Meteorology: is the science of weather. It is essentially an inter-disciplinary science because the atmosphere, land and ocean constitute an integrated system. The three basic aspects of meteorology are observation, understanding and prediction of weather.

PRESSURE:

- force per unit area exerted by an atmospheric column (that is, the entire body of air above the specified area).
- Atmospheric pressure can be measured with a mercury barometer (hence the commonly used synonym barometric pressure), which indicates the height of a column of mercury that exactly balances the weight of the column of atmosphere over the barometer.
- The SI unit of atmospheric pressure is Pascal (Pa), and another unit is atm. One atmosphere (atm) is equal to 101,325 Pa.
- Atmospheric pressure drops as altitude increases.
- $\mathbf{P_h = P_0 e^{-mgh/kT}}$

  P_h = Pressure at hight h
  P_0= sea level pressure
  g = gravitational acceleration
  k = Boltzmann's constant (ideal gas constant divided by Avogadro's number)
  T = absolute temperature
  m = mass of one air molecule

Pressure Belts

1. Equatorial Low-Pressure Belt or Doldrums:

- This belt lies between 10°N and 10°S latitudes.
- The width of this pressure belt may vary between 5°N and 5°S and 20°N and 20°S.
- This belt is known as Doldrums because of the extremely calm air movements.
- There is variation in the position of this belt based on the movement of the Sun.

2. Subtropical High-Pressure Belt or Horse Latitudes:

- The height of this belt extends from near the tropics to about 35°N and S.
- In this belt subsiding air is warm and dry and that's why most of the deserts are present along this belt, in both hemispheres.

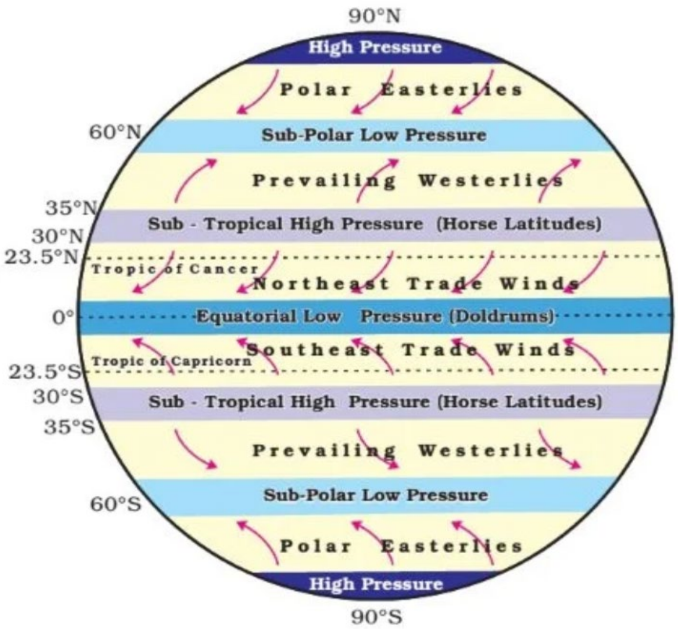
3. Sub-Polar Low-Pressure Belt:

- This belt is located between 45°N and S latitudes along with the Arctic and the Antarctic circles (66.5° N and S latitudes).
- As temperature is low in these latitudes the sub polar low-pressure belts are not very well pronounced year long.

• In the southern hemisphere such belts surround the periphery of Antarctica and are not as well differentiated.

4. Polar High-Pressure Belt:

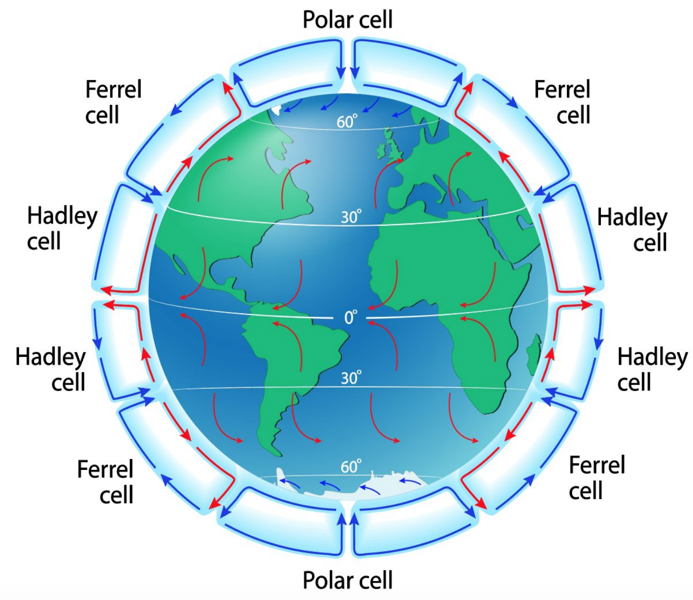
• This belt is small in areas and extends around the poles.
• This belt is situated around poles between 80 – 90° N and S latitudes.
• In this belt the lowest temperature is found over the poles.



Major Pressure Belts and Wind System

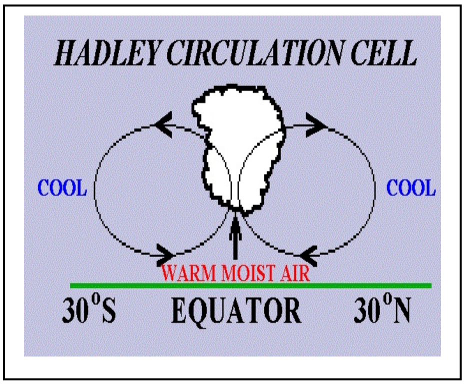
General Circulation of Atmosphere

- The circulation of wind in the atmosphere is driven by the rotation of the earth and the incoming energy from the sun.
- Wind circulates in each hemisphere in three distinct cells which help transport energy and heat from the equator to the poles.
- The winds are driven by the energy from the sun at the surface as warm air rises and colder air sinks.
- To compensate for the surplus and deficit of radiation in different regions of the globe, atmospheric and oceanic transport processes distribute the energy equally around the earth.
- This transport is accomplished by atmospheric winds and ocean currents.
- **Three Cell Model -** This model represents the average circulation of the atmosphere and is used to describe the atmospheric transport of energy.
- Also called as **General Meridional Circulation**



Hadley Cell/Tropical Cell

- The intense incoming solar radiation in the equatorial region creates rising air.
- The rising air cools condenses and forms a region of intense clouds and heavy precipitation. This area is called the Inter-Tropical Convergence Zone (**ITCZ**) and corresponds regions over which the tropical rain forests are found.
- The ITCZ moves north and south following the sun during the year.
- Because the stratosphere is stable, rising air that reaches the tropopause moves poleward.
- By the time the air moving northward reached about 30 N it has become a westerly wind (it is moving to the east) due to the Coriolis force.
- Because of conservation of angular momentum, the poleward moving air increases speed. The increased speed and the Coriolis force are responsible for the **subtropical jet**.
- This poleward moving air piles up (notice on a globe how lines of constant longitude converge) forming an area of high pressure at the surface-- the **subtropical highs**.
- Some of the air sinks toward the surface. Subsidence inhibits cloud formation and this is the reason many large deserts are found near 30N and 30S.
- Once the sinking air reaches the ground, some flows to the equator, turning west (in the northern hemisphere) as it goes due to the Coriolis force. This surface air forms the **trade winds**, that blow steadily from the northeast in the northern hemisphere and southeast in the southern hemisphere.



Ferrel Cell/Polar Front Cell/Middle Latitude Cell

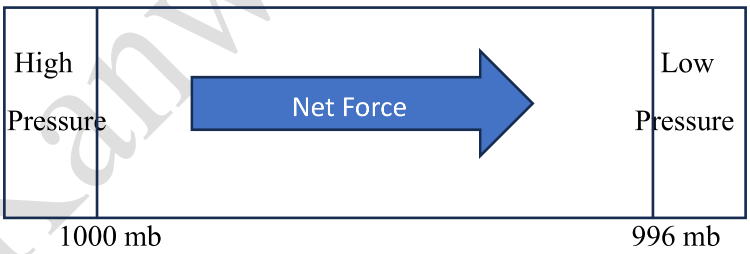
- Some of the diverging air at the surface near 30N moves poleward and is deflected to the east by the Coriolis force resulting in the prevailing westerly winds at the surface.
- At about 60N the air rises cool and condenses and forms clouds and precipitation.
- This is the general region of the polar front. Some of this rising air returns equatorward to complete the Ferrel Cell.

Polar Cell/Sub-polar cell

- Sinking air at the poles warms and results in a high pressure over the poles.
- At the surface, the poleward moving air gets pulled to the right by the Coriolis force (in the northern hemisphere) forming the **polar easterly winds**.
- The cold polar air meets with the warm subtropical air moving poleward and forms the boundary between these two air masses known as the **polar front**.
- The warm air from the subtropics pushes up over the cold equatorward moving polar air.
- The large temperature contrast results in the polar front jet stream in the vicinity of the polar front.

Global Phenomenon-

1) **Pressure Gradient Force** - A change in pressure per unit distance.
   i) It is always directed from higher toward lower pressure.
   ii) Air would accelerate along the pressure gradient toward the lower pressure if this were the only force acting on the air.
   iii)



   iv) This force is responsible for triggering the initial movement of air.

2) **Coriolis Force:** Occurs because of rotation of earth.
   i) Any moving object in the Northern Hemisphere will experience an acceleration to the right of their path of motion.
   ii) This apparent deflection occurs because of our frame of reference has been shifted as the earth rotates.

iii) Coriolis force dependent on two factors:

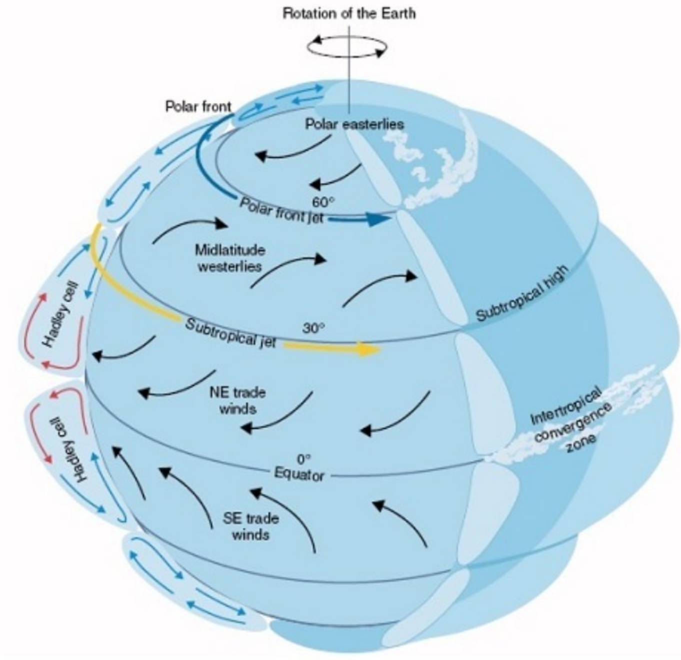
(1) Latitude - Increases poleward; Coriolis force greatest at poles, zero at equator.

Reason - "Twisting" of frame of reference enhanced near pole.

(2) Velocity - The faster the wind, the stronger the Coriolis Force.

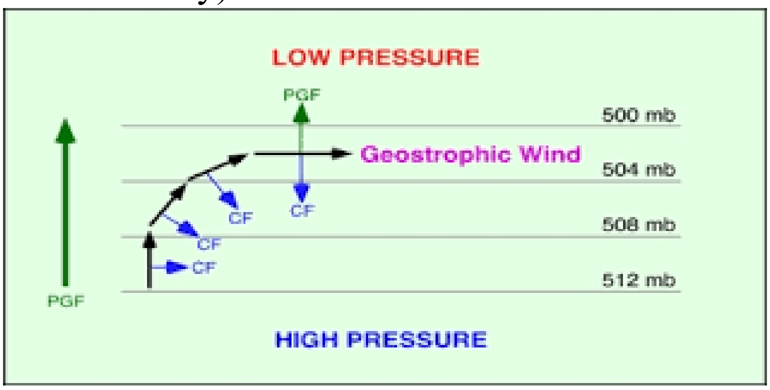
Reason - In a given period of time, faster air parcels cover greater distances. Longer trajectories have greater deflections than shorter trajectories.

iv) Coriolis force is length scale dependent. It is negligible at short distances.



3) Geostrophic Wind (Vg) represents a balance between the CF and PGF.

a) Assumptions: 1. Straight isobars. 2. No friction from viscosity or the ground; valid above 1 km.
b) Wind flows in a straight path, parallel to isobars.
c) The stronger the PGF (the closer the isobar spacing), the faster the wind.
d) The less dense the air, the faster the wind (there is an inverse proportionality between wind and air density).



4) **Friction and Boundary Layer Winds**: important in 'friction layer' below 1 km.
   a) Reduces wind speed.
   b) Since CF proportional to wind speed (V), the magnitude of CF is reduced.
   c) Consequently, CF no longer balanced PGF, and wind blows across isobars toward lower pressure ("cross-isobaric flow").
   d) Friction force always in opposite direction of wind.

5) **Centrifugal Force and Gradient Wind** - occurs with curved flow.
   a) An object in motion tends to move in a straight line unless acted upon by an outside force.
   b) This tendency is the centrifugal force (analogy - driving around a corner).
   c) It is directed outwards from curved flow.
   d) Implications on air flow:
      i) Wind is subgeostrophic $V < Vg$ in trough.
      ii) Wind is supergeostrophic $V > Vg$ in ridge.
   e) Minor influence, except in tornadoes and hurricanes.

<u>TEMPERATURE</u>- is the measure of thermal or internal energy of the molecules within an object or gas. Average earth surface temperature is 15°C.

In the atmosphere, temperature is related to volume, pressure, and density. Temperature is inversely related to density but directly related to pressure and volume.

When temperature increases, density decreases, and volume and pressure of the gas also increase. So, air that is warm and dry will tend to rise when surrounded by cooler air because warm air is less dense than the cooler air around it.

Heat energy transfer is the cause of temperature change. If there are two objects with different temperatures, energy always flows from the warmer object to the colder object.

Ideal gas law: If air contains no water, it is called dry air. The state of a parcel of dry air is described by three properties:

temperature (T, expressed in °K, where 273°K = 0°C),

pressure (p, force per unit area, expressed in Newtons m^{-2}) and

density (ρ, the mass of a unit volume, in Kg m^{-3}).

In a gas these properties are related by a relatively simple physical law called the ideal gas law (ideal because it is not exact, albeit quite accurate for most applications in meteorology).

This law states that: **p = ρR T**

The relationship between Celsius (°C), Fahrenheit (°F), and Kelvin (K) temperatures can be expressed by the following formulas:

Celsius to Fahrenheit: F = 1.8 C + 32
Fahrenheit to Celsius: C = 0.55 (F – 32)
Celsius to Kelvin: K = C + 273.15

The atmosphere exhibits a characteristic vertical temperature profile. Generally, temperature decreases with altitude in the troposphere (the lowest layer of the atmosphere) due to decreasing air pressure. This lapse rate is around 6.5°C per kilometre.

Adiabatic Lapse Rate:

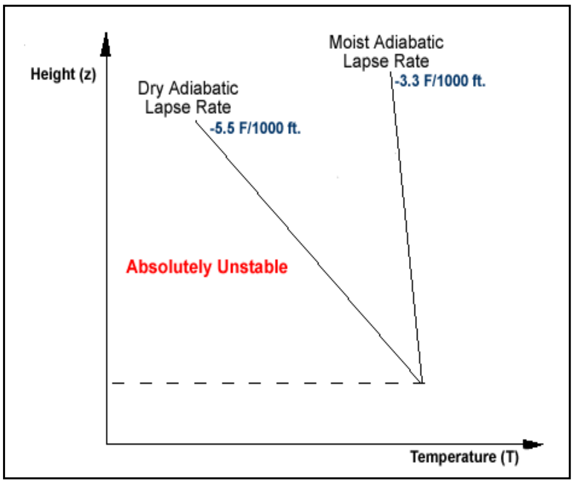
- the air is ***stable***, that is, air at a given altitude has physical forces acting on it that make it want to remain at that elevation. Stable air discourages the dispersion and dilution of pollutants.
- the air is ***unstable***. In this case, rapid vertical mixing takes place that encourages pollutant dispersal and increases air quality.
- If the ambient lapse rate is equal to the adiabatic lapse rate, moving the parcel upward or downward results in its temperature changing by the same amount as its surroundings. In any new position, it experiences no forces that either make it continue its motion or make it want to return to its original elevation. The parcel likes where it was, and it likes its new position too. Such an atmospheric is said to be *neutrally stable*.
- If the ambient lapse rate shows cooling at a faster rate than the dry adiabatic lapse rate, the atmosphere is *absolutely unstable*.
- The air will always want to move to some new altitude so vertical dispersion of pollution is enhanced. For ambient temperatures that cool less rapidly than the saturated adiabatic lapse rate, the atmosphere is *absolutely stable*.
- Relationship between atmospheric stability and temperature. It is useful to imagine a "parcel" of air being made up of a number of air molecules with an imaginary boundary around them. If this parcel of air moves upward in the atmosphere, it will experience less pressure, causing it to expand and cool. On

the other hand, if it moves downward, more pressure will compress the air, and its temperature will increase.

- The **adiabatic lapse** rate is the rate at which the temperature of a parcel of air decreases as it is lifted in the atmosphere. The air parcel cannot exchange heat with its environment.

1. <u>Dry Adiabatic Lapse Rate (DALR):</u> The dry adiabatic lapse rate is the rate at which the temperature of a dry air parcel changes as it ascends or descends without exchanging heat with its surroundings. The average value of the dry adiabatic lapse rate is approximately **9.8°C per kilometer** (or 5.5°F per 1,000 feet).
Explanation: As an air parcel rises, it expands due to decreasing atmospheric pressure. This expansion leads to a decrease in temperature without the addition or removal of heat. Conversely, as an air parcel descends, it compresses due to increasing atmospheric pressure, causing an increase in temperature without the addition or removal of heat.

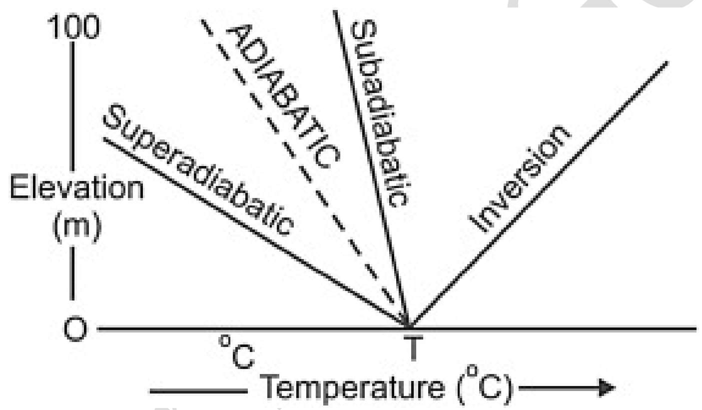
2. <u>Moist Adiabatic Lapse Rate (MALR):</u> The moist adiabatic lapse rate is the rate at which the temperature of a moist air parcel changes as it ascends or descends without exchanging heat with its surroundings. The moist adiabatic lapse rate is variable and depends on the amount of water vapor present in the air parcel. The average value of the moist adiabatic lapse rate is approximately **5.5 °C per kilometer**
Explanation: Unlike the dry adiabatic process, the moist adiabatic process involves the condensation or evaporation of water vapor as the air parcel rises or descends. This latent heat release or absorption affects the temperature change. The moist adiabatic lapse rate is generally less than the dry adiabatic lapse rate and varies with atmospheric conditions.
3. <u>Environmental Lapse Rate (ELR):</u> The environmental lapse rate is the actual rate at which temperature changes with altitude in the surrounding atmosphere. It may vary from the dry adiabatic lapse rate and the moist adiabatic lapse rate depending on factors such as humidity, cloud cover, and atmospheric stability. **6.5°C per kilometer**



Super Adiabatic:
Ambient lapse rate > adiabatic
indicates unstable atmosphere. Vertical motion and mixing processes are enhanced. Dispersion of pollution plume is enhanced.

Sub Adiabatic: Ambient lapse rate < adiabatic.
It indicates stable atmosphere, vertical motion, and mixing are suppressed. Dispersion is suppressed, and contamination is trapped.

Inversion: An extreme case of sub adiabatic, where temperature actually increases with altitude near the ground before it begins to decrease with altitude. This results in warm, low-density air riding on top of cool high-density air; a very stable air column that traps pollution near the ground.



2 types of Inversion

- <u>Radiation inversions</u> are caused by nocturnal cooling of the Earth's surface, especially on clear winter nights.
  The surface of the Earth cools down at night by radiating energy toward space. On a cloudy night, the Earth's radiation tends to be absorbed by water vapor, which in turn reradiates some of that energy back to the ground.
  On a clear night, however, the surface more readily radiates energy to space, and thus ground cooling occurs much more rapidly. As the ground cools, the temperature of the air in contact with the ground also drops. As is often the case on clear winter nights, the temperature of this air just above the ground becomes colder than the air above it, creating an inversion. Radiation inversions begin to form at about dusk.
  As the evening progresses, the inversion extends to a higher and higher elevation, reaching perhaps a few hundred meters before the morning sun warms the ground again, breaking up the inversion.
- <u>Subsidence inversions</u> are the result of the compressive heating of descending air masses in high pressure zones.

While radiation inversions are mostly a short-lived, ground-level, wintertime phenomenon, the other important cause of inversions, subsidence, creates quite the opposite characteristics.

Subsidence inversions may last for months on end, occur at higher elevations, and are more common in summer than winter. Subsidence inversions are associated with high-pressure weather systems, known as *anticyclones.*

Air in the middle of a high pressure zone is descending, while on the edges, it is rising. Air near the ground moves outward from the center, while air aloft moves toward the center from the edges. The result is a massive vertical circulation system.

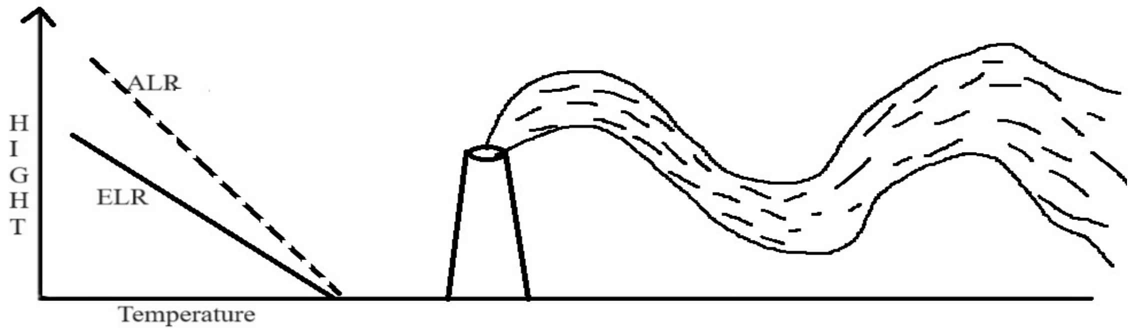
- There are other, less important, causes of inversions such as frontal inversions. A frontal inversion is created when a cold air mass passes under a warm air mass, but these are short lived and tend to be accompanied by precipitation that cleanses the air.

Plume Behaviour:

- Plume behaviour is the pattern of how gaseous pollutants disperse in the atmosphere.
- Typically, in lower atmosphere up to 300m from ground surface.

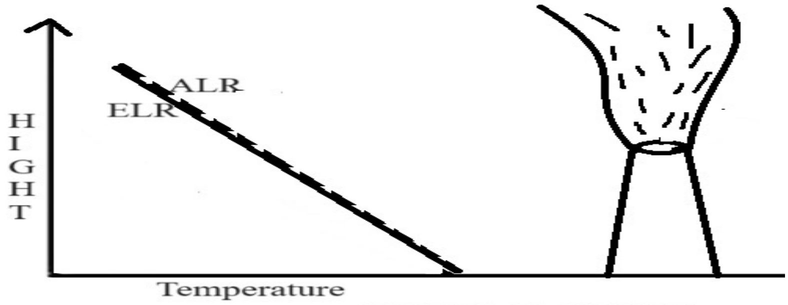
1. **<u>Looping Plume:</u>**

- Super Adiabatic Lapse Rate prevail in Atmosphere, (ELR>ALR), resulting in a very unstable atmosphere due to rapid mixing.
- Light to Moderate wind speed, Hot summer afternoon
- Wavy Plume
- High turbulence so rapid dispersion
- High concentration touch at ground level



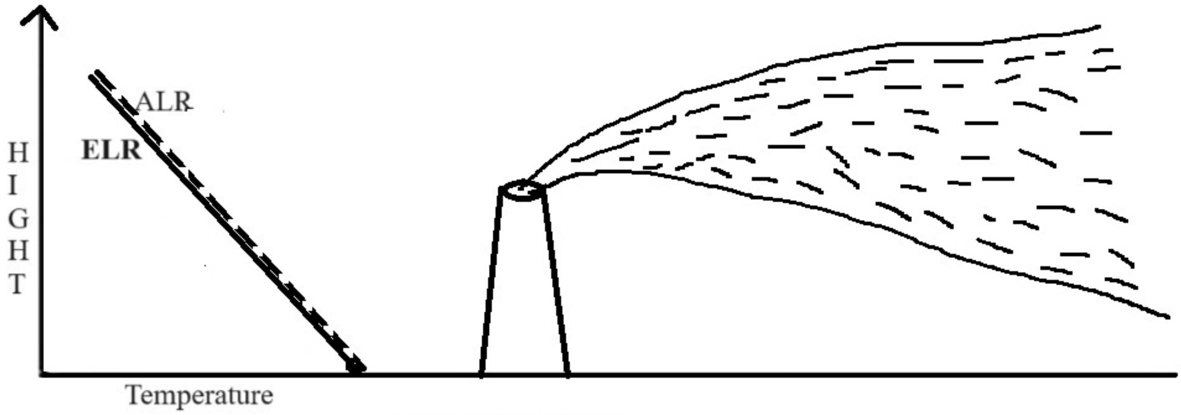
2. **Neutral Plume:**

- In neutral atmospheric circumstances (ELR=ALR), a neutral plume form. A neutral plume rises vertically in an upward direction.
- The plume will continue to rise until it reaches a height where the density and temperature of the surrounding air are equal.



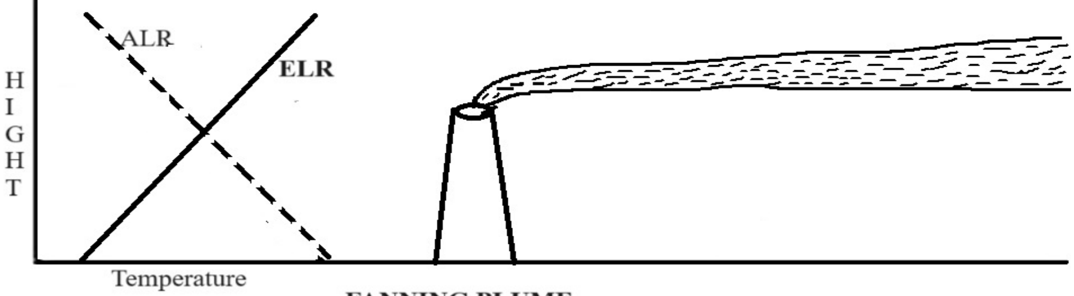
NEUTRAL PLUME

3. **Coning Plume:**
   - Formed when horizontal wind velocity exceeds 32 km/h and cloud blocks solar radiation during the day and terrestrial radiation during the night.
   - There is little vertical mixing.
   - The environment is slightly stable under sub-adiabatic conditions (ELR<ALR).
   - The plume shape is vertically symmetrical about the plume line.



CONING PLUME

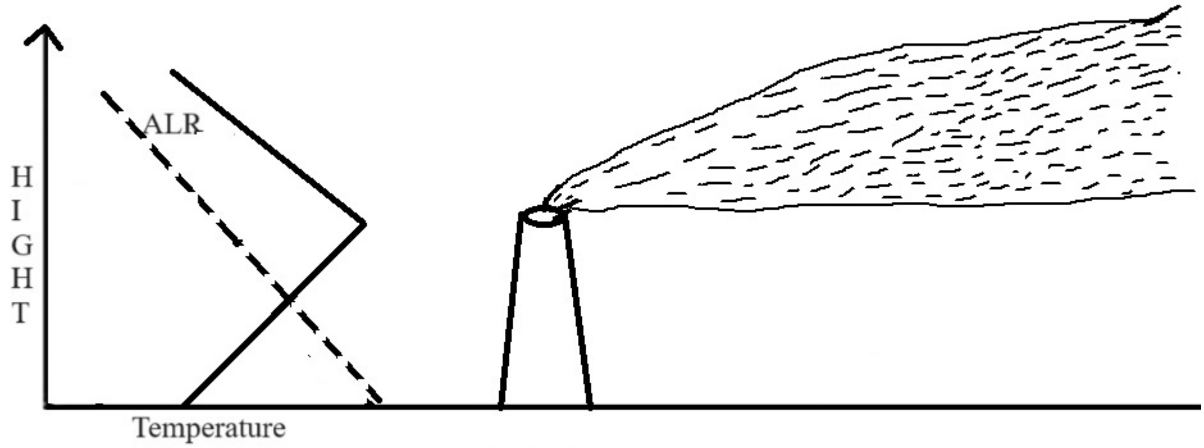
4. **Fanning Plume:**
   - Formed at extreme inversion conditions owing to a negative lapse rate.
   - When the environment is under conditions of inversion, a stable environment occurs just above the stack, and the plume moves horizontally rather than upwards.
   - Occurs more frequently when there is less turbulence.
   - For high stack, fanning is considered a favourable meteorological condition as it doesn't cause ground pollution.



FANNING PLUME

5. **Lofting Plume:**

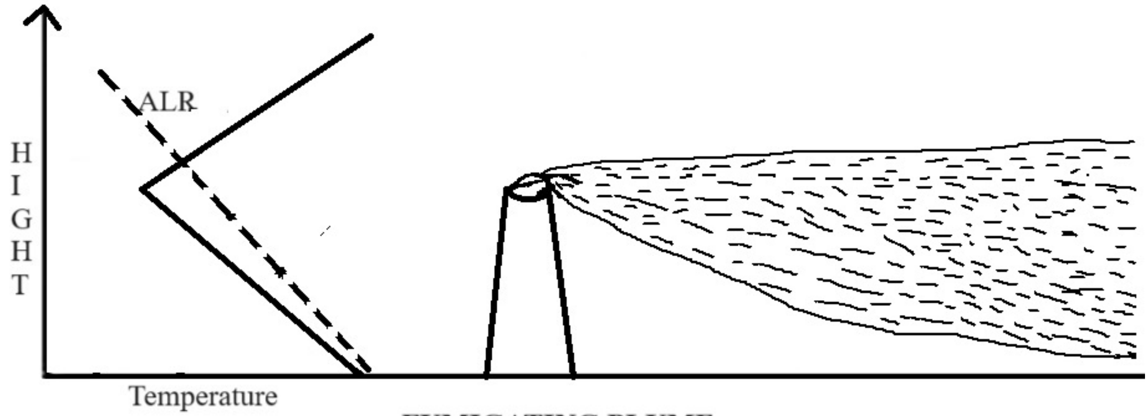
- Lofting plume is produced by a strong super adiabatic lapse rate immediately above the stack and a negative lapse rate (inversion) immediately below the stack opening.
- The downward movement is stopped by inversion.
- This results in a very rapid and turbulent upward mixing of the plume. But the downward mixing is less.
- As a result, the dispersion of pollutants becomes quick, and pollutants cannot come down to the ground.
- Such a plume is good for dispersing air contaminants and providing significant protection to living beings.



LOFTING PLUME

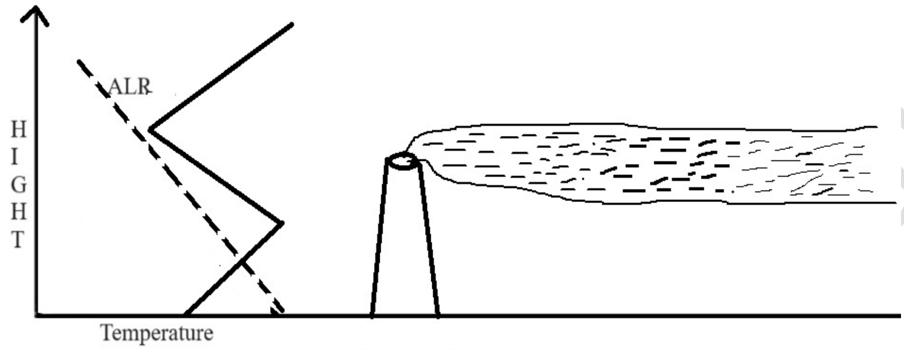
6. **Fumigating Plume:**

- The fumigant plume is the exact opposite of the lofting plume.
- Formed when there is a negative lapse rate (inversion) just above the stack and a strong super adiabatic lapse rate below the stack.
- Pollutants cannot escape above the stack under these conditions; thus, they settle towards the ground due to turbulence and mixing.
- As a result, the dispersion of contaminants in a fumigant plume is exceedingly poor.



FUMIGATING PLUME

7. **Trapping Plume:**
   - When an inversion layer exists above and below the stack, the plume does not rise or fall.
   - Rather, it is constrained or trapped between the two inversion levels, resulting in a trapping plume.
   - This plume isn't optimal for pollution dispersion since it can't go past a particular height.



Trapping Plume

Humidity:
is the concentration of water vapor present in the air. Water vapor, the gaseous state of water, is generally invisible to the human eye. Humidity indicates the likelihood for precipitation, dew, or fog to be present. The average concentration of water vapor in the atmosphere is 0.48%

The **dew point** of a given body of air is the temperature to which it must be cooled to become saturated with water vapor. This temperature depends on the pressure and water content of the air. When the air is cooled below the dew point, its moisture capacity is reduced and airborne water vapor will condense to form liquid water known as dew. When this occurs through the air's contact with a colder surface, dew will form on that surface. The dew point is affected by the air's humidity. The more moisture the air contains, the higher its dew point.
Humidity depends on the temperature and pressure of the system of interest. The same amount of water vapor results in higher relative humidity in cool air than warm air.

Humidity is measured using instruments such as ***hygrometers***. These devices can be based on various principles, including the use of hair tension, electrical resistance, or condensation.
Three primary measurements of humidity are widely employed:
absolute, relative, and specific.
Absolute humidity is expressed as either mass of water vapor per volume of moist air (in grams per cubic meter) or as mass of water vapor per mass of dry air (usually in grams per kilogram).

Relative humidity, often expressed as a percentage, indicates a present state of absolute humidity relative to a maximum humidity given the same temperature.
Specific humidity is the ratio of water vapor mass to total moist air parcel mass.

Vapor pressure (denoted e): It is the partial pressure of water vapor molecules in the atmosphere. Partial pressure is a term in thermodynamics of gas mixtures (in our case - air). We can break down the air pressure into the pressure each of its individual gas constituents would exert, had all the others been removed. The pressure in an air parcel is the sum of the partial pressures of all the constituents. The smaller the concentration of a gas in the mixture, the lower its partial pressure.

However, since molecules of different constituents have different mass, the partial pressure is not directly proportional to the molecular concentration.

The concept of vapor pressure is important for understanding the processes of evaporation and saturation. If we hold a parcel of air still over flat water surface, water molecules will escape the surface and start mixing with the other gases in the air parcel. This is evaporation - it can happen even if the liquid is not at its boiling temperature. Evaporation can only go on until the maximum amount of water vapor that air can hold is reached. At this point, the pressure that the water molecules exert as they are trying to escape the liquid is equaled by the partial pressure of water in the air parcel, called the saturation vapor pressure. Saturation is a process of equilibrium where water molecules cross back and forth across the boundary between water and air, maintaining a fixed concentration in the air. The saturation vapor pressure is a function of temperature.

Relative humidity: It is the ratio of actual vapor pressure to saturation vapor pressure (expressed as % if multiplied by 100). This is a common way to indicate air humidity. Because perspiration plays a very important function in maintaining body temperature, relative humidity figures into consideration of the degree of comfort we have when following our daily activities.

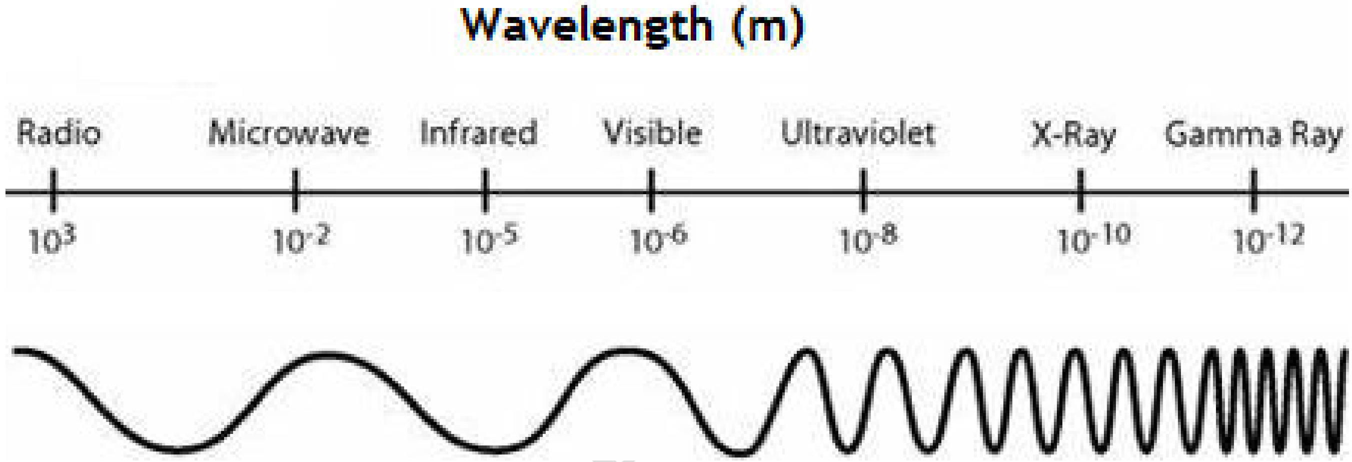
Mixing ratio: It is the mass of variable atmospheric constituent in grams per kilogram of air. Here it is the mass of water vapor in grams per kilogram of air. This is the most common way to indicate air humidity in scientific applications. At the Earth's surface, mixing ratio varies from ~18 g kg^{-1} in the tropics to less than 2 g kg^{-1} near the poles.

RADIATION: Atmospheric radiation is the flow of electromagnetic energy between the sun and the Earth's surface as it is influenced by clouds, aerosols, and gases in the Earth's atmosphere. It includes both solar radiation (sunlight) and long-wave (thermal) radiation.

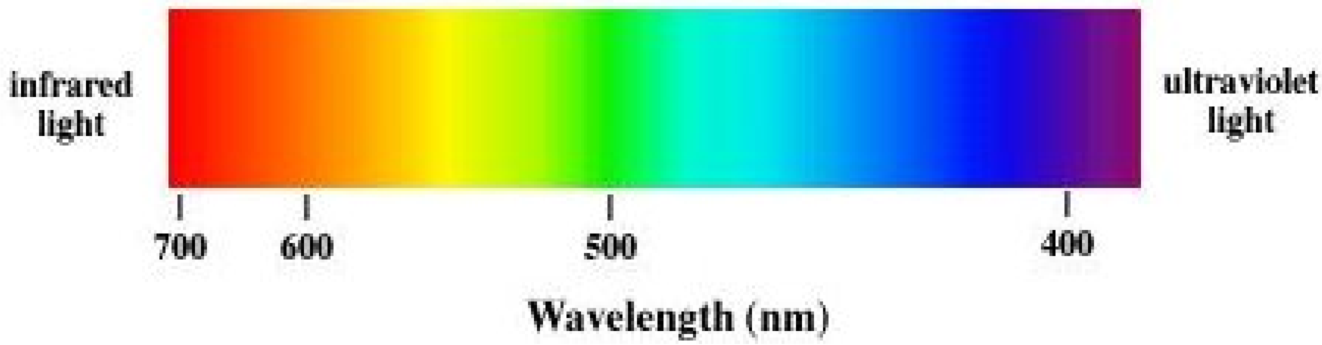
Nuclear fusion deep within the Sun releases a tremendous amount of energy that is slowly transferred to the solar surface, from which it is radiated into space. The planets intercept minute fractions of this energy, the amount depending on their size and distance from the Sun. A 1-square-metre area perpendicular (90°) to the rays of the Sun at the top of Earth's atmosphere, for example, receives about 1,367 watts of solar power known as ***Solar Constant***. (1367 w/m^2)

- EM energy travels in a harmonic, sinusoidal fashion at the velocity of light, c. Distance from one wave peak to the next is wavelength λ, and the number of peaks passing a fixed point in space per unit time is the wave frequency v.
- Waves obey the equation: $c = v\lambda$

EM Spectrum –



- Visible light has a wavelength range from ***~400 nm to ~700 nm***.
- Violet light has a wavelength of ~400 nm, and a frequency of $\sim 7.5 \times 10^{14}$ Hz.
- Red light has a wavelength of ~700 nm, and a frequency of $\sim 4.3 \times 10^{14}$ Hz.



Plank's Law

- Every object emits radiation at all times and at all wavelengths.
- Plank's Law states that every object emits over the entire electromagnetic spectrum.

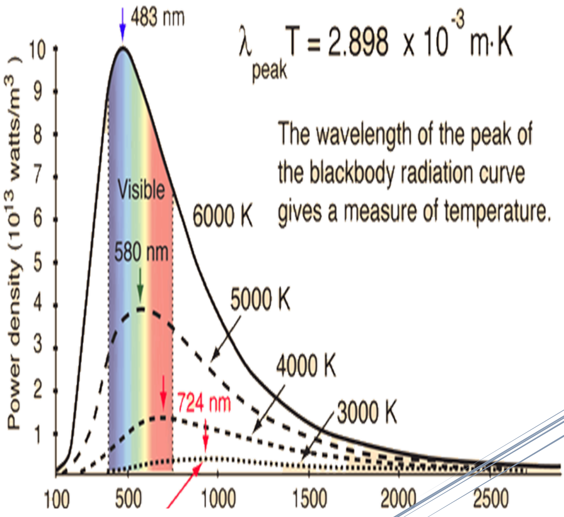
- That means that you emit radiation at all wavelengths -- so does everything around us

Stefan–Boltzmann law

- Specifically, the Stefan–Boltzmann law states that the total energy radiated per unit surface area of a black body across all wavelengths per unit time (also known as the black-body radiant exitance or emissive power), is directly proportional to the fourth power of the black body's thermodynamic temperature
- $P = e A \sigma T^4$ watts
  - where T is the absolute temperature,
  - A is the surface area of the radiator, and
  - e is the emissivity, a function of emitted wave length;
  - P= Power radiated by hot body.
- For a perfect black body e = 1.
- The Stefan Boltzmann Constant, σ, is equal to 5.67×10^{-8} W/($m^2 \cdot K^4$).

Wien's Displacement Law

- When the temperature of a blackbody radiator increases, the overall radiated energy increases and the peak of the radiation curve moves to shorter wavelengths.
- When the maximum is evaluated from the Planck radiation formula, the product of the peak wavelength and the temperature is found to be a constant.
- $\lambda_{max} T =$ 0.2898 centimetre-degree Kelvin.



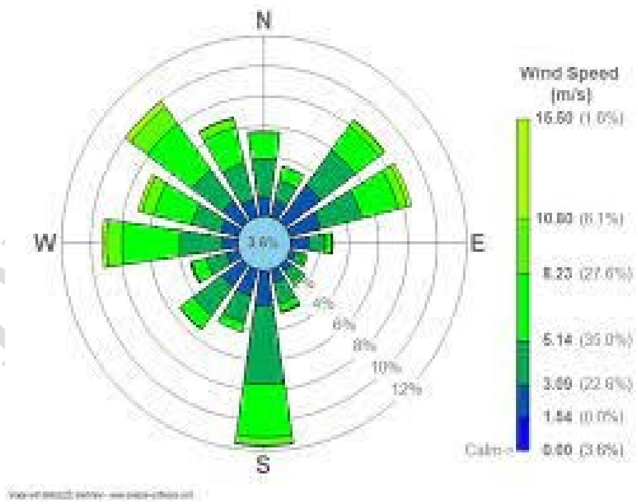
Albedo: Albedo is the fraction of light that a surface reflects. If it is all reflected, the albedo is equal to 1. If 30% is reflected, the albedo is 0.3. The average albedo of Earth's surface is 0.31. (Fresh snow 0.80, Desert 0.40, Green grass 0.25, Ocean surface 0.06)

Wind Velocity:

- Wind velocity, or wind speed, is the measurement of the speed at which air moves horizontally. It is typically expressed in units like meters per second (m/s) or kilometers per hour (km/h).
- Wind direction indicates the compass direction from which the wind is coming. It is expressed in terms of cardinal or azimuthal directions (north, south, east, west).
- ***Anemometers*** are instruments used to measure wind speed. Wind vanes are used to determine wind direction. Together, they provide information on both speed and direction.
- Wind is primarily influenced by pressure differences in the atmosphere. Air flows from high-pressure areas to low-pressure areas, generating wind.
- wind speed measured at 2 m above ground.
- The average wind velocity observed on earth is ***9 m/s.***

Wind Rose:

- A wind rose is a circular chart that shows the ***speed*** and ***direction*** of wind at a location over a ***period of time***.
- The length of each spoke around the circle indicates the amount of time that the wind blows from a particular direction.
- The direction from which the longest radial line extends indicates the prevailing wind direction.



PRECIPITATION:

- The term "precipitation" denotes all forms of water that reach the earth from the atmosphere.
- The usual forms are rainfall, snowfall, hail, frost and dew. The magnitude of precipitation varies with time and space.

- For precipitation to form:
  (i) the atmosphere must have moisture,
  (ii) there must be sufficient nuclei present to aid condensation,
  (iii)Weather conditions must be good for condensation of water vapour to take place,
  (iv) The products of condensation must reach the earth.

- Some of the common forms of precipitation are rain, snow, drizzle, glaze, sleet and hail.

Rain: It is the principal form of precipitation in India.

- The term rainfall is used to describe precipitation in the form of water drops of sizes larger than 0.5mm.
- The maximum size of a raindrop is 6mm.
- Any drop larger in size than this tends to break up into drops of smaller sizes during its fall from the clouds.
- On the basis of its intensity rainfall is classified as follows:
  Light rain: trace to 2.5 mm/hr
  Moderate rain: 2.5mm/hr to 7.5mm/hr
  Heavy rain: > 7.5mm/hr

Snow is another important form of precipitation. Snow consists of ice crystals which usually combine to form flakes. When fresh, snow has an initial density varying from 0.06 to 0.15g/cm^3 and it is usual to assume an average density of 0.1 g /cm^3. In India, snow occurs only in the Himalayan regions.

Drizzle: A fine sprinkle of numerous water droplets of size less than 0.5mm and intensity less than 1mm/hr is known as drizzle. In this, the drops are so small that they appear to float in the air.

Glaze: When rain or drizzle comes in contact with cold ground at 00C, the water drops freeze to form an ice coating called glaze or freezing rain.

Sleet: It is frozen raindrops of transparent grains which form when rain falls through air at sub freezing temperature. In Britain, sleet denotes precipitation of snow and rain simultaneously.

Hail: It is a showery precipitation in the forms of irregular pellets of lump of ice of size more than 8mm. Hails occur in violent thunderstorms in which vertical currents are very strong.

For the formation of clouds and subsequent precipitation, it is necessary that the moist air masses cool to form condensation. This is normally accomplished by adiabatic cooling of moist air through a process of being lifted to higher altitude. Some of the terms and processes connected with weather systems associated with precipitation are given below.

- A ***front*** is the interface between two distinct air masses. Under certain favourable conditions when a warm air mass and cold air mass meet, the warmer air mass is lifted over the colder one with the formation of front. The ascending warmer air cools adiabatically with the consequent formation of clouds and precipitation.

- A ***cyclone*** is a large low pressure region with circular wind motion.

  Two types of cyclones are recognized: tropical cyclones and extra tropical cyclones.

  1. Tropical cyclone: A tropical cyclone, also called cyclone in India, hurricane in USA and typhoon in south East Asia, is a wind system with an intensely strong depression with MSL pressures sometimes below 915 m bars. The normal areal extend of cyclone is about 100-200 km in diameter. The isobars are closely spaced and the winds are anticlockwise in the northern hemisphere. The center of the storm called the eye, which may extend to about 10-50 km in diameter, will be relatively quiet. However, right outside the eye, very strong winds/reaching to as much as 200 km per hr exist. The wind speed gradually decreases towards the outer edge. The pressure also increases outwards. The rainfall will normally be heavy in the entire area occupied by the cyclone.
  2. Extra tropical cyclone: These are cyclones formed in locations outside the tropical zone. Associated with a frontal system, they possess a strong counter clockwise wind circulation in the northern hemisphere. The magnitude of precipitation and wind velocities are relatively lower than those of a tropical cyclone. However, the duration of precipitation is usually longer and the areal extend is also larger.

- ***Anticyclones:*** These are regions of high pressure, usually of large areal extent. The weather is usually calm act the center. Anticyclones cause clockwise wind circulations in the northern hemisphere. Winds are of moderate speed, and at the outer, cloudy and precipitation conditions exist.

- ***Convective precipitation:*** In this type of precipitation, a packet of air which is warmer than the surrounding air due to localized heating rises because of its lesser density. Air from cooler surroundings flows to take up its place, thus setting up a convective cell. The warm air continues to rise, undergoes cooling and results in precipitation. Depending upon the moisture, thermal and other conditions, light showers to thunderstorms can be expected in convective precipitation. Usually, the aerial extent of such rains is small, being limited to a diameter of about 10km.

- ***Orographic precipitation:*** The moist air masses may get lifted up to higher altitudes due to the presence of mountain barriers and consequently undergo cooling, condensation and precipitation. Such a precipitation is known as orographic precipitation. Thus, in mountain ranges, the windward slopes of heavy precipitation and the leeward slopes have light rainfall.

Annual Average Rainfall: Considerable areal variation exists for the annual rainfall of the magnitude of 200cm in Assam and north-eastern parts and Western-Ghats, and scanty rainfall in eastern Rajasthan and parts of Gujarat, Maharashtra and Karnataka. The ***average*** annual ***rainfall*** for the entire ***country*** is estimated as ***118.3cm.***