Chapter 11

The Water in the Atmosphere

Important definitions

1. Humidity : A generic term to refer to the amount of water vapour present in the atmosphere.

2. Absolute Humidity : Its the actual weight of the water vapour(grams) present per unit volume(cubic meter m^3) of the atmosphere. This gives us an estimate of the actual amount of water present in a given atmosphere.

3. Relative Humidity : The % of water vapour present in the atmosphere compared to its full capacity at a given temperature is called Relative Humidity.

4. Condensation : Transformation of water vapour into water is called condensation. It releases heat.

5. Sublimation : When the water vapour directly condenses into solid form, it is called sublimation

Water Cycle – Hydrological cycle

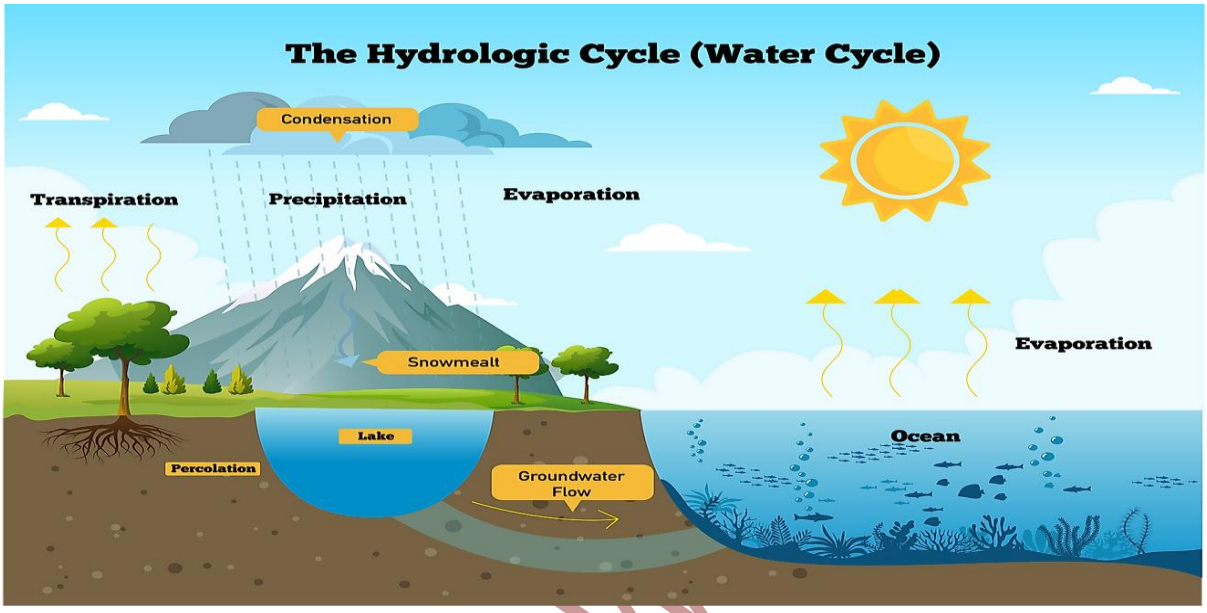
• There is a continuous exchange of water between the atmosphere, the oceans and the continents through the processes of evaporation, transpiration, condensation and precipitation.

• The moisture in the atmosphere is derived from water bodies through evaporation and from plants through transpiration (evapotranspiration).

• Evaporated water undergoes condensation and forms clouds.

• When saturation is reached, clouds give away water in the form of

• Since the total amount of moisture in the entire system remains constant, a balance is required between evapotranspiration and precipitation. The hydrological cycle maintains this balance.



Evaporation

- Evaporation is a process by which water is converted from liquid to gaseous state.
- Temperature is the main cause for evaporation.
- The temperature at which the water starts evaporating is known as latent heat of vaporisation.
- Rise in temperature escalates water absorption and retention capacity of the given parcel of air.
- Movement of air substitutes the saturated layer with the unsaturated layer.
- Hence, the greater the movement of air, the greater is the evaporation.

Factors Affecting Rate of Evaporation

- **Amount of water available.**
- **Temperature.**
- **Relative humidity. [explained in previous post]**
- **Area of evaporating surface.**

Wind speed: A high wind speed removes the saturated air from the evaporating surface and replaces it with dry air which favors more evaporation.

- Whenever there is a combination of high temperature, very low relative humidity and strong winds, the rate of evaporation is exceptionally high. This leads to dehydration of soil to a depth of several inches.

- **Air Pressure:** Evaporation is also affected by the atmospheric pressure exerted on the evaporating surface. Lower pressure over open surface of the liquid results in a higher rate of evaporation.

- **Composition of water:** Evaporation is inversely proportional to salinity of water.

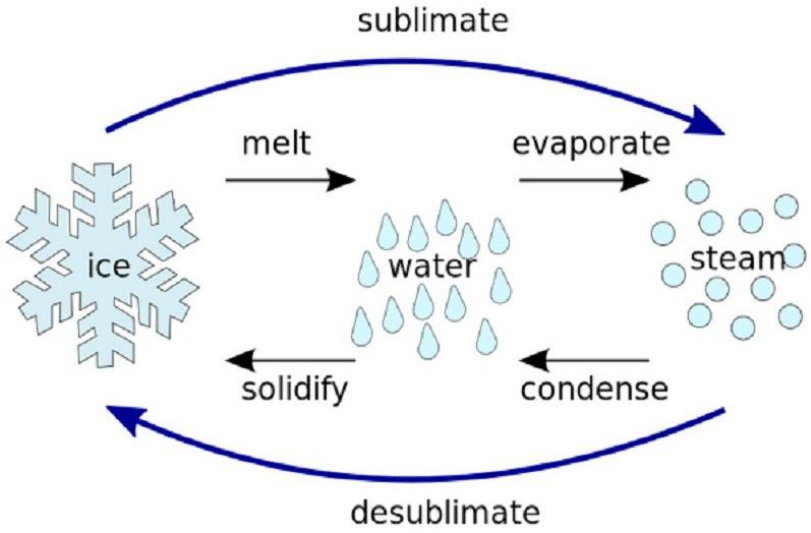
- Rate of evaporation is always greater over fresh water than over salt water. [Because of the reduction in the water vapor pressure at the water surface due to salinity.]

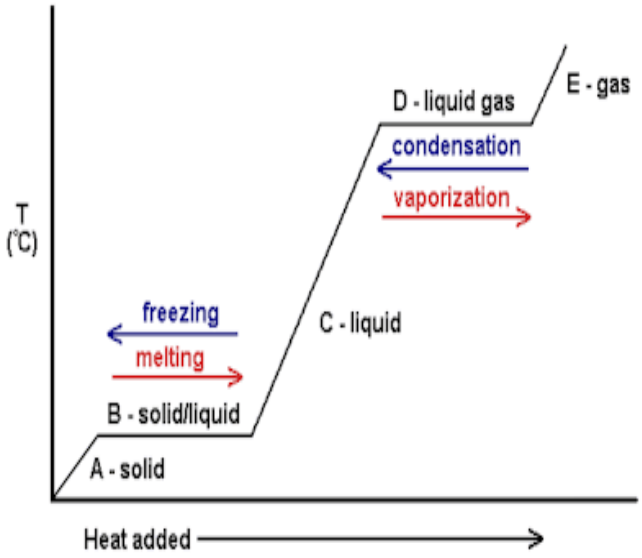
- Under similar conditions, ocean water evaporates about 5% more slowly than fresh water.

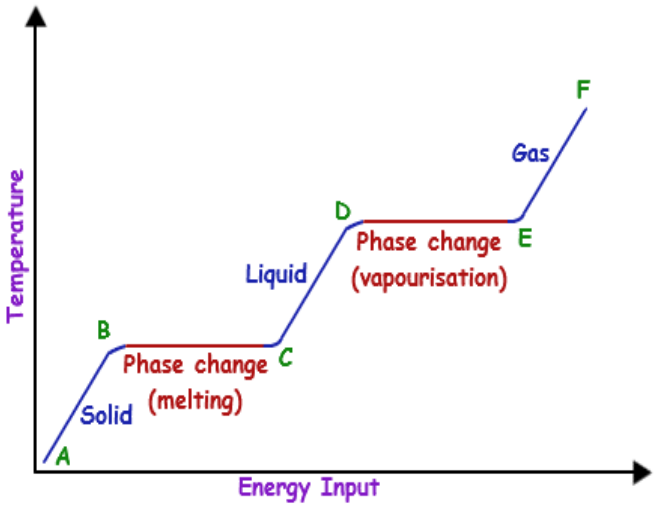
- More evaporation by plants: Water from plants generally evaporates at a faster rate than from land.

Condensation

- The transformation of water vapour into water is called condensation.
- Condensation is caused by the loss of heat (latent heat of condensation, opposite of latent heat of vaporization).
- 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.







- In free air, condensation results from cooling around very small particles termed as hygroscopic condensation nuclei. Particles of dust, smoke, pollen and salt from the ocean are particularly good nuclei because they absorb water.
- Condensation also takes place when the moist air comes in contact with some colder object and it may also take place when the temperature is close to the dew point.
- Condensation, therefore, depends upon the amount of cooling and the relative humidity of the air.
- Condensation takes place: 1. when the temperature of the air is reduced to dew point with its volume remaining constant (adiabatically), 2. when both the volume and the temperature are reduced, 3. when moisture is added to the air through evaporation,
- After condensation the water vapour or the moisture in the atmosphere takes one of the following forms — dew, frost, fog and clouds.
- Condensation takes place when the dew point is lower than the freezing point as well as higher than the freezing point

Processes of Cooling for Producing Condensation

• These processes can be studied under the" headings, **adiabatic and non-adiabatic.**

Adiabatic Temperature Changes

- (Explained in detail in previous posts)
- When the air rises, it expands. Thus, heat available per unit volume is reduced and, therefore, the temperature is also reduced. Such a temperature change which does not involve any

subtraction of heat, and cooling of air takes place only by ascent and expansion, is termed 'adiabatic change'

- • The vertical displacement of the air is the major cause of adiabatic and katabatic (cold, dense air flowing down a slope) temperature changes.
- Near the earth's surface, most processes of change are nonadiabatic because horizontal movements often produce mixing of air and modify its characteristics

Non-Adiabatic Temperature Changes

- Non-adiabatic processes include cooling by radiation, conduction or mixing with colder air. The air may be cooled due to loss of heat by radiation.
- In case there is direct radiation from moist air, the cooling produces fog or clouds, subject to presence of hygroscopic nuclei in the air.
- Cooling by contact with a cold surface produces dew, frost or fog depending on other atmospheric conditions.
- But the effect of cooling produced by radiation, conduction and mixing is confined to a thin layer of the atmosphere
- • The non-adiabatic processes of cooling produce only dew, fog or frost. They are incapable of producing a substantial amount of precipitation.

Forms of Condensation

• The forms of condensation can be classified on the basis of temperature at which the dew point is reached.

• Condensation can take place when the dew point is

1. lower than the freezing point,

2. higher than the freezing point.

• White frost, snow and some clouds (cirrus clouds) are produced when the temperature is lower than the freezing point.

• Dew, fog and clouds result even when the temperature is higher than the freezing point.

• Forms of condensation may also be classified on the basis of their location, i.e. at or near the earth's surface and in free air

• Dew, white frost, fog and mist come in the first category, whereas clouds are in the second category

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.

• The excess moisture is deposited in the

form of minute ice crystals instead of water droplets.

• The ideal conditions for the formation of white frost are the same as those for the formation of dew, except that the air temperature must be at or below the freezing point

Fog

• When the temperature of an air mass containing a large quantity of water vapour falls all of a sudden, condensation takes place within itself on fine dust particles.

• So, the fog is a cloud with its base at or very near to the ground. Because of the fog and mist, the visibility becomes poor to zero.

• In urban and industrial centers smoke provides plenty of nuclei which help the formation of fog and mist. Such a condition when fog is mixed with smoke, is described as smog (will be discussed in detail in next post). [Related Question Asked in Mains 2015: Mumbai, Delhi and Kolkata are the three mega cities of the country but the air pollution is much more serious problem in Delhi as compared to the other two. Why is this so?]

• Radiation fog results from radiation, cooling of the ground and adjacent air. These fogs are not very thick. Usual in winters.

• Fogs formed by condensation of warm air when it moves horizontally over a cold surface, are known as advectional fog. These fogs are thick and persistent. Occurs over warm and cold water mixing zones in oceans.

• Frontal or precipitation fog is produced due to convergence of warm and cold air masses where warm air mass is pushed under by the heavier cold air mass.

• Precipitation in the warm air mass condenses to produce fog at the boundary of the two air masses. These are called frontal or precipitation fog

In fog visibility is less than one kilometer.

Mist

• The difference between the mist and fog is that mist contains more moisture than fog.

• In mist each nuclei contains a thicker layer of moisture.

• Mists are frequent over mountains as the rising warm air up the slopes meets a cold surface.

• Mist is also formed by water droplets, but with less merging or coalescing. This means mist is less dense and quicker to dissipate.

• Fogs are drier than mist and they are prevalent where warm currents of air come in contact with cold currents.

• In mist visibility is more than one kilometer but less than two kilometres

Haze

• Haze is traditionally an atmospheric phenomenon where dust, smoke and other dry particles obscure the clarity of the sky (No condensation. Smog is similar to

haze but there is condensation in smog).

• Sources for haze particles include farming (ploughing in dry weather), traffic, industry, and wildfires.

Smog

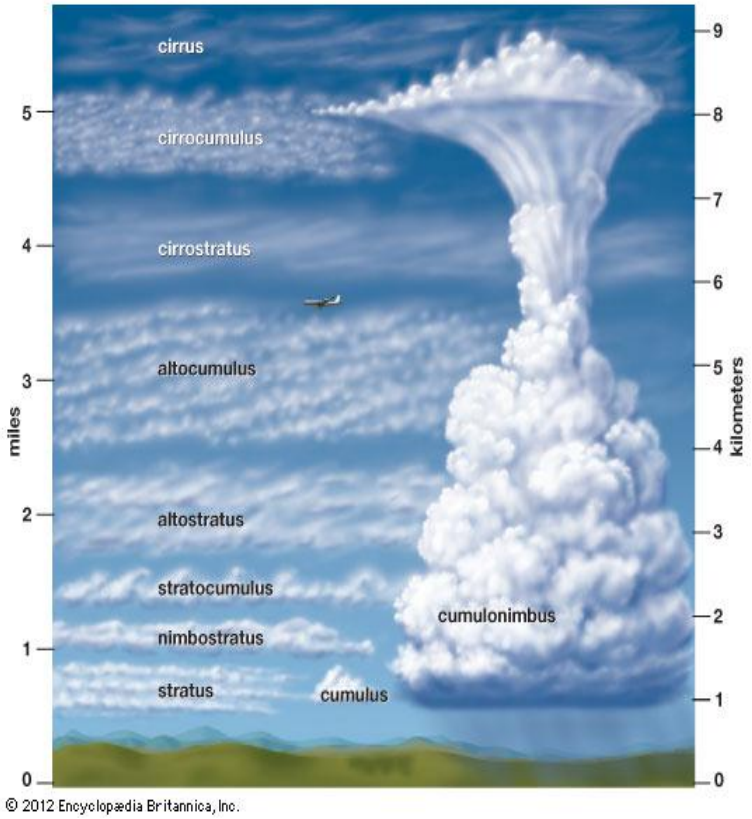
Smog = smoke + fog (smoky fog) caused by the burning of large amounts of coal, vehicular emission and industrial fumes (Primary pollutants).

CLOUD

Cloud is a mass of minuscule water drops or minute crystals of ice formed by the condensation of water vapour in free air at significant altitudes.

According to **their altitude, stretch, density, and transparency or opaqueness clouds are classified under four types:**

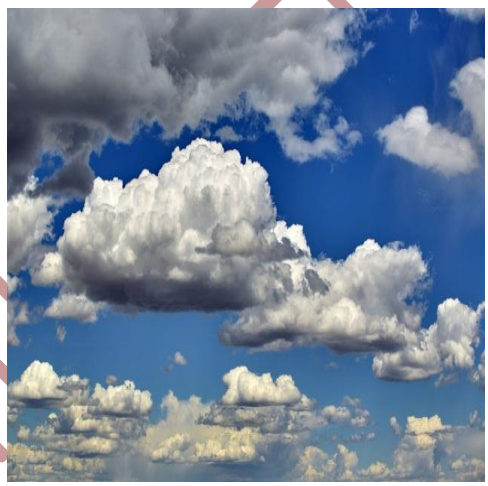
- Cirrus
- Cumulus
- Stratus
- Nimbus



Cirrus

- Cirrus clouds are formed at high altitudes of 8,000 – 12,000m.
- •They are detached thin clouds. They have a feathery appearance.
- •They are always white in colour

Cumulus



•Cumulus clouds are generally formed at a height of 4,000 – 7,000 m.

•They look like cotton wool. They exist in patches and can be seen dispersed here and there.

•They have a flat base.

Stratus

•Stratus clouds are layered clouds covering big portions of the sky.

•These clouds are usually formed due to the mixing of air masses with various temperatures or due to loss of heat

Nimbus

•Nimbus clouds form at middle levels or very near to the surface of the earth.

•They are usually found in black or dark gray colour.

•These are very dense and opaque to the

rays of the sun.

•Occasionally, the clouds are so low that they seem to touch the ground.

•These clouds are shapeless masses of thick vapour.

A combination of these four types can give rise to the following types of clouds:

•High clouds

Cirrus

Cirrostratus

Cirrocumulus

•Middle clouds

Altostratus

Altocumulus

•Low clouds

Stratocumulus

Nimbostratus

•Clouds with extensive vertical development

Cumulus

Cumulonimbus

Precipitation

The process of continuous condensation in free air helps the condensed particles to grow in size. When the resistance of the air fails to hold them against the force of gravity, they fall on to the earth's surface. So after the condensation of water vapour, the release of moisture is known as precipitation. This may take place in liquid or solid form.

• Precipitation in the form of drops of water is called rainfall, when the drop size is more than 5 mm.

• It is called VIRGA when raindrops evaporate before reaching the earth while passing through dry air.

• Drizzle is light rainfall with drop size being less than 0.5 mm, and when evaporation occurs before reaching the ground, it is referred to as

• When the temperature is lower than the 0° C, precipitation takes place in the form of fine flakes of snow and is called snowfall. Moisture is released in the form of hexagonal crystals. These crystals form flakes of snow. Besides rain and snow, other forms of precipitation are sleet and hail (more about hail while studying thunderstorms), though the latter are limited in occurrence and are sporadic in both time and space.

Sleet is frozen raindrops and refrozen melted snow-water. When a layer of air with the temperature above freezing point overlies a subfreezing layer near the ground, precipitation takes place in the form of sleet.

• Raindrops, which leave the warmer air, encounter the colder air below. As a result, they solidify and reach the ground as small

pellets of ice not bigger than the raindrops from which they are formed. Sometimes, drops of rain after being released by the clouds become solidified into small rounded solid pieces of ice and which reach the surface of the earth are called hailstones. These are formed by the rainwater passing through the colder layers. Hailstones have several concentric layers of ice one over the other.

• Rainfall: drop size more than 0.5 mm. • Virage: raindrops evaporate before reaching the earth. • Drizzle: light rainfall; drop size less than 0.5 mm.

• Mist: evaporation occurs before reaching the ground leading to foggy weather.

• Snowfall: fine flakes of snow fall when the temperature is less than 0°C.

• Sleet: frozen raindrops and refrozen melted snow; mixture of snow and rain or merely partially melted snow.

• Hail: precipitation in the form of hard rounded pellets is known as hail; 5 mm and 50 mm.

Types of Rainfall

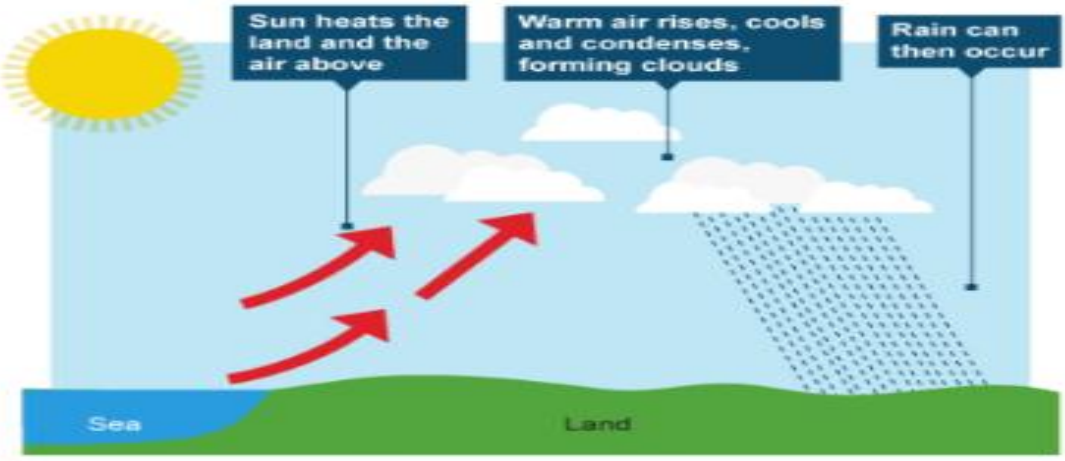
• On the basis of origin, rainfall may be classified into three main types –

the convectional,

orographic or relief and the cyclonic or frontal.

Convectional Rainfall

• The, air on being heated, becomes light and rises up in convection currents. As it rises, it expands and loses heat and consequently, condensation takes place and cumulous clouds are formed. This process releases latent heat of condensation which further heats the air and forces the air to go further up.



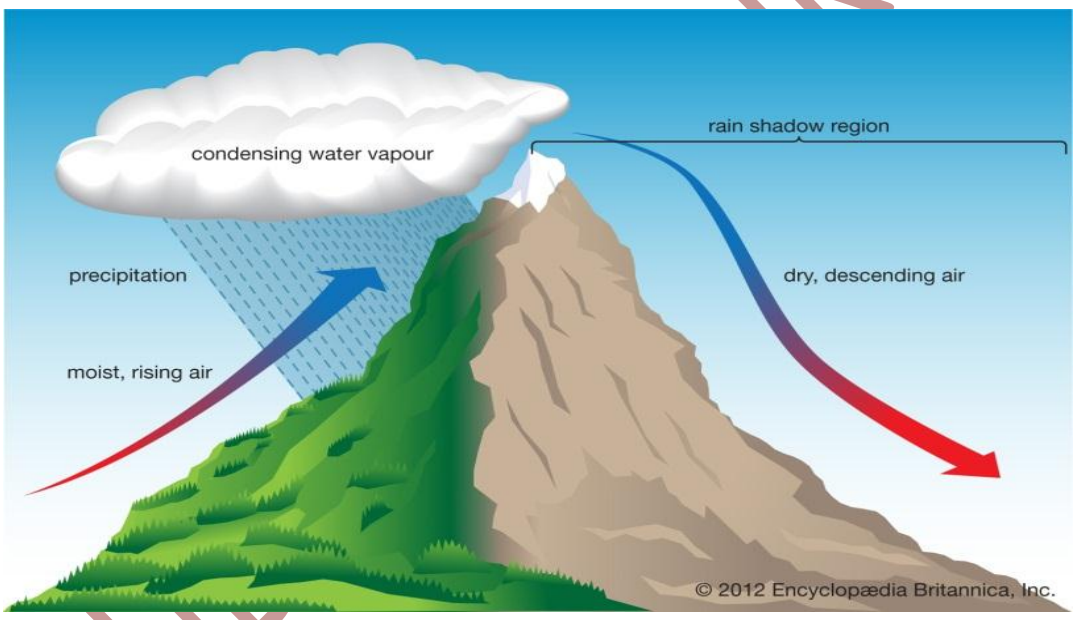
• Convectional precipitation is heavy but of short duration, highly localised and is associated with minimum amount of cloudiness. It occurs mainly during summer and is common over equatorial doldrums in the Congo basin, the Amazon basin and the islands of south-east Asia.

• Adiabatic Lapse Rate – Latent Heat of Condensation

Orographic Rainfall

• When the saturated air mass comes across a mountain, it is forced to ascend and as it rises, it expands (because of fall in pressure); the temperature falls, and the moisture is condensed.G

• This type of precipitation occurs when warm, humid air strikes an orographic barrier (a mountain range) head on. Because of the initial momentum, the air is forced to rise. As the moisture laden air gains height, condensation sets in, and soon saturation is reached. The surplus moisture falls down as orographic precipitation along the windward slopes



• The chief characteristic of this sort of rain is that the windward slopes receive greater rainfall. After giving rain on the windward side, when these winds reach the other slope, they descend, and their temperature rises. Then their capacity to take in moisture increases and hence, these leeward slopes remain rainless and dry. The area situated on the leeward side, which gets less rainfall is known as the rain-shadow area (Some arid and semi-arid regions are a direct consequence of rain-shadow effect. Example: Patagonian

desert in Argentina, Eastern slopes of Western Ghats). It is also known as the relief rain.

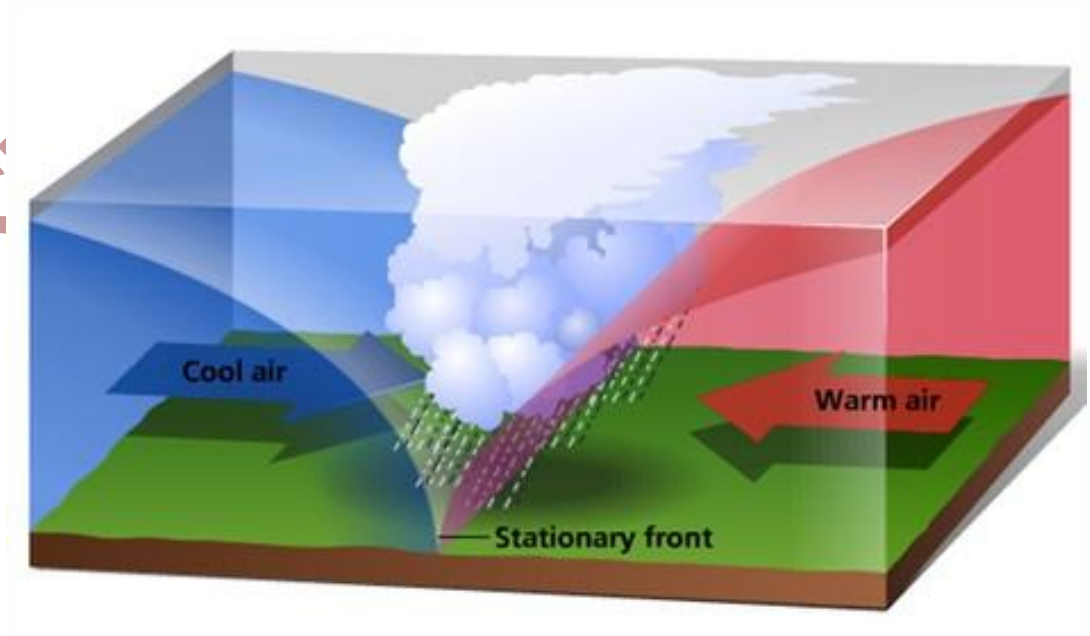
• Example: Mahabaleshwar, situated on the Western Ghats, receives more than 600 cm of rainfall, whereas Pune, lying in the rain shadow area, has only about 70 cm

The Wind Descending on the Leeward Side is heated adiabatically and is called **Katabatic Wind**

Frontal Precipitation

• When two air masses with different temperatures meet, turbulent conditions are produced. Along the front convection occurs and causes precipitation (we studied this in Fronts). For instance, in north-west Europe, cold continental air and warm oceanic air converge to produce heavy rainfall in adjacent areas.

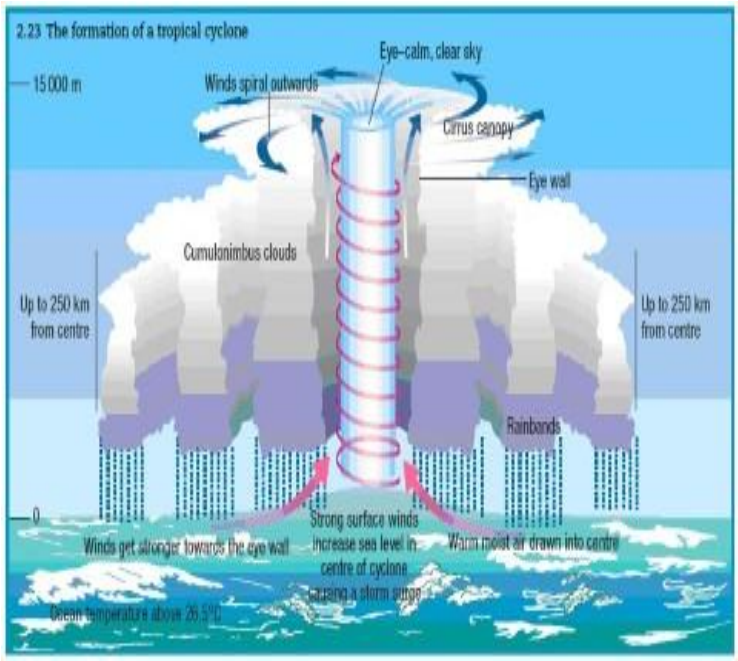
Fronts – Frontogenesis – Stationary Front, Cold Front, Warm Front, Occluded Front



Cyclonic Rain

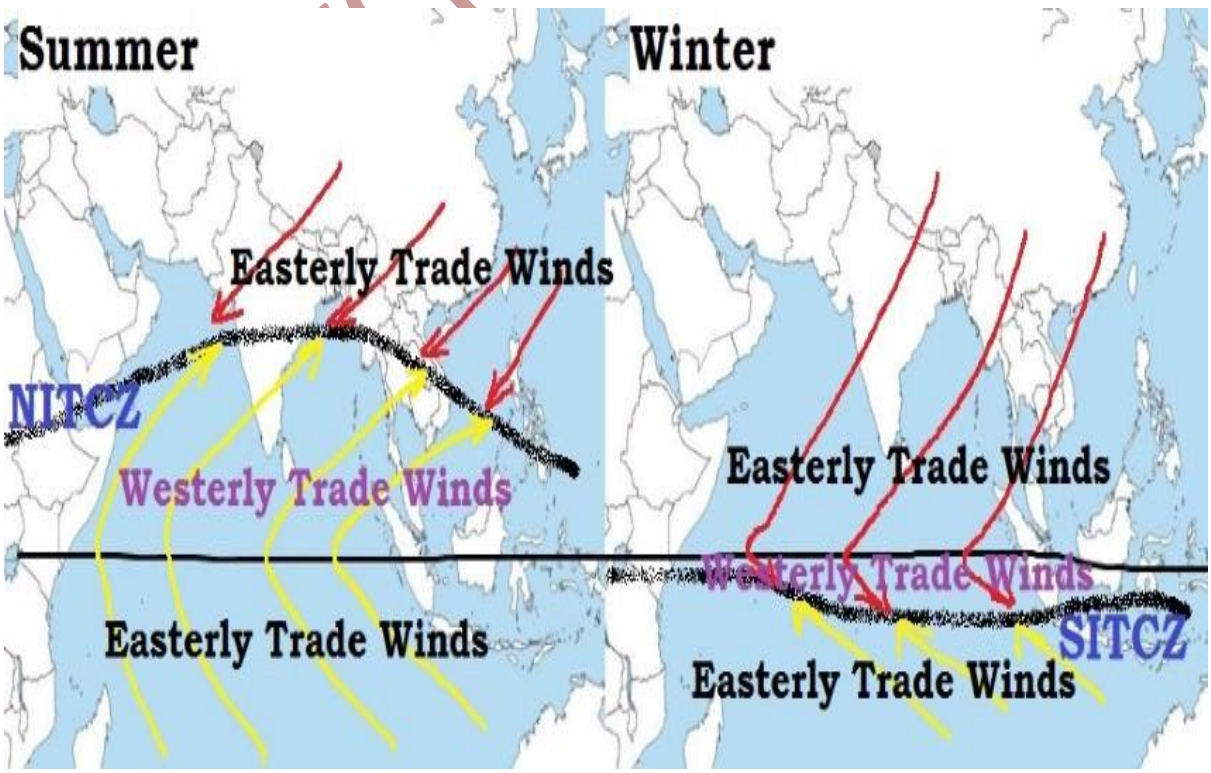
• Cyclonic Rainfall is convectional rainfall on a large scale. (we will see this in detail later)

• The precipitation in a tropical cyclone is of convectional type while that in a temperate cyclone is because of frontal activity



Monsoonal Rainfall

• This type of precipitation is characterized by seasonal reversal of winds which carry oceanic moisture (especially the south-west monsoon) with them and cause extensive rainfall in south and southeast Asia. (More while studying Indian Monsoons)



World Distribution of Rainfall

• Different places on the earth's surface receive different amounts of rainfall in a year and that too in different seasons. In general, as we proceed from the equator towards the poles, rainfall goes on decreasing steadily.

• The coastal areas of the world receive greater amounts of rainfall than the interior of the continents. The rainfall is more over the oceans than on the landmasses of the world because of being great sources of water.

• Between the latitudes 35° and 40° N and S of the equator, the rain is heavier on the eastern coasts and goes on decreasing towards the west. But, between 45° and 65° N and S of equator, due to the westerlies, the rainfall is first received on the western margins of the continents and it goes on decreasing towards the east.

Wherever mountains run parallel to the coast, the rain is greater on the coastal plain, on the windward side and it decreases towards the leeward side.

• On the basis of the total amount of annual precipitation, major precipitation regimes of the world are identified as follows.

• The equatorial belt, the windward slopes of the mountains along the western coasts in the cool temperate zone and the coastal areas of the monsoon land receive heavy rainfall of over 200 cm per annum.

• Interior continental areas receive moderate rainfall varying from 100 – 200 cm per annum. The coastal areas of the continents receive moderate amount of rainfall.

• The central parts of the tropical land and the eastern and interior parts of the temperate lands receive rainfall varying between 50 – 100 cm per annum.

• Areas lying in the rain shadow zone of the interior of the continents and high latitudes receive very low rainfall – less than 50 cm per annum.

• Seasonal distribution of rainfall provides an important aspect to judge its effectiveness. In some regions rainfall is distributed evenly throughout the year such as in the equatorial belt and in the western parts of cool temperate regions.