic and Pacific oceans**

➔ **Volcanic Activity**

- ★ When a volcano erupts, it emits gasses and dust particles, causing a partial block of the Sunrays.
- ★ **This can lead to the cooling of the weather.**
- ★ Though the volcanic activities last only for a few days, the gasses and ashes released by it can last for a long period, leading to it influencing climate patterns.
- ★ **Sulfur dioxide** emitted by the volcanic activities can combine with water to form tiny droplets of **sulphuric acid.** These droplets are so small that many of them can stay in the air for several years.

➔ **Ocean Currents**

- ★ **Ocean current is one of the major components of the climate system.**
- ★ It is driven by horizontal winds causing the movement of the water against the sea surface.
- ★ **The temperature differences of the water influence the climate of the region**

➢ **Anthropogenic Factors**

➔ **Greenhouse Gasses**

- ★ The greenhouse gasses absorb heat radiation from the sun
- ★ This resulted in an increase in Global Temperature

★ The greenhouse gasses mostly **do not absorb the solar radiation but absorb most of the infrared emitted by the Earth's surface.**

★ **The main greenhouse gasses include**

1. water vapor
2. Carbon dioxide
3. Chlorofluorocarbons
4. Methane
5. Nitrous oxide

➔ **Change in the land use pattern**

★ **Half of the land-use change is said to have happened during the industrial era**.Most of the forests were replaced by agricultural cropping and grazing of lands.

★ The increased **albedo (reflectivity of an object in space)** in the snow-covered high altitude regions due to deforestation led to the cooling of the planet's surface.

★ **The lower the albedo, the more of the Sun's radiation gets absorbed by the planet and the temperatures will rise**. If the albedo is higher and the Earth is more reflective, the more of the radiation is returned to space, leading to the cooling of the planet.

★ Tropical deforestation changes the evapotranspiration rates (the amount of water vapor put in the atmosphere through evaporation and transpiration from trees), causes **desertification and affects soil moisture characteristics.**

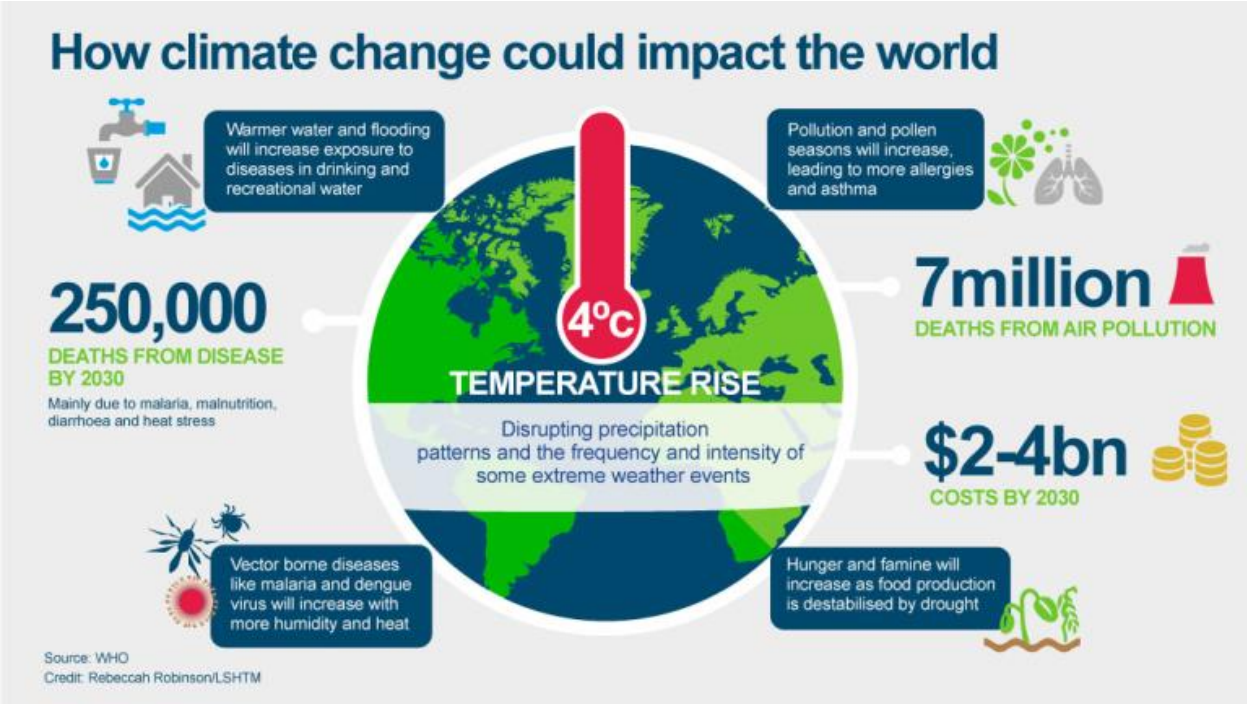
➔ **Atmospheric aerosols**

★ **Atmospheric aerosols can Scatter and absorb the solar and infrared radiation**, change microphysical and chemical properties of the clouds, Solar radiation, when scattered, cools the planet.

- ★ On the other hand, when the **aerosols absorb solar radiation,** it causes an increase in the temperature of the air instead of allowing the sunlight to be absorbed by the Earth's surface.
- ★ **Aerosols can directly affect climate change by absorbing or reflecting solar radiation.**
- ★ They can also produce indirect effects by modifying the cloud's formation and properties.
- ★ They can even be **transported thousands of kilometers away from its source through wind and upper-level circulation in the atmosphere.**

❖ **<u>Impacts of Climate Change</u>**

- ➢ A rise in atmospheric temperature
- ➢ Change in landscapes
- ➢ A risk to the ecosystem
- ➢ Rising sea levels
- ➢ Ocean Acidification
- ➢ Increase in the risk of natural and manmade disasters
- ➢ Health issues
- ➢ Economic impacts
- ➢ Agriculture productivity and food security



- Climate and agriculture
  - ❖ Agriculture and fisheries depend on specific climate conditions.
  - ❖ Temperature changes can cause habitat ranges and crop planting dates to shift and droughts and floods due to climate change may hinder farming practices.
  - ❖ **<u>Agriculture Affecting Climate</u>**
    - ➢ Greenhouse Gasses
      - ➔ Farming in particular releases significant amounts of methane and **nitrous oxide**, two powerful greenhouse gasses.
      - ➔ **Methane** is produced by livestock during digestion due to enteric fermentation and is released via belches.
      - ➔ **Livestock** is alone responsible for **44% of methane emissions.**
      - ➔ **53% of Nitrous oxide** emissions are an indirect product of organic and mineral nitrogen fertilizers.
      - ➔ Fertilizers rich in nitrogen pollute water and threaten the aquatic ecosystem.

- ➢ Monocultural Practices
  - ➔ Monocultures along with pesticides and herbicides lead to the loss of biodiversity.
  - ➔ These practices leave **soils low in organic matter and prevent formation of deep, complex root systems leading to reduced water holding capacity.**
- ➢ Clearing uncultivated land for farming can lead to the destruction of natural ecosystems, which may have a devastating effect on the local wildlife and biodiversity and the micro-climate.
- ➢ Many agricultural sectors need large amounts of water, which may cause water scarcity and drought.

❖ Changing Climate Affecting Agriculture

- ➢ Extreme heat
  - ➔ Crops need suitable **soil, water, sunlight, and heat to grow**.
  - ➔ However, extreme heat events and reductions in precipitation and water availability have hampered the crop productivity.
- ➢ Changing Rainfall Patterns
  - ➔ Rainfall patterns have already begun shifting across the country, and such changes are expected to intensify over the coming years
  - ➔ This is likely to mean more intense periods of heavy rain and longer dry periods, even within the same regions.
- ➢ Floods
  - ➔ Flooding in many agricultural regions of the country have been witnessed and these floods have devastated crops and livestock, accelerated soil erosion and have polluted water.

- Climate and diseases

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Environmental changes	Example diseases	Pathway of effect
Dams, canals, irrigation	Schistosomiasis	▲ Snail host habitat, human contact
	Malaria	▲ Breeding sites for mosquitoes
	Helminthiasies	▲ Larval contact due to moist soil
	River blindness	▼ Blackfly breeding, ▼ disease
Agricultural intensification	Malaria	Crop insecticides and ▲ vector resistance
	Venezuelan haemorraghic fever	▲ rodent abundance, contact
Urbanization, urban crowding	Cholera	▼ sanitation, hygiene; ▲ water contamination
	Dengue	Water-collecting trash, ▲ *Aedes aegypti* mosquito breeding sites
	Cutaneous leishmaniasis	▲ proximity, sandfly vectors
Deforestation and new habitation	Malaria	▲ Breeding sites and vectors, immigration of susceptible people
	Oropouche	▲ contact, breeding of vectors
	Visceral leishmaniasis	▲ contact with sandfly vectors
Reforestation	Lyme disease	▲ tick hosts, outdoor exposure
Ocean warming	Red tide	▲ Toxic algal blooms
Elevated precipitation	Rift valley fever	▲ Pools for mosquito breeding
	Hantavirus pulmonary syndrome	▲ Rodent food, habitat, abundance

▲ increase ▼ reduction

- Microclimate in urban areas
  - ❖ A microclimate is the climate of any small area that is different to its surrounding area. An urban heat island is one type of microclimate.
  - ❖ **<u>Urban heat islands</u>**
    - ➢ An urban heat island is a type of microclimate that is created when an urban area becomes warmer than the surrounding area.
    - ➢ It is common in larger urban areas such as **Tokyo, New York City and Paris**
  - ❖ **<u>Key terms about urban heat islands</u>**

- Urban Heat Island
  - the increased temperature over urban areas compared to surrounding rural areas.
  - It is called an island because in map view, it appears as though the urban area is an **'island' of heat in a colder 'sea' of the rural area surrounding it**
- Urban Heat Island Intensity
  - the amount of the temperature difference.
  - A large intensity means the temperature is a lot warmer in the urban area compared to the surrounding rural area.
- Structures
  - Any artificial construction including buildings, scaffolding, landscaped vegetation, roads, paths and covered farmland (e.g. a greenhouse or plasticulture)
- Human activities
  - any undertaking being done by humans, including the effects of non-climate related activities such as transport and agriculture
- Microclimate
  - the average weather conditions of a small area.
- Aspect
  - the direction in which something faces. In the northern hemisphere, south facing buildings receive more sunlight and therefore warmth; they have a **'southerly aspect'**
- Urban canyons
  - the tall buildings in urban areas create streets that act like canyons or deep valleys.
  - **Canyons create shade and thus cooler temperatures**, and can funnel winds increasing their speeds. A good example is

Q**ueen's Road Central in Hong Kong,** or **7th Avenue around Times Square in New York.**

- ➢ Albedo
  - ➔ the reflectivity of a surface. Dark surfaces have a lower albedo and absorb more heat.

❖ Features of microclimates

- ➢ Temperature
- ➢ Wind speed
- ➢ Wind direction
- ➢ Humidity

❖ **Causes of urban microclimates**

- ➢ **Albedo**
- ➢ **Building material**
  - ➔ **Construction materials can affect albedo**, not just through their color but also their **specific heat capacity** and **thermal conductivity.**
  - ➔ Specific heat capacity is a scientific term that relates to the amount of heat energy (usually measured in joules) that is required to raise the temperature of a material by **1 Kelvin.**
  - ➔ **Concrete surfaces** cause temperatures to rapidly rise when they are heated by the sun, then rapidly cool when the sun goes down
- ➢ **Building density and height**
  - ➔ **Buildings are an important blockage of wind.**
  - ➔ The obstacle created by dense buildings causes the wind to be pushed over and around the city, which can lead to lower urban wind speeds.
  - ➔ As the wind is diverted around corners, it can also change direction.

- ➔ Wind is affected from ground level, and the point in the atmosphere at which wind is no longer affected by buildings is known as the **Urban Boundary Layer.**
- ➔ The diagrams below show how wind patterns will change due to the interference of buildings.

➢ **Anthropogenic heat**

- ➔ Mechanical heat, produced by vehicles, air conditioning units and so on
- ➔ Ambient heat, produced by the heating systems of buildings in cooler climates

➢ **Air conditioning**

- ➔ Although air conditioning makes individual indoor spaces cooler, the overall impact is to increase the urban temperature.
- ➔ All air conditioning works on the basis of using a mechanism to push air around gas coolants. A byproduct of this mechanism is to produce heat, especially from the fan that pushes the air through the system.
- ➔ Air conditioning units commonly have an indoor air circulator and an outdoor one that prevents the heat generated remaining inside.

➢ **Drainage systems**

- ➔ Water acts like a giant heat **'sponge',** absorbing energy during warm periods and gradually releasing it during cool periods.
- ➔ Cities with effective drainage systems have less surface water as the rainfall (or floodwater) is removed quickly, so the urban area will experience faster warming and cooling as a result.
- ➔ **Cities without effective drainage will see a more gradual rise and fall in temperature.**