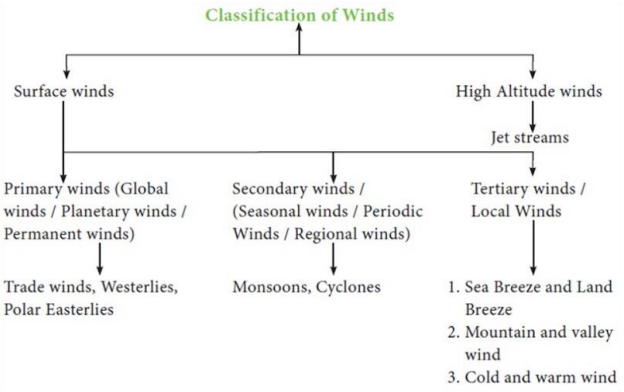
LECTURE 4 – CLIMATOLOGY II

WINDS

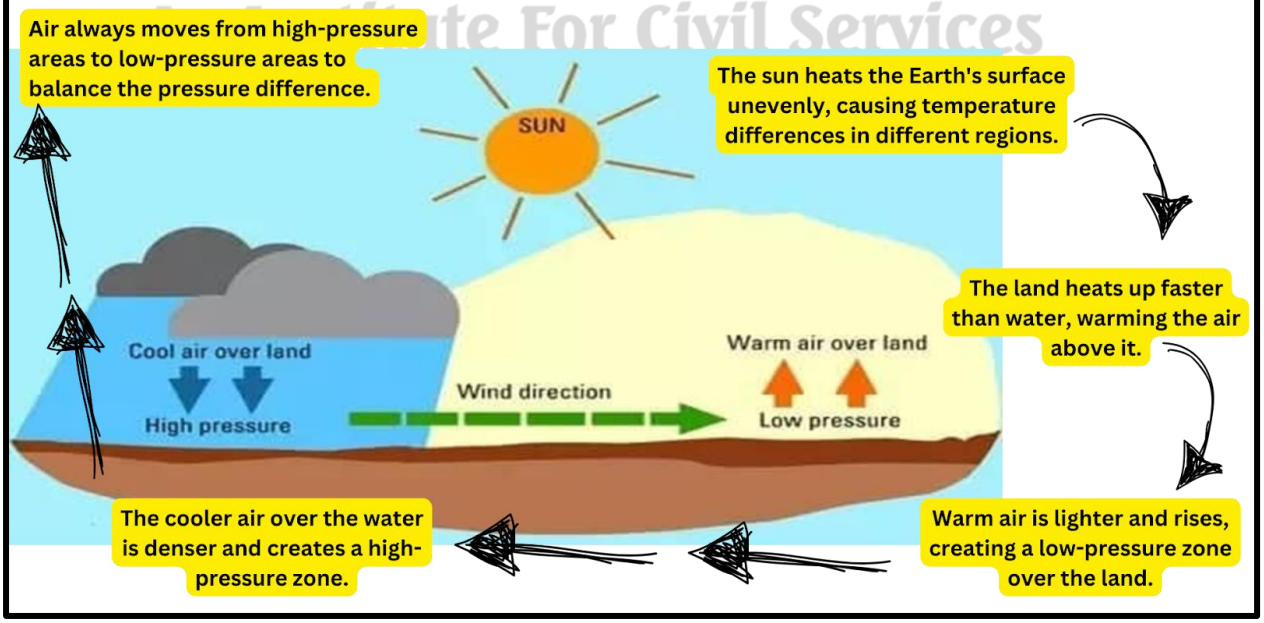
WINDS

- Winds are horizontal movements of air caused by differences in atmospheric pressure.
- They play a crucial role in weather patterns and climate.
- Winds are classified into three main types based on their occurrence and characteristics:
- Permanent Winds (Primary Winds or Planetary Winds)
- Secondary Winds (Periodic Winds)
- Local Winds (Tertiary Winds)

ANOTHER CLASSIFICATION OF WINDS



WIND FORMATION

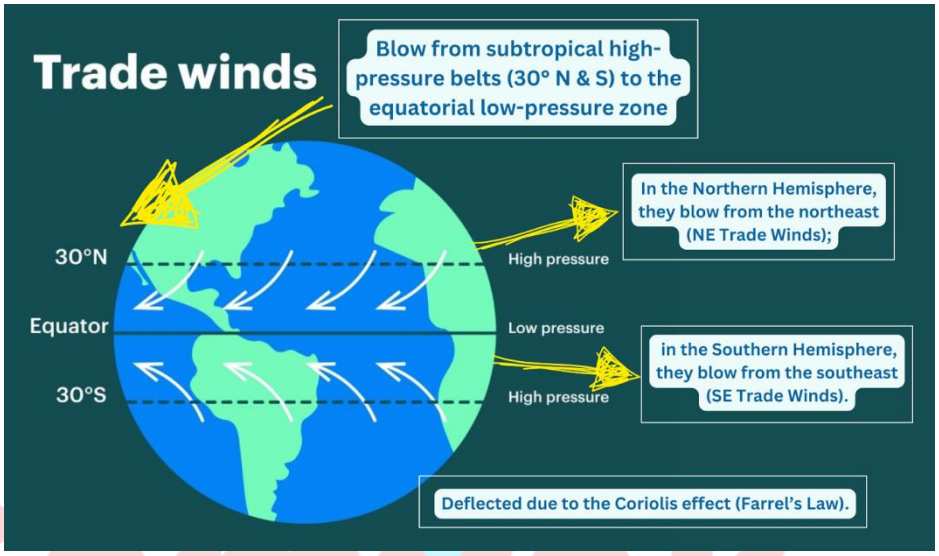


CLASSIFICATION OF WINDS

PLANETARY WINDS

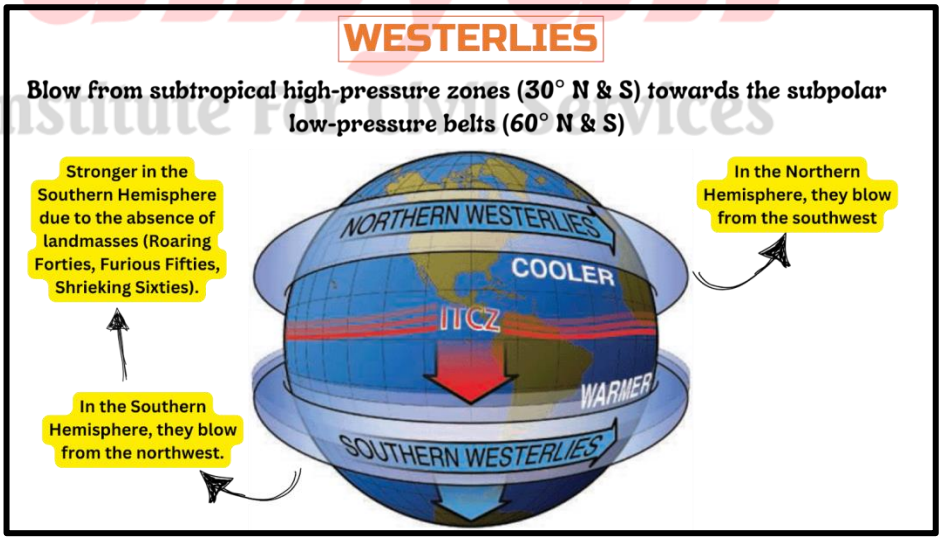
- These winds blow consistently throughout the year in a specific direction, driven by the general atmospheric circulation and the Earth's rotation. They include:

TRADE WINDS

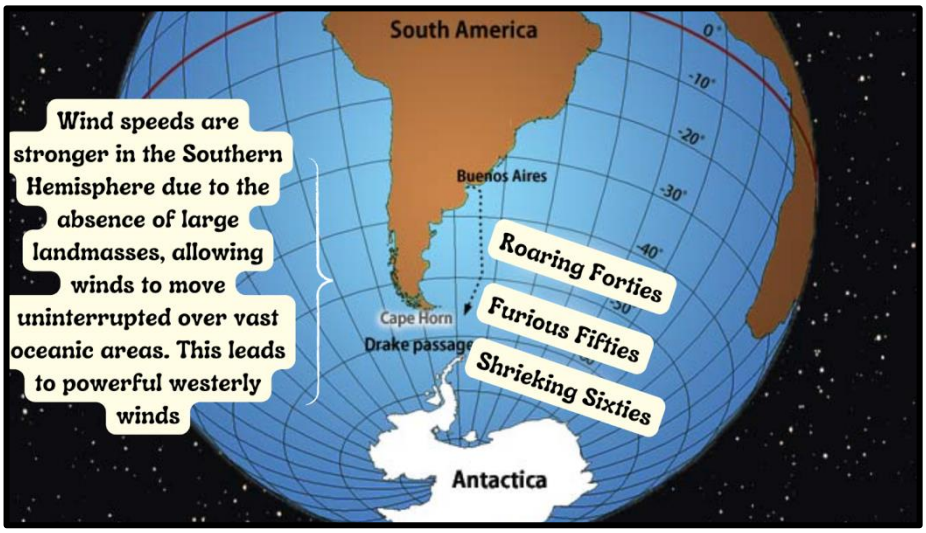


- These winds are **warm and moist**, leading to heavy rainfall near the equator (ITCZ – Intertropical Convergence Zone).

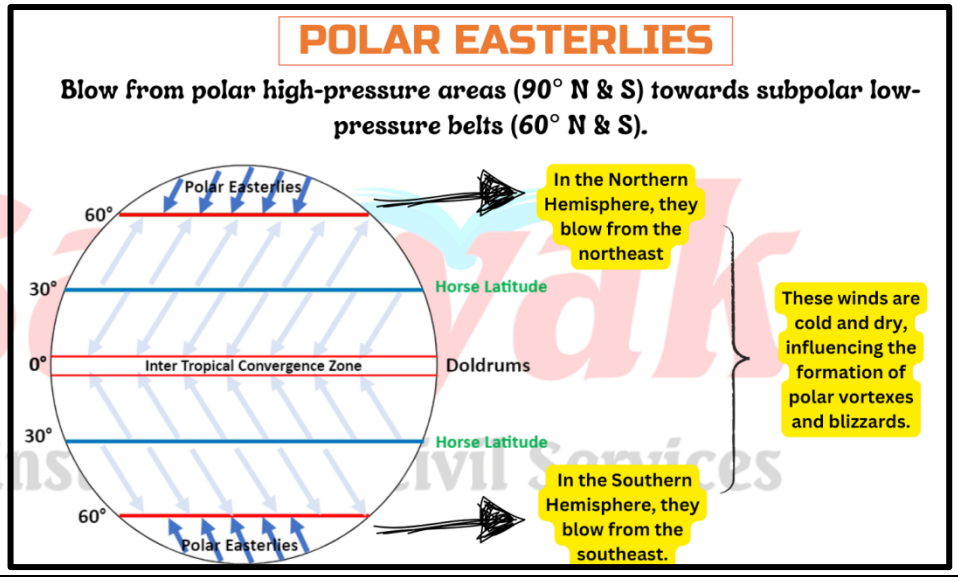
WESTERLIES

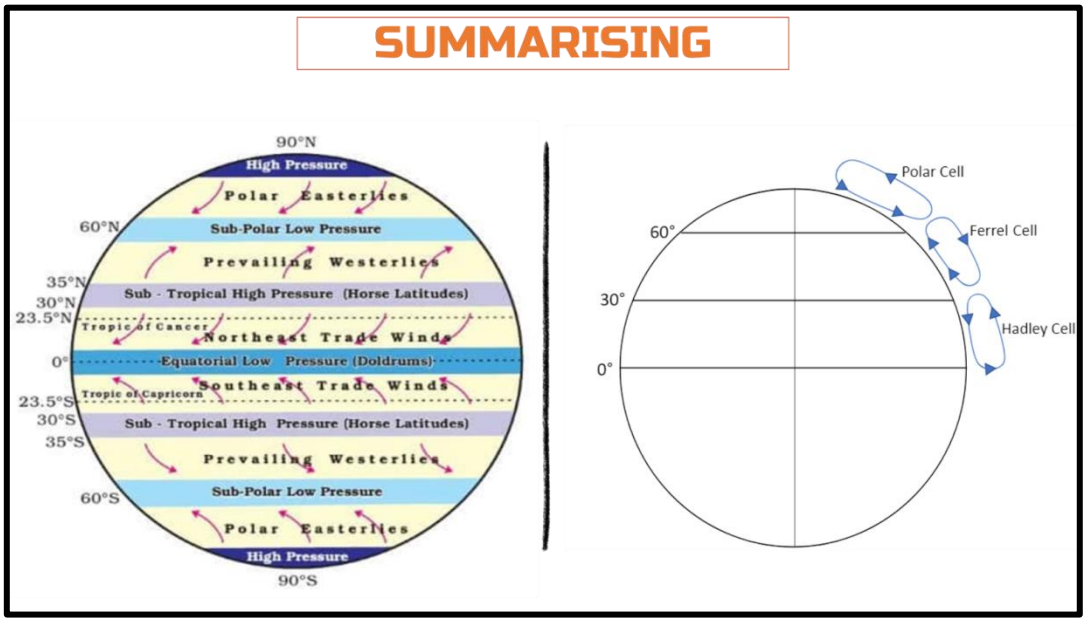


- Bring much **precipitation in the western parts of the continents** (e.g. north-west European coasts)



POLAR EASTERLIES





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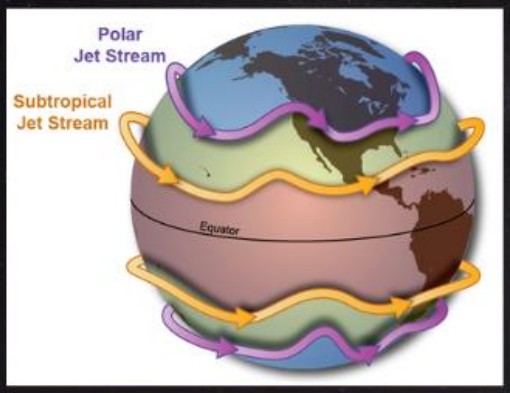
JET STREAMS

Jet streams are narrow bands of strong winds that exist in the upper levels of the atmosphere, typically around 30,000 feet (9,100 meters) in elevation. These winds flow from west to east and are influenced by global temperature contrasts and the Earth's rotation.



FORMATION OF JET STREAMS

Jet streams form due to the temperature differences between hot and cold air masses. The strongest jet streams occur in winter when these temperature differences are the most pronounced.

CHARACTERISTICS OF JET STREAMS

- High-Speed Wind Bands – Jet streams are strong, fast-moving air currents in the upper troposphere, flowing at speeds that can reach 300 km/h.
- Altitude and Location – Found at altitudes between 11 to 13 km, their position varies with latitude and season.
- Direction and Flow Pattern – These winds move from west to east due to the Earth's rotation, exhibiting a wavelike motion rather than a straight path.
- Temperature Influence – They form due to sharp temperature differences between warm and cold air masses.
- Discontinuity and Variability – While jet streams circle the globe, they are often discontinuous and shift positions seasonally.
- Number of Jet Streams – The atmosphere contains four primary jet streams, each playing a role in weather and climate regulation.

TYPES OF JET STREAMS

Polar Jet Streams

- Found between 50° and 70° latitude in both hemispheres, at 7–12 km altitude.
- Stronger in winter, reaching speeds of 250 km/h due to increased temperature contrast between polar and mid-latitude air masses.
- Affects weather in North America, Europe, and Asia, steering storm systems and influencing cold waves.

Subtropical Jet Streams

- Located near 30° latitude in both hemispheres, at altitudes of 10–16 km.
- Weaker than polar jets, with speeds up to 150 km/h.
- Plays a role in the global circulation system, affecting tropical cyclone development.

Tropical Easterly Jet Streams (TEJ)

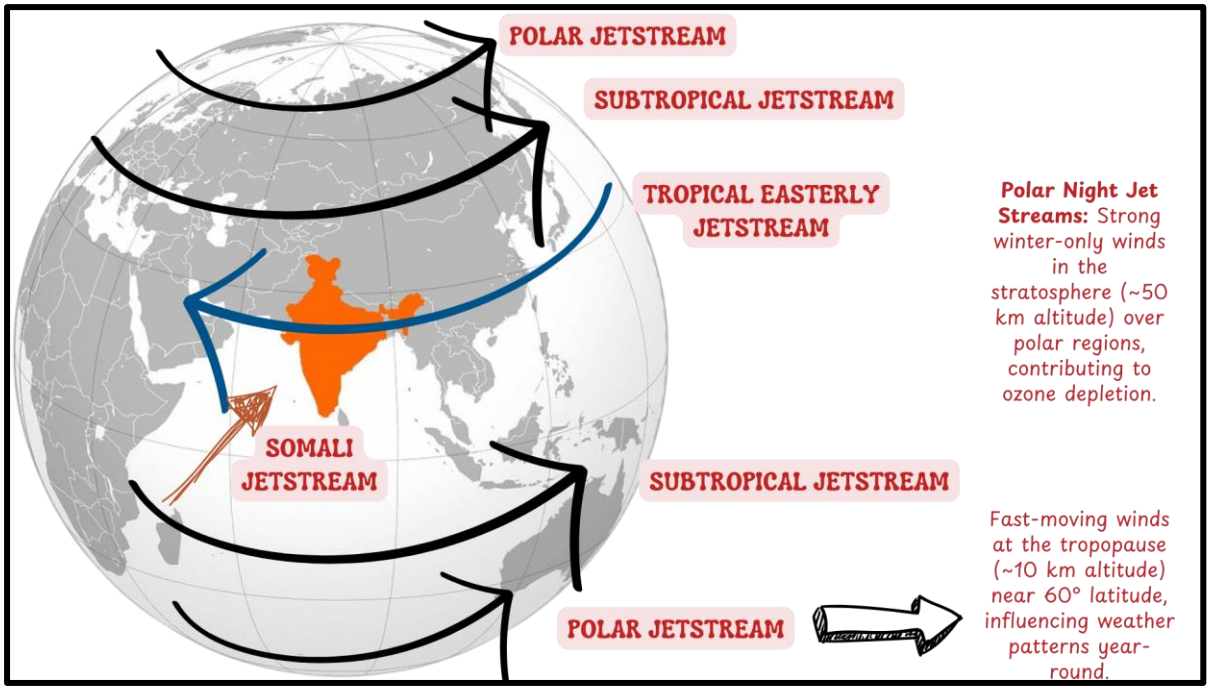
- Found between 10° and 20° latitude, primarily over India, Africa, and the Indian Ocean.
- Occurs during summer, linked to the intense heating of the Tibetan Plateau.
- Directly influences South Asian monsoons, guiding the movement of tropical depressions.

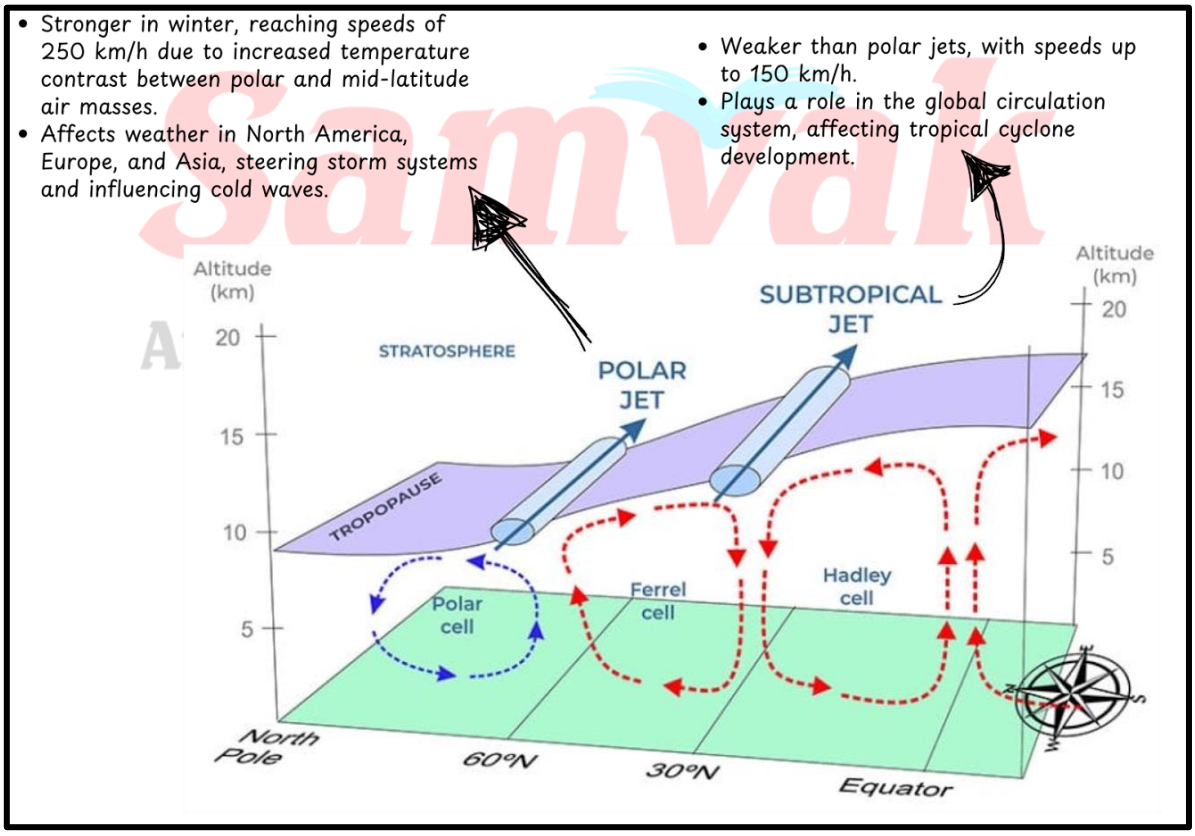
Low-Level Jet Streams

- Found closer to the Earth's surface, at 0.5–3 km altitude.
- Strongest at night, often associated with severe thunderstorms and tornadoes.
- Common in regions like the Great Plains of the United States

Polar Night Jet Streams

- Present in polar stratospheric regions at 20–30 km altitude during winter.
- Form due to the temperature gradient between the dark polar regions and sunlit lower latitudes.
- Plays a role in polar vortex formation and influences ozone layer dynamics.

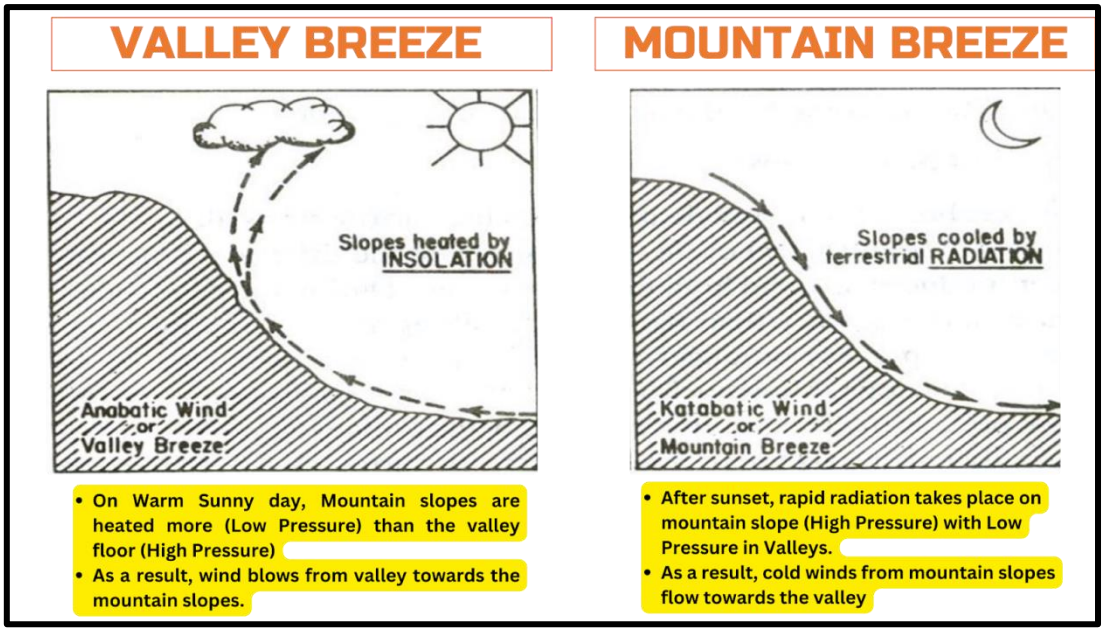




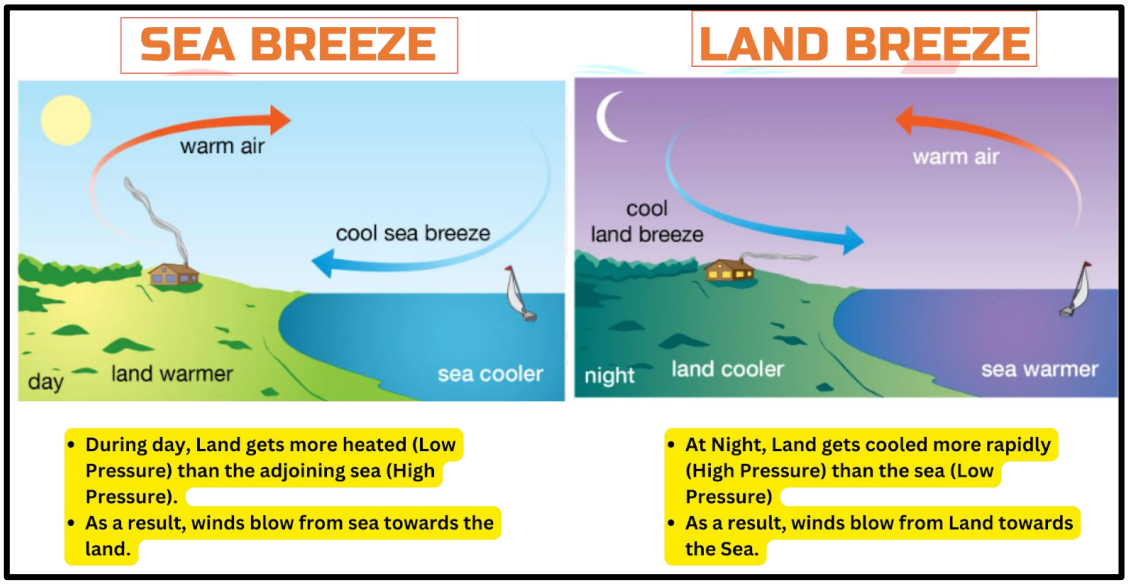
SECONDARY WINDS/PERIODIC WINDS

- These winds change direction based on seasons or time of the day.

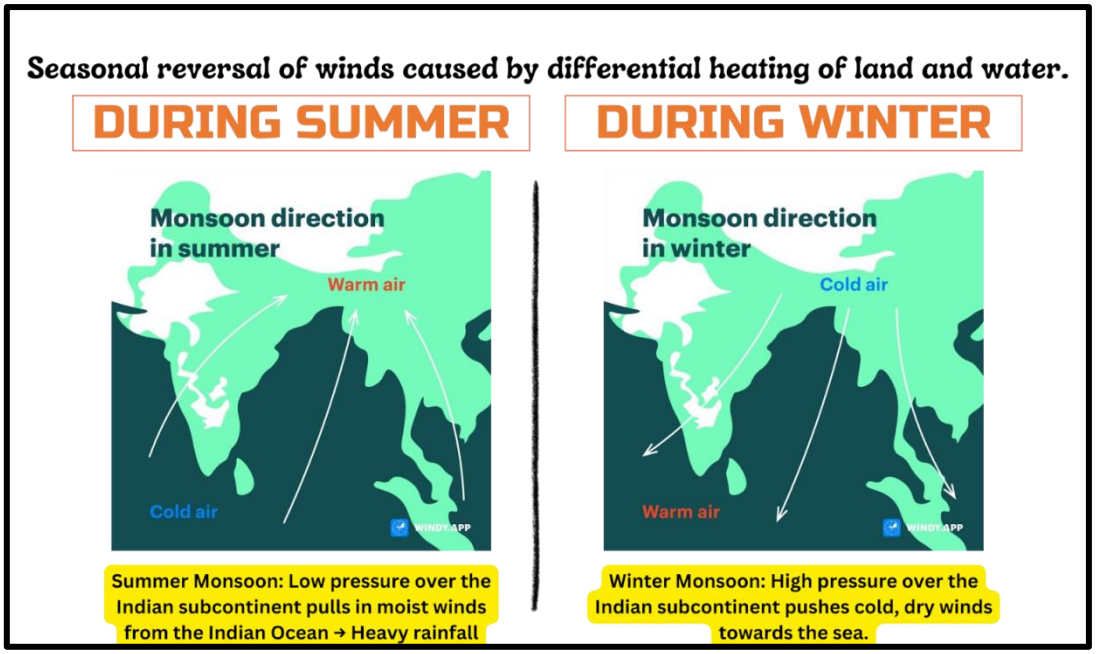
VALLEY BREEZE AND MOUNTAIN BREEZE



SEA BREEZE AND LAND BREEZE

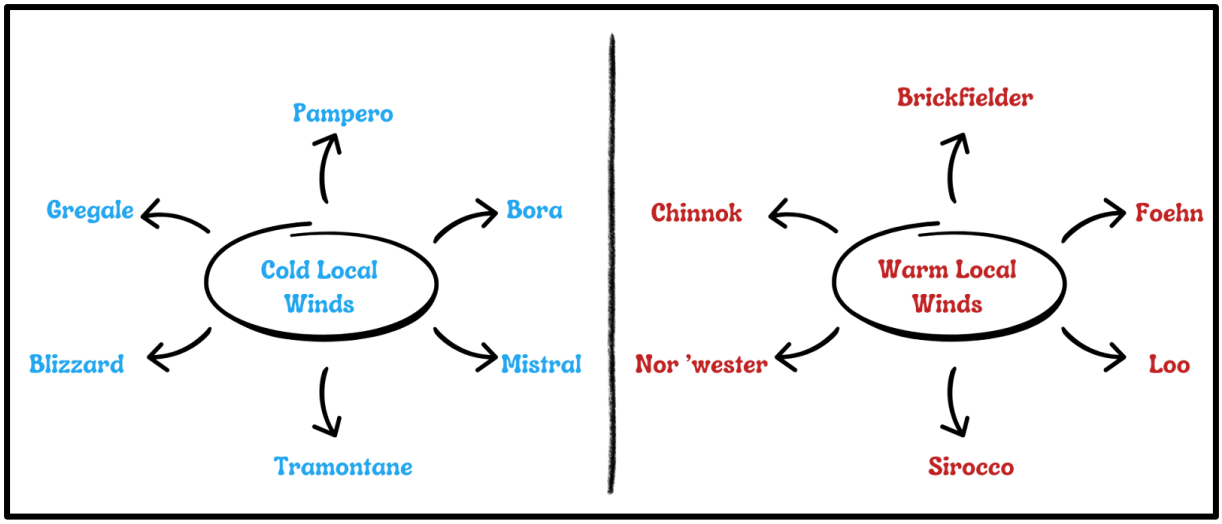


MONSOON WINDS



LOCAL WINDS

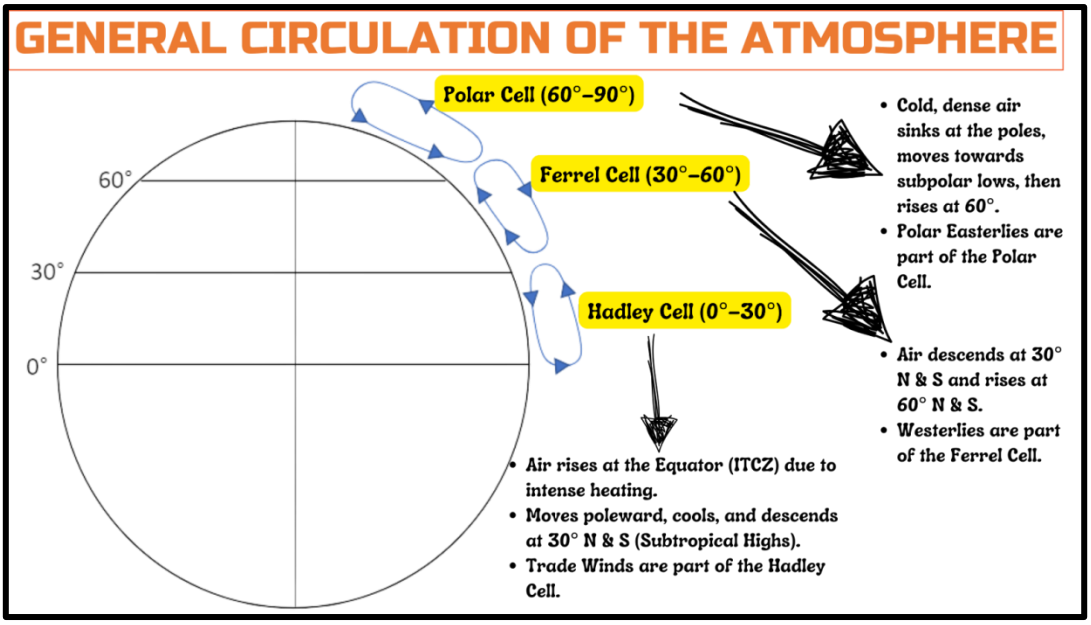
- These winds are confined to specific regions and are influenced by local temperature and pressure variations.



COLD LOCAL WINDS	
Pampero	➢ In the pampas region of South America ➢ Associated with **cold fronts, thunderstorms, rain, and temperature drops**.
Bora	➢ Strong cold wind that blows from the northeast onto the **Adriatic region of Italy, Slovenia, and Croatia.** ➢ Causes **cold, blustery, but clear** weather.
Mistral	➢ Originates from the **Alps**, moving through the **Rhone Valley** to the **Mediterranean Sea**; Cold, dry, and high-velocity wind ➢ People protect **orchards with thick hedges** and build homes facing the sea.
Tramontane	➢ **From Alps to Italy Coast**
Gregale	➢ Strong and cold wind that blows in the **Mediterranean region**
Blizzard	➢ Stormy polar wind carrying dry snow. ➢ Low visibility due to ice crystals, wind speeds of 80-96 km/h. ➢ Causes a sudden temperature drop and heavy snowfall. ➢ Known as '**Norther'** in southern USA and '**Burran'** in Siberia

WARM LOCAL WINDS	
Chinnok	➢ Winds in **USA and Canada** move down the west slopes of the **Rockies** ➢ Keeps the grasslands clear of snow during much of the winter.
Foehn	➢ Warm winds in the region of Alps mountains ➢ **Helps animal grazing** by melting snow and **aids the ripening of grapes**.
Loo	➢ In Northern India and Pakistan, hot and dry wind blows from the west in the months of **May and June**
Sirocco	➢ **Mediterranean wind that comes from the Sahara** and reaches hurricane speeds in North Africa and Southern Europe.
Brickfielder	➢ Warm summer wind that blows dust and sand **across Australia.**
Nor 'wester	➢ **East coast of New Zealand**; Warm dry winds

WIND MEASUREMENT
➢ **Anemometers** – used for measuring the speed of the wind. ➢ **Wind vanes** –used for determining the direction of the wind.



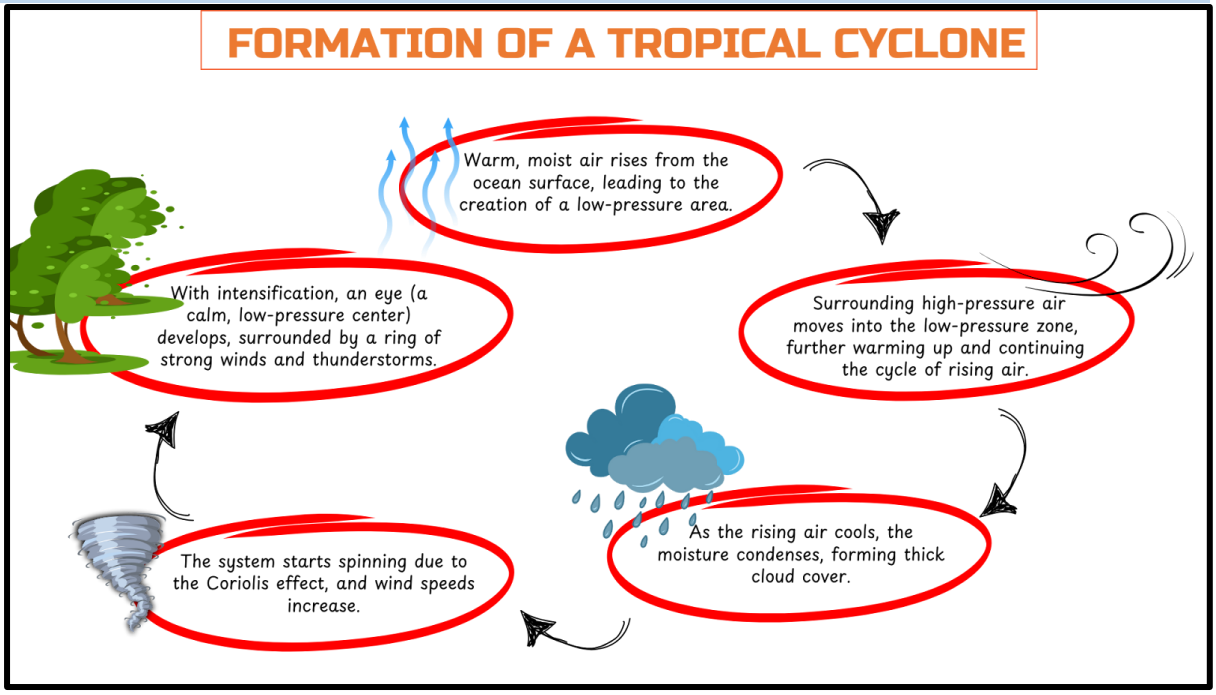
TROPICAL CYCLONES

- Tropical cyclones are intense circular storms that originate over warm ocean waters near the equator. They are characterized by strong winds, heavy rainfall, and low-pressure centers.
- These storms significantly impact coastal regions, causing flooding, storm surges, and destruction.
- The cyclonic wind movements are **anti-clockwise in the northern hemisphere** and **clockwise in the southern hemisphere** (This is due to Coriolis force).

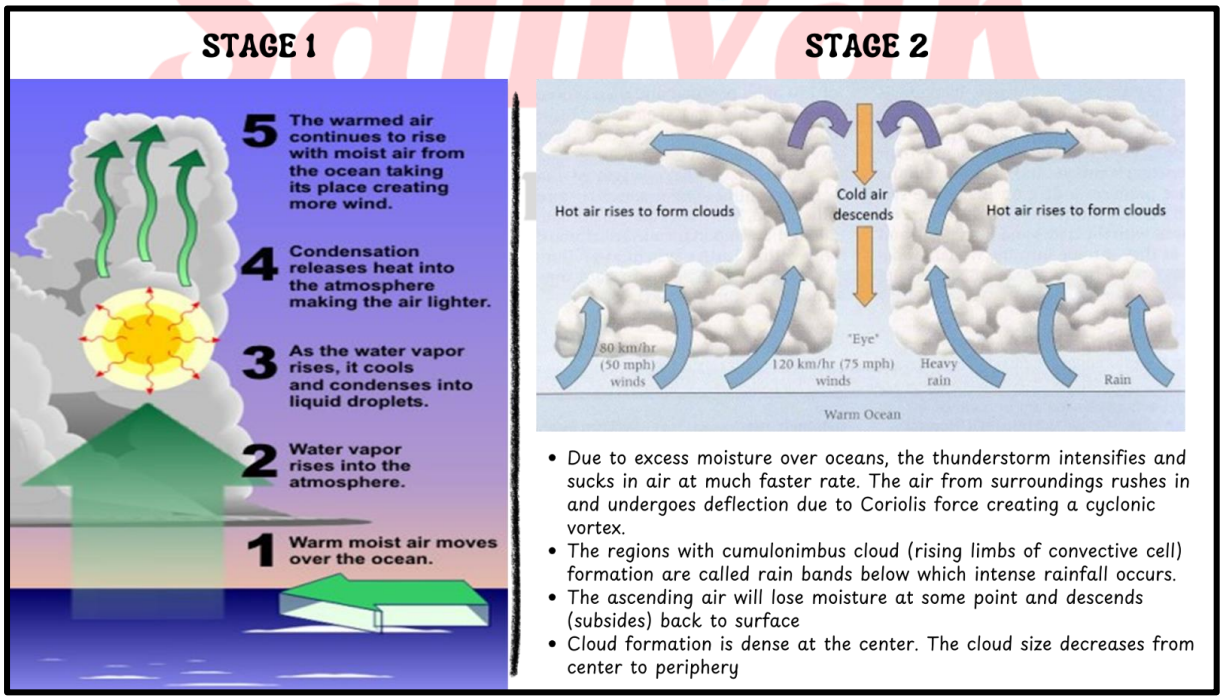
CONDITIONS FAVOURABLE FOR TROPICAL CYCLONE FORMATION

CONDITIONS	EXPLANATIONS
Large sea surface with temperature higher than 27° C	➢ It's a **source of moisture** which feeds the storm. The condensation of moisture **releases enough** latent heat of condensation to drive the storm.
Presence of the Coriolis force enough to create a cyclonic vortex	➢ To create a **cyclonic vortex** ➢ **No cyclones at equator because of zero Coriolis Force**
Wind Shear - difference between wind speeds at different heights.	➢ Tropical cyclones develop **when the wind is uniform that is Wind shear is weak or small variation in the vertical wind speed**
Upper Tropospheric Divergence	➢ Necessary so that the rising air currents within the cyclone continue to be pumped out and **a low pressure is maintained at the center.**

FORMATION OF TROPICAL CYCLONES



- Tropical cyclones have a **thermal origin**, and they **develop over tropical seas during late summers** (August to mid-November).



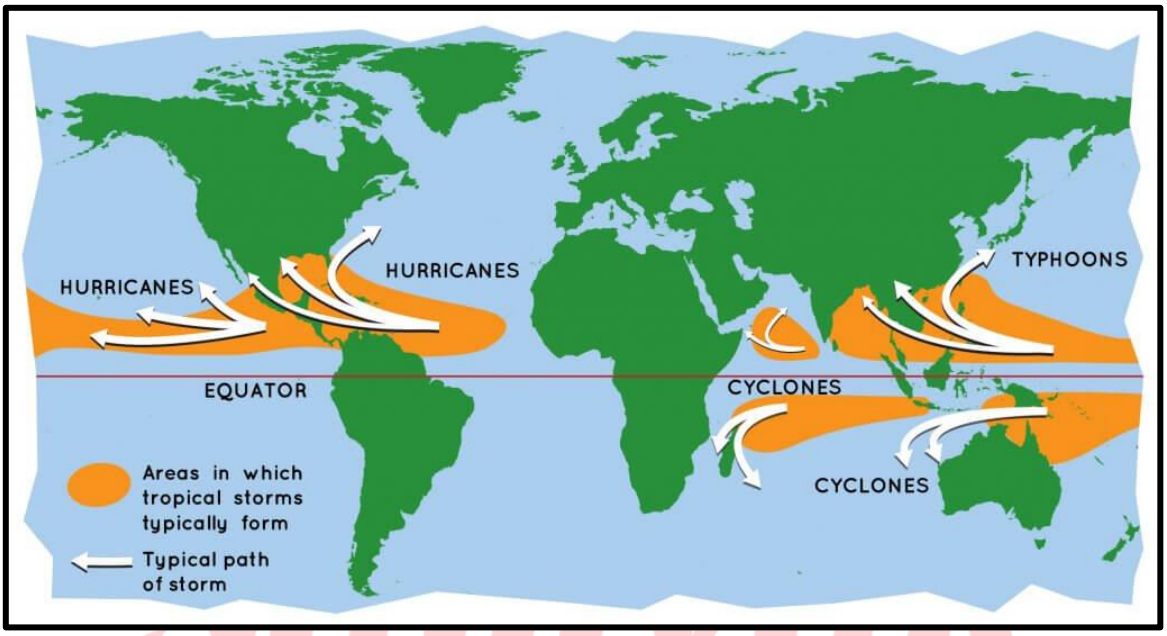
- Due to excess moisture over oceans, the thunderstorm intensifies and sucks in air at much faster rate. The air from surroundings rushes in and undergoes deflection due to Coriolis force creating a cyclonic vortex.
- The regions with cumulonimbus cloud (rising limbs of convective cell) formation are called rain bands below which intense rainfall occurs.
- The ascending air will lose moisture at some point and descends (subsides) back to surface
- Cloud formation is dense at the center. The cloud size decreases from center to periphery

EYE OF A TROPICAL CYCLONE

- ✓ **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**

- ✓ 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.

PATH AND NOMENCLATURE OF TROPICAL CYCLONES



- ➢ 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.

HOW ARE CYCLONES NAMED?

- ✓ In 2000, a group of nations called WMO/ESCAP (World Meteorological Organisation/United Nations Economic and Social Commission for Asia and the Pacific), which comprised Bangladesh, India, the Maldives, Myanmar, Oman, Pakistan, Sri Lanka and Thailand, decided to start naming cyclones in the region.
- ✓ After each country sent in suggestions, the WMO/ESCAP Panel on Tropical Cyclones (PTC) finalised the list.
- ✓ The WMO/ESCAP expanded to include five more countries in 2018 — Iran, Qatar, Saudi Arabia, United Arab Emirates and Yemen.
- ✓ In 2004, a formula for naming cyclones in the Indian Ocean was agreed upon. Bangladesh, India, the Maldives, Myanmar, Oman, Pakistan, Sri Lanka, and Thailand are the eight countries that contributed names that are assigned sequentially whenever a cyclonic storm develops.

NOTE – As per the guidelines to adopt names of cyclones the maximum length of the name will be eight letters

REGIONS	REGIONAL NAMES
Indian Ocean	Cyclones
Atlantic Ocean	Hurricanes
Western Pacific and South China Sea	Typhoons
Western Australia	Willy-Willies

RECENT CYCLONES

ARABIAN SEA	BAY OF BENGAL
➢ Cyclone Vayu (2019) ➢ Cyclone Nisarga (2020) ➢ Cyclone Tauktae (2021), ➢ Cyclone Biporjoy.(2023)	➢ Cyclone Michaung(2023) ➢ Cyclone Sitrang(2022) ➢ Cyclone Mocha(2023) ➢ Cyclone Midhili(2023)

SQUALLS

- A **squall** refers to a rapid increase in wind speed of at least 8 meters per second (18 miles per hour) or more that lasts for a minimum of one minute. This term is commonly used by weather forecasters to describe a brief but intense wind event, which often includes gusts that are short-lived but strong.
- Squalls are typically associated with certain weather phenomena such as rain, hail, or thunder.
- When associated with a group of thunderstorms, a **line squall** refers to the strong winds that occur along a squall line—a linear band of thunderstorms. These squalls can extend over hundreds of kilometers and bring intense, gusty winds as well as severe weather conditions.

STORM SURGE

- It is a sudden rise in sea level near the coast caused by a powerful tropical cyclone.
- Storm surge causes seawater to inundate low-lying coastal areas.

ANTI-CYCLONES

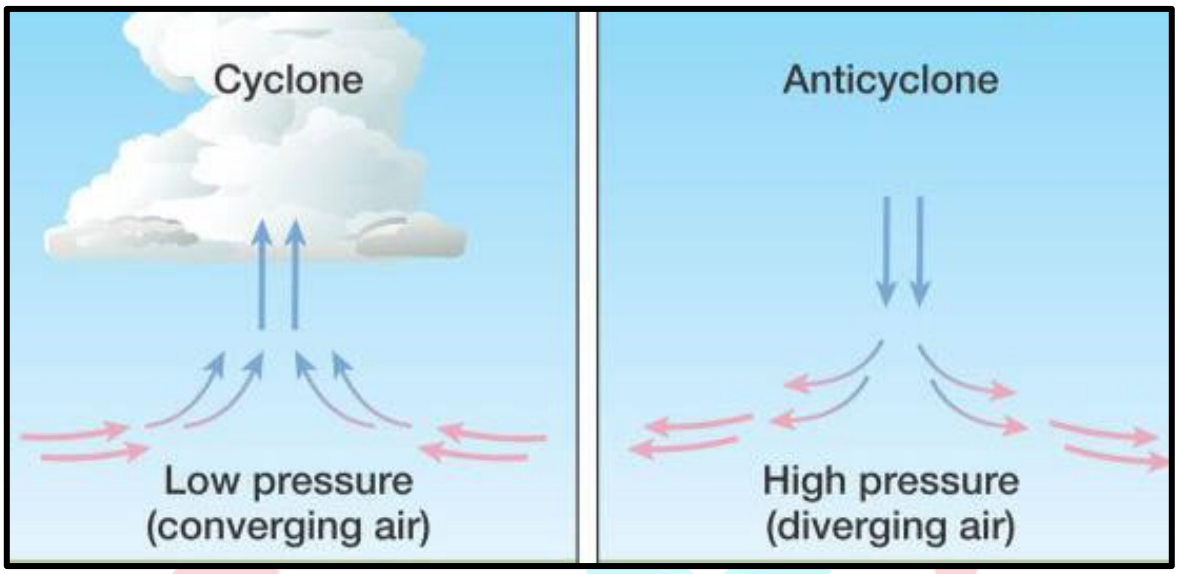
- An **anticyclone** is a weather phenomenon characterized by a large-scale circulation of winds that rotate around a central area of high atmospheric pressure. It is the opposite of a cyclone, where winds rotate counterclockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere.

SEQUENCE OF AN ANTICYCLONE:

- **Formation of High Pressure Area:** An anticyclone forms when there is a high-pressure system in the atmosphere, typically created by descending air. As air descends, it compresses and warms, leading to higher atmospheric pressure in the center.
- **Wind Circulation:** In the Northern Hemisphere, winds rotate in a clockwise direction around the high-pressure center due to the Coriolis effect. In the Southern Hemisphere, the rotation is counterclockwise.
- **Weather Effects:**
    - The circulation of winds around an anticyclone suppresses upward air movement, leading to clear skies. This happens because the descending air inhibits the formation of clouds and storms.

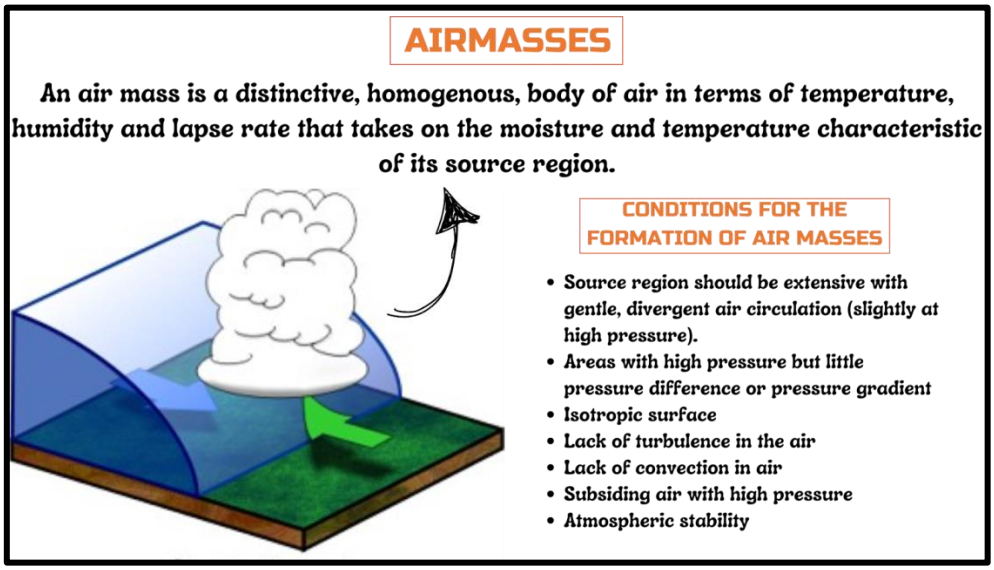
- Air within the anticyclone is generally cooler and drier. As the descending air warms, it reduces the moisture content, contributing to lower humidity and often leading to dry conditions.

➢ **Formation of Fog:** During the night, especially in regions with an established anticyclone, the clear skies allow for rapid cooling of the surface. The cooling air can cause moisture to condense, leading to the formation of fog, particularly in valleys or low-lying areas.



CYCLONES	ANTI-CYCLONES
➢ It's a low pressure system with surroundings of high pressure	➢ It's a high pressure system with of low pressure
➢ It blows anti-clockwise in the Northern Hemisphere	➢ It blows clockwise in the Northern Hemisphere
➢ It blows clockwise in Southern Hemisphere	➢ It blows anti-clockwise in the Southern Hemisphere
➢ It is associated with cloudy skies, heavy rainfall and stormy winds	➢ Its associated with clear skies, mild winds and dry weather

AIRMASS AND FRONTS



SIZE AND DIMENSION

- Extend till **Tropopause**
- Width is hundreds of km
- **Height varies b/w 8-12 km**

COLD AIRMASS	WARM AIRMASS
➢ A **cold air mass** is one that is **colder than the underlying surface**	➢ A **warm air mass** is one that is **warmer than the underlying surface**
Cold source regions (polar air masses) ➢ Arctic Ocean – cold and moist ➢ Siberia – cold and dry ➢ Northern Canada – cold and dry ➢ Southern Ocean – cold and moist	**Warm source regions (tropical air masses)** ➢ Sahara Desert – warm and dry ➢ Tropical Oceans – warm and moist

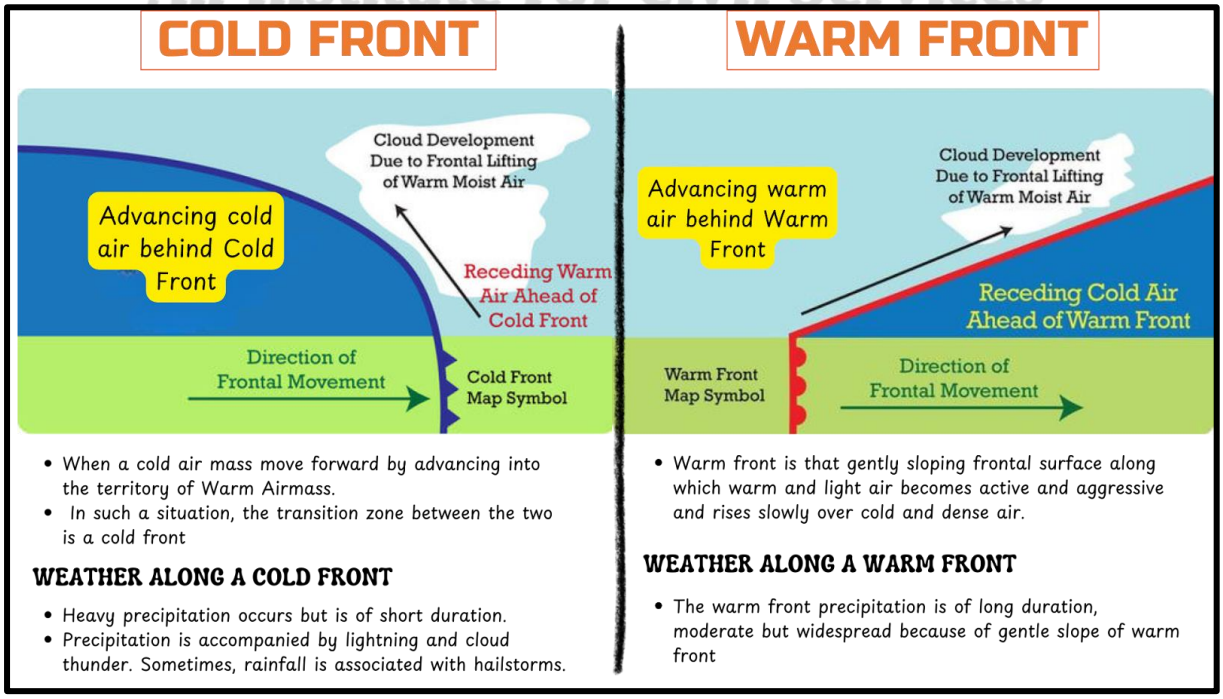
FRONTS

- Front is a **three-dimensional boundary zone** or **Transition Zone** formed **between two converging air masses with different physical properties** (temperature, humidity, density, etc.).

FRONT FORMATION

- **Frontogenesis** - The process of formation of a front. It begins with the convergence of two contrasting air masses.
- **Frontolysis** - dissipation of a front. It involves overriding of one of the airmass by another.

CLASSIFICATION OF FRONTS



- When a cold air mass move forward by advancing into the territory of Warm Airmass.
- In such a situation, the transition zone between the two is a cold front

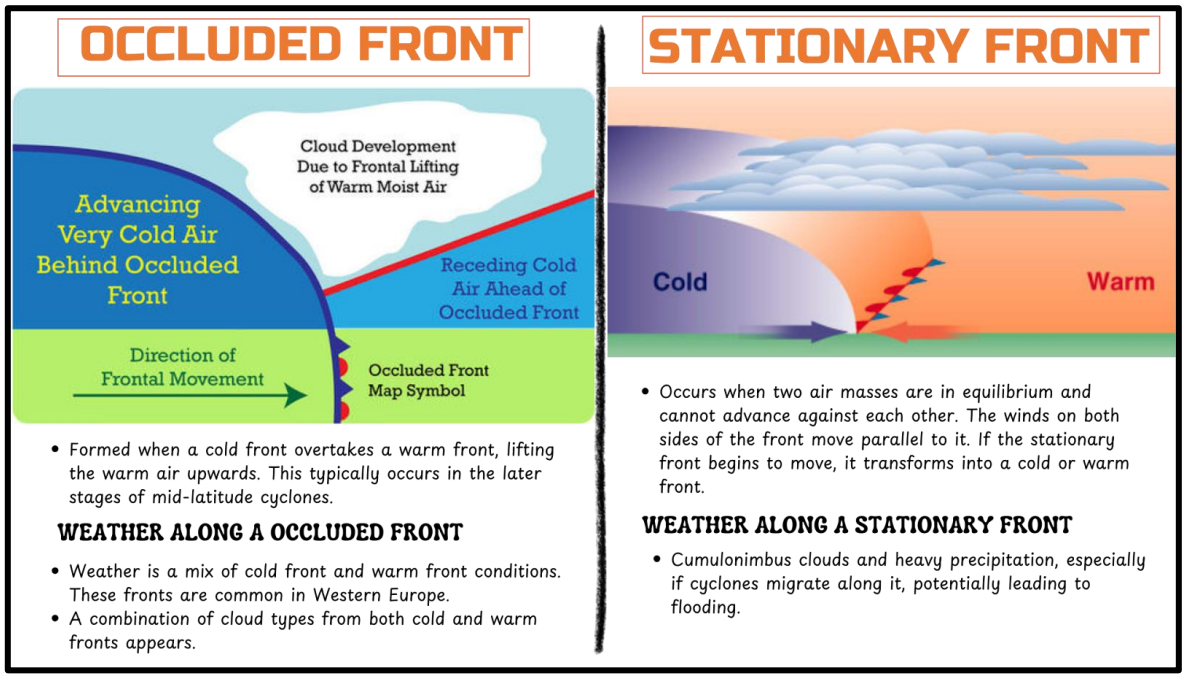
WEATHER ALONG A COLD FRONT

- Heavy precipitation occurs but is of short duration.
- Precipitation is accompanied by lightning and cloud thunder. Sometimes, rainfall is associated with hailstorms.

- Warm front is that gently sloping frontal surface along which warm and light air becomes active and aggressive and rises slowly over cold and dense air.

WEATHER ALONG A WARM FRONT

- The warm front precipitation is of long duration, moderate but widespread because of gentle slope of warm front



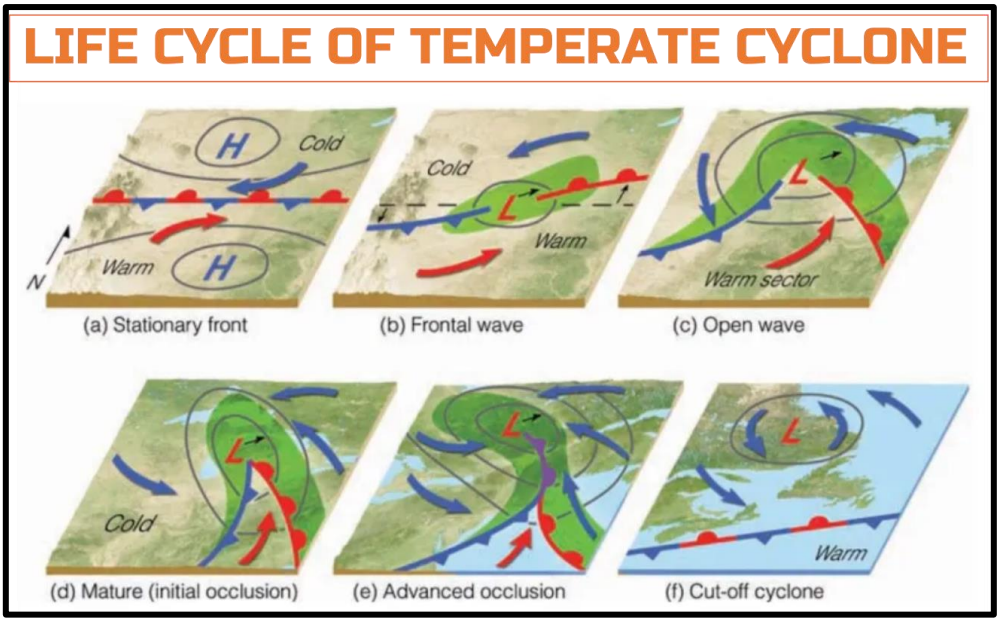
TEMPERATE CYCLONES

- Temperate cyclones, also known as extra-tropical cyclones or frontal cyclones, develop in mid-latitude regions (35° to 65° N/S) beyond the tropics.
- These cyclones are common in temperate zones and play a significant role in weather patterns across regions like North America, Europe, and parts of Asia.

FORMATION OF TEMPERATE CYCLONES

- **Cyclogenesis**: Development and strengthening of mid latitude wave cyclone is known as cyclogenesis. This is called the polar front theory, given by **Bjerkness in 1918.**

STAGES	DEVELOPMENTS
Stage A	➢ The first stage involves the **convergence of two air masses** of contrasting physical properties and direction.
Stage B	➢ '**Incipient stage'** during which the warm and cold air masses penetrate into the territories of each other.
Stage C	➢ It is mature when the **cyclone is fully developed** and isobars become almost circular.
Stage D	➢ Warm sector is narrowed in extent due to advancement of cold front at a faster rate than a warm front, and **cold front comes nearer to warm front.**
Stage E	➢ This stage starts with the **occlusion of cyclone** when the advancing cold front finally overtakes the warm front and occluded front is formed.
Stage F	➢ In the final stage, warm sector completely disappears, **occluded front is eliminated and ultimately cyclone dies out.**



CHARACTERISTICS OF TEMPERATE CYCLONES

- The temperate cyclones are **asymmetrical and shaped like an inverted 'V'**.
- They stretch over 500 to 600 km.
- They have a height of 8 to 11 km.
- Temperate cyclone **moves counter clockwise in northern hemisphere and clockwise in southern hemisphere**.
- **Cold air mass moves faster than the warm air mass.**
- Temperate cyclones generally move from west to east due to the influence of westerlies (Jet Streams).

WATER VAPOUR IN ATMOSPHERE

- Water vapour in air varies from **zero to four per cent** by volume of the atmosphere (averaging around **2%** in the atmosphere).
- Amount of water vapour (Humidity) is measured by, an instrument called **Hygrometer**

CONDENSATION

- Condensation refers to the transformation of water vapor into liquid water. This process occurs when moist air cools to a point where it can no longer hold the water vapor, resulting in condensation.
- When moist air is cooled, it may reach a level when its capacity to hold water vapour ceases (Saturation Point = 100% Relative Humidity = Dew Point reached). Then, the excess water vapour condenses into liquid form. **If it directly condenses into solid form, it is known as sublimation.**

FORMS OF CONDENSATION

HUMIDITY

- Humidity refers to the amount of water vapor present in the air. There are different ways to measure and categorize humidity, each offering unique insights into atmospheric conditions.

- **ABSOLUTE HUMIDITY**
    - Absolute humidity is the measure of the water vapor content in the air, expressed in grams per cubic meter (g/m^3) or grams per kilogram (g/kg). This value represents the total mass of water vapor present in a given volume of air.
- **RELATIVE HUMIDITY**
    - Relative humidity (RH) measures the amount of water vapor in the air relative to the maximum amount the air can hold at a given temperature. It is expressed as a percentage, and a higher percentage indicates a greater level of moisture in the air.
- **SPECIFIC HUMIDITY**
    - Specific humidity refers to the mass of water vapor present in a given mass of air. It is the ratio of the mass of water vapor to the total mass of the air parcel.

DEW POINT

- The dew point is the temperature at which air reaches full saturation, meaning it holds the maximum amount of moisture at 100% relative humidity. At this stage, the air cannot accommodate any additional moisture.
- When the temperature drops below the dew point, water vapor condenses. If the dew point is above 0°C, the vapor forms liquid droplets, while at temperatures below 0°C, it transitions into ice crystals.
- Condensation occurs in the open atmosphere around tiny particles known as **hygroscopic condensation nuclei**, which include dust, smoke, and sea salt. These particles have the ability to attract water, making them effective sites for condensation.
- The **dew point temperature** is the specific temperature at which humid air must be cooled (at constant pressure) for condensation to begin. It marks the point at which the air becomes fully saturated and the process of condensation is initiated.

EVAPORATION

- A process by which water is transformed from **liquid to gaseous state**. Heat is the main cause for evaporation.

DEW

- When the moisture is deposited in the form of water droplets on cooler surfaces of solid objects (rather than nuclei in air above the surface) such as stones, grass blades and plant leaves, it is known as dew.
- The ideal conditions for its formation are **clear sky, calm air, high relative humidity**, and **cold and long nights**.
- For the formation of dew, it is necessary that the **dew point is above the freezing point.**

WHITE FROST

- Frost forms on cold surfaces when condensation takes place below freezing point (0° C), i.e. the dew point is at or below the freezing point.

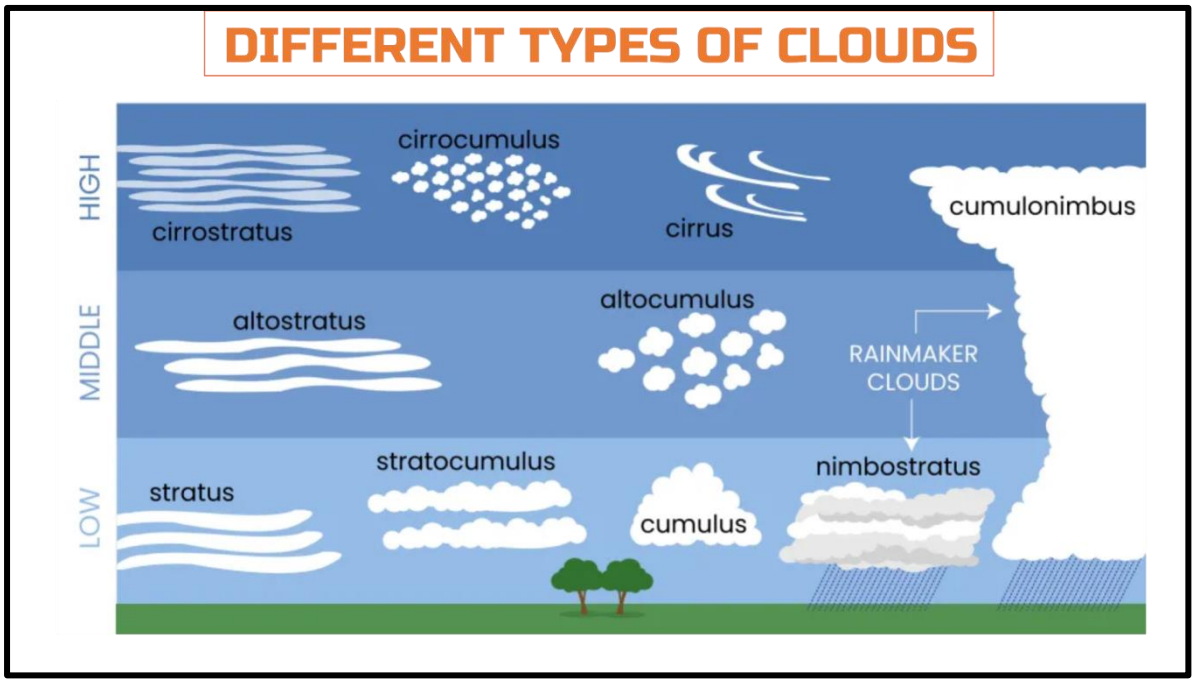
FOG	MIST
➢ Thick cloudlike mass or layer of tiny water droplets near the surface of the Earth	➢ Cloud of tiny droplets suspended in the atmosphere
➢ Reduce visibility to less than 1km	➢ Usually, visibility above 1km
➢ Denser	➢ Less Dense
➢ Less Moisture	➢ Contains more moisture

CLOUDS

- ✓ A mass of minute water droplets or tiny crystals of ice formed by the condensation of the water vapour in free air at considerable elevations.
- ✓ Clouds are caused mainly by the **adiabatic cooling of air below its dew point.**

Naming for clouds

- ✓ **Stratus/strato** - flat/layered and smooth
- ✓ **Cumulus/cumulo** - heaped up/puffy, like cauliflower
- ✓ **Cirrus/cirro** - High up/wispy
- ✓ **Alto** - Medium level
- ✓ **Nimbus/Nimbo** - Rain-bearing cloud



DETAILING

TYPES	FEATURES
Cirrus Clouds	➢ White, fibrous (hair-like) and/or silky sheen appearance. ➢ Composed of ice crystals and transparent ➢ Before sunrise and after sunset, cirrus is often colored bright yellow or red
Cirrostratus Clouds	➢ **Sun's Halo** is produced because of refraction because of Ice crystals of these clouds
Cumulonimbus	➢ The **thunderstorm** cloud, this is a heavy and dense cloud in the form of a mountain or huge tower.
Nimbostratus	➢ The **continuous rain** cloud

IN NEWS – In 2023, a massive Shelf Cloud formation has been observed in Haridwar, Uttarakhand.

What are Shelf Clouds?

- Shelf clouds, also known as Arcus clouds, are often associated with **powerful storm systems.**
- These clouds are frequently observed beneath cumulonimbus clouds.
- They often precede intense Thunderstorms characterized by heavy rain, strong winds, and occasionally hail or tornadoes.

Formation Process:

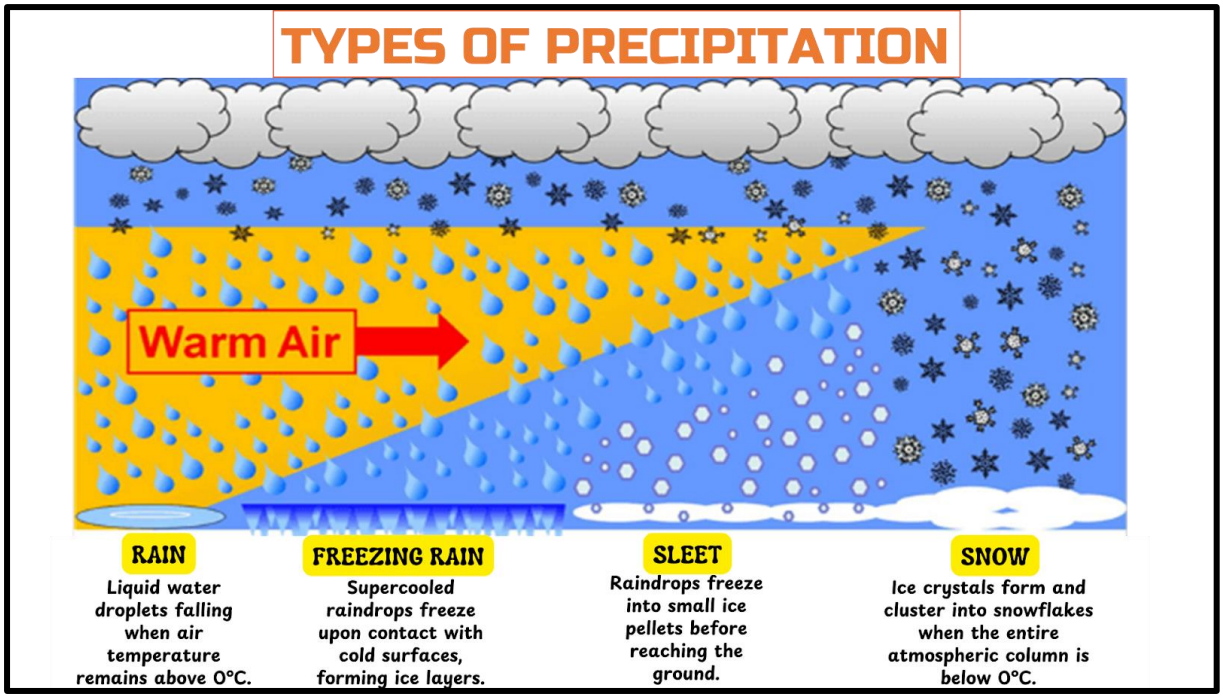
- The formation of shelf clouds involves a cold downdraft from a cumulonimbus cloud reaching the ground.
- The cold air from the downdraft spreads rapidly along the ground, displacing warm moist air upward.
- As the cold air descends and pushes warm air upward, condensation occurs, leading to cloud formation.
- This process results in the distinctive horizontal shape and appearance of a shelf cloud.

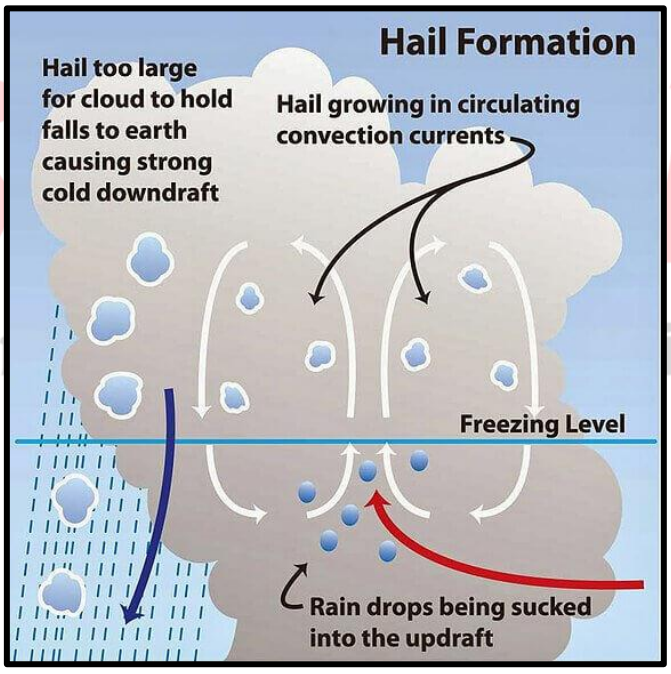
PRECIPITATION

- Precipitation is any form of liquid or solid water particles that fall from the atmosphere and reach the surface of the Earth.

TYPES OF PRECIPITATION

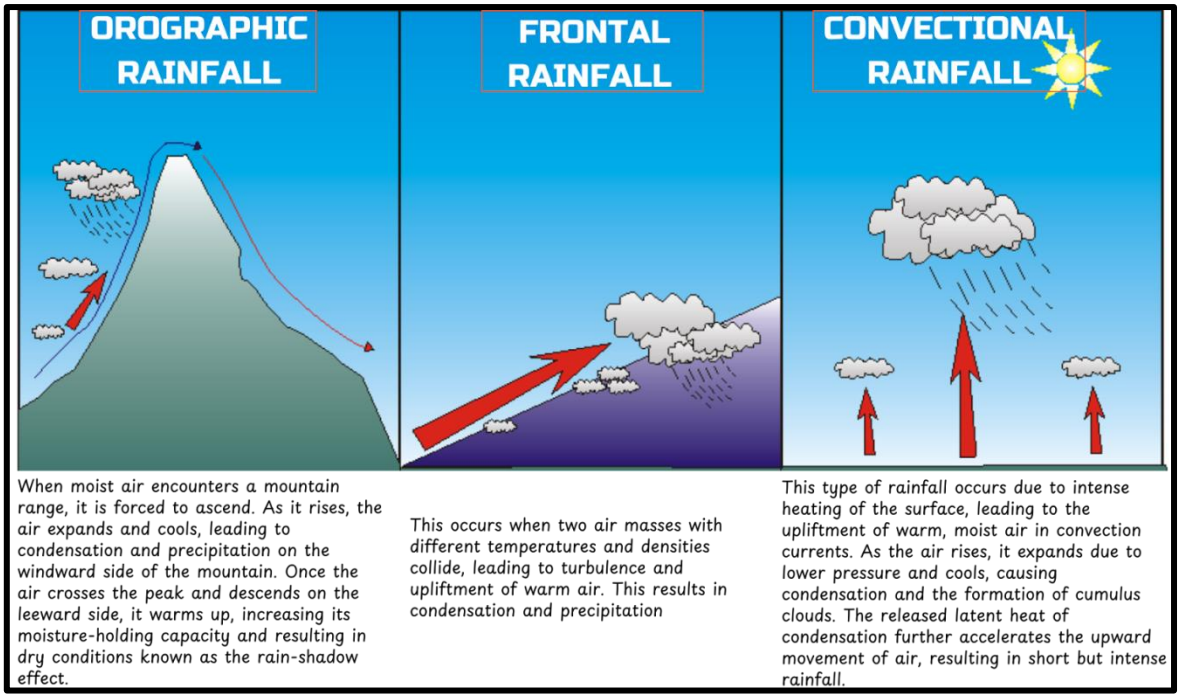
TYPES	MEANING
Rainfall	➢ Precipitation that falls to the surface of the Earth as **water droplets**. ➢ Raindrops form **around microscopic cloud condensation nuclei**, such as a particle of dust or a molecule of pollution.
Drizzle	➢ **It consists of light water precipitation where liquid water droplets are smaller than those of rain**. ➢ This can occur when updrafts in clouds are not strong enough to allow them to produce rain. ➢ Drizzle usually happens thanks to **low-level clouds called 'stratiform clouds.'**
Snow	➢ Ice crystals in a flaky form
Sleet	➢ Frozen raindrops that are formed **when rainfall passes through the air in the atmosphere at subfreezing temperatures.** ➢ **Mixture of rain and snow**.
Hail	➢ **Precipitation in the form of pellets or lumps that have a size greater than 8mm**. ➢ Consists of **concentric layers of ice alternating with layers of snow**. Its structure resembles that of **onion.**





TYPES OF RAINFALL

- Rainfall is categorized based on its origin into three primary types: **Convectional Rainfall, Orographic Rainfall, and Cyclonic (Frontal) Rainfall.**
- Additionally, **Monsoonal Rainfall** is considered a distinct type due to its seasonal nature.



CONVECTIONAL RAINFALL

- **Key Characteristics:**
  - Heavy rainfall of **short duration**
  - **Localized** in nature
  - Common in **equatorial regions** (e.g., **Amazon Basin, Congo Basin, Southeast Asian Islands**)
  - Frequently leads to **thunderstorms**
  - Occurs mainly **during summer**

OROGRAPHIC (RELIEF) RAINFALL

- **Key Characteristics:**
  - **Heavy rainfall on windward slopes**
  - **Dry conditions on leeward slopes** (**rain-shadow region**)
  - Common in regions with **mountainous terrain**

CYCLONIC (FRONTAL) RAINFALL