INDIANCIVILS – Sample Material

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CLIMATOLOGY – Sample Material

INTRODUCTION

The atmosphere of Earth is a layer of gases surrounding the planet Earth that is retained by Earth's gravity. The Earth is home to a hospitable environment for life, almost solely because of the atmosphere. It protects life on Earth by

1. absorbing ultraviolet solar radiation,
2. warming the surface through heat retention (greenhouse effect),
3. And reducing temperature extremes between day and night (the diurnal temperature variations).

The Earth's Atmosphere has distinct layers, each with specific characteristics such as temperature or composition. The atmosphere has a mass of about 5×1018 kg, 75% of which is within about 11 km of the surface. With increasing altitude, the atmosphere gets thinner and **at Kármán line**, at 100 km from surface, it becomes so thin that this line is considered to be the boundary between earth's atmosphere and outer space.

KÁRMÁN LINE

Kármán line or "Edge of space" was named after Theodore von Kármán, a scientist active in field of aeronautics and astronautics. The line lies at 100 km above earth's Sea Level and makes a boundary between Earth's atmosphere and Outer space for aeronautical purposes. The definition is internationally accepted and is used to differentiate between aeronautics and astronautics. As per *Fédération Aéronautique Internationale* (FAI), Aeronautics is the aerial activity, including all air sports, within 100 kilometres of Earth's surface, while Astronautics is the activity more than 100 kilometres above Earth's surface.

Importance of Kármán line

We all know that when a satellite is launched into an orbit, the speed with which it is thrown in a direction tangential to earth's circumference is very important. This is called **Orbital speed**. An object which is thrown in the orbit stays in the sky only if the centrifugal component of its movement around the Earth is enough to balance the downward pull of gravity. If this component is lesser, the pull of gravity will gradually cause its altitude to decrease. For example, a satellite or space shuttle will stay in the Low Earth Orbit only if the speed is about 27,000 km per hour. To understand the concept, we need to imagine about a pilot who wants to fly as higher as possible. We know that when we go higher in the air, the atmospheric pressure comes down. If an aeroplane pilot wants to try to fly his plane in higher and higher altitude, the thinning of the air will give it lesser and lesser lift. This means that to get required lift, the pilot will need to increase the speed of the airplane so that he can avoid stalling. Then, a point comes where the airplane would need so much speed that it will be equal to the orbital speed, just to keep it there. This altitude where the required flying speed is equal to orbital velocity is called the Kármán line. Above this line, if the pilot is capable to provide a speed equal to orbital speed, there would be no need for lift. Otherwise, it will stall. This means that above this point, the airplane would be counted in outer space and the field of aeronautics will be now called astronautics.

EARTH'S MAGNETOSPHERE

We all know that the most important influence of Sun on Earth is its gravity, which keeps her, in its one-year orbit. Apart from the visible light, the Sun emits other, less benign sources of radiation such as energetic photons (ultraviolet, X-ray, and gamma ray) and energetic particles from solar flares, collectively called as solar winds.

1. The Earth and its abundant life are sheltered from the outbursts of the Sun by its protective cocoon, the **Magnetosphere.**
2. A magnetosphere is the region surrounding a planet where the planet's magnetic field dominates. The magnetosphere is the sphere of influence of the Earth's magnetic field. But this is not at all spherical. Its shape is more or less like a comet. The most beautiful effect of the magnetosphere is the **aurora borealis,** or **northern lights**.

AURORA

Charged particles ejected at great speeds from the sun ionise the air molecules resulting in spectacular colour display. These are seen from Polar Regions and are called aurora or polar lights. It is the luminous phenomenon of earth's upper atmosphere that occurs primarily in high latitudes of both hemispheres; aurora in the northern hemisphere are called aurora borealis, or northern lights; aurora australis, or southern lights in the southern hemisphere.

1. Earth is surrounded by a magnetosphere, as are the other planets with intrinsic magnetic fields: Mercury, Jupiter, Saturn, Uranus, and Neptune.
2. Please note that Earth's Magnetosphere is not a part of the atmosphere but it represents the outermost limits of the earth.
3. It lies beyond the exosphere along with MANGNETOPAUSE which marks the outer boundary of the magnetosphere.
4. Earth's magnetosphere protects the ozone layer from the solar wind. The ozone layer protects the Earth (and life on it) from dangerous ultraviolet radiation.
5. The magnetosphere interacts with the solar winds. The solar winds, despite of low density and accompanying low magnet field, are strong enough to interact with the planets and their magnetic fields to shape magnetospheres. Because the ions in the solar plasma are charged, they interact with these magnetic fields, and solar wind particles are swept around planetary magnetospheres. Life on Earth has developed under the protection of this magnetosphere.
6. The shape of the magnetosphere is direct result of being blasted by solar wind.
7. The shape is determined by the Earth's internal magnetic field, the solar wind plasma, and the interplanetary magnetic field (IMF). The boundary of the magnetosphere ("magnetopause") is roughly bullet shaped.
8. Solar wind compresses its sunward side to a distance of only 6 to 10 times the radius of the Earth. A supersonic shock wave is created sunward of Earth somewhat like a sonic boom. This shock wave is called the bow shock.
9. Most of the solar wind particles are heated and slowed at the bow shock and detour around the Earth. Solar wind drags out the night-side magnetosphere to possibly 1000 times Earth's radius; its exact length is not known. This extension of the magnetosphere is known as the magnetotail. Many other planets in our solar system have magnetospheres of similar, solar wind-influenced shapes.

BENEFITS OF MAGNETOSPHERE

Magnetosphere saves us from worst effects of space weather. Without the protective shells of the magnetosphere and the atmosphere, the Earth would be blasted by cosmic rays, very energetic particles that come both from the Sun and from the galaxy. The solar outbursts are more common at times of Solar Maximum, when the Sun's surface is most active. Solar maxima occur every 11 years. The Earth's magnetic field, which excludes most of these energetic particles, can also trap, store, and energize charged particles, causing at times damage to communication spacecraft systems. The electric currents that flow in the Earth's vicinity from its interaction with the solar wind drive the shimmering aurora; but in the process can create overloads on electric power distribution grids, creating massive power blackouts. Turbulence in the Earth's ionosphere can cause disruption of radio transmission, and errors in satellite navigation systems. By understanding the natural processes and variability of this system, we can be prepared for the disasters that at times can occur and understand the conditions necessary for life to exist on any planetary system.

COMPOSITION OF ATMOSPHERE

Earth's atmosphere is mainly consisted of nitrogen, oxygen, and argon, which together constitute the major gases of the atmosphere. The remaining gases are often referred to as trace gases. The following table shows the composition of Dry atmosphere.

Gas Volume

Nitrogen N2	**78.08%**
O2	**20.95%**
Ar	**0.93%**
Co2	**0.04%**
Ne	**0.00%**
He	**0.00%**
Kr	**0.00%**
H2	**0.00%**
N2O	**0.00%**
CO	**0.00%**
XE	**0.00%**
O3	**0-6%**
NO2	**0.00%**
I2	**0.00%**
NH3	**trace**

ATMOSPHERIC LAYERS

As we read above, the upper boundary of the atmosphere is not sufficiently clearly defined. The Kármán line does not mean that there is no atmosphere beyond this line. The composition of the atmosphere above the 100 km level also includes mainly the nitrogen and oxygen. However, under the effect of the solar ultraviolet radiation the oxygen molecules split into atoms and oxygen become atomic. This is important for the formation of Ozone Layer. Below the 100 kilometres or so, the atmosphere behaves like a fluid. The outermost layer of Earth's atmosphere is mainly composed of hydrogen and helium. The particles are so far apart that they can travel hundreds of kilometres without colliding with one another. Since the particles rarely collide, the atmosphere no longer behaves like a fluid. These free-moving particles follow ballistic trajectories and may migrate into and out of the magnetosphere or the solar wind. The atmosphere has been divided into several layers on the basis of change in height and some other factors such as change in climate etc. These include the Troposphere (the lowermost), Stratosphere (stratified), Mesosphere, Thermosphere, Exosphere (outer space). Between individual spheres there are usually distinguished transitory layers, called 'PAUSES' where temperature varies but little with height. The character and composition of the atmosphere change as we go higher and higher. The atmosphere can be divided into several layers according to differences in temperature and rates of temperature change. There are 4 important spheres, with 3 pauses as follows:

1. Troposphere with tropopause
2. Stratosphere with stratopause
3. Mesosphere with mesopause, and
4. Ionosphere or thermosphere.

TROPOSPHERE

This is the lowest portion of Earth's atmosphere and contains approximately 80% of the atmosphere's mass and 99% of its water vapour and aerosols. The average depth of the troposphere is approximately 17 km in the middle latitudes. **It is maximum at equator, deeper in the tropics,** up to 20 km, and **shallower near the Polar Regions**, **at 7 km in summer**, and indistinct in winter. In India, it is taken to be 16 Kilometres. The boundary between troposphere and stratosphere, called the tropopause, is a temperature inversion. The characteristic features of the Troposphere are its great density. In addition to nitrogen and oxygen, carbon dioxide, and water vapour (nearly all of the water vapour contained in the atmosphere is concentrated in the troposphere) and of numerous particles of various origin.

Why troposphere is thicker over the equator?

One of the laws of Ideal gases called **Charles' law** says that in an ideal gas, density decreases with increasing temperature, we pressure is constant. The hot air rises and the Earth is not equally heated everywhere. The troposphere is thicker over the equator than the poles because the equator is warmer. The warmer the weather, the thicker is the troposphere. Thus the simple reason is thermal expansion of the atmosphere at the equator and thermal contraction near the poles. But here, please note that almost same amount of atmospheric mass exists at both of the places, and density of the air is less at equator and greater at poles.

Chemical Composition of Troposphere

The chemical composition of the troposphere is essentially uniform, with the notable exception of water vapour. The Amount of water vapour existing in the atmosphere decreases strongly with the height. Thus the proportion of water vapour is normally greatest near the surface and decreases with height.

Temperature of Troposphere

Temperature of the troposphere decreases with height. The rate at which the temperature decreases is called the **Environmental Lapse Rate** (ELR). Thus Environment Lapse rate is the rate of temperature decrease (or vertical temperature gradient) in the atmosphere with increasing altitude. The ELR is nothing more than the difference in temperature between the surface and the tropopause divided by the height. The environmental lapse-rate is about 0.6°C per every 100 meters. This normal lapse-rate may be interrupted by inversion, and it is affected markedly by the vertical ascent of air parcels of different temperature and humidity (this is called process lapse rate).

Why the temperature of Troposphere goes down with altitude?

The reason for this temperature difference is the absorption of the sun's energy occurs at the ground which heats the lower levels of the atmosphere, and the radiation of heat occurs at the top of the atmosphere cooling the earth, this process maintaining the overall heat balance of the earth. Please note that the temperature decreases at a **nearly uniform rate** with increased altitude.

Tropopause

Tropopause refers to the altitude at which the normal lapse-rate ceases to function. This means that the fall in the temperature is stalled. This layer separates the troposphere from the stratosphere (the second layer of the atmosphere). This layer is usually quiet and no major movement of air takes place in it. Its height at tropic of cancer and that of Capricorn is roughly 10 to 15 km, highest at the equator 18 km and at the poles it is about 8 km above the earth. In India, the tropopause is generally at a height of around 16 km. The height of the Tropopause depends upon the following:

- Temperature of the lower layers
- Cyclonic activities

Thus we cannot say that Tropopause is a hard lined boundary. The higher is the temperature of the lower layers, the higher is the height of this layer, the layer is lower where there is a cyclone below it, but higher where there is an anticyclone. Please note that the tops of cumulus-nimbus clouds often float in his region. These clouds we will discuss in this module.

STRATOSPHERE

1. The stratosphere is the second major layer of Earth's atmosphere, just above the troposphere, and below the mesosphere.
2. It is called stratosphere because **it is stratified in temperature**, with **warmer layers higher up** and **cooler layers farther down**. Top of the stratosphere has a temperature of about −3°C, just slightly below the freezing point of water.
3. This is in contrast to the troposphere near the Earth's surface, which is cooler higher up and warmer farther down. This **inversion begins in tropopause.**
4. The stratosphere is situated between about 10 km and 50 km altitude above the surface at moderate latitudes, while at the poles it starts at about 8 km (5 mi) altitude. Thus, stratosphere is nearest to poles attitudinally.

Why the Stratosphere is stratified?

In the stratosphere, temperature has a tendency to rise. This is due to the presence of Ozone. The first thing we have to note is that the air is highly rarefied and there are only eight ozone molecules to a million. The ozone (O3) here absorbs high energy Ultraviolet energy waves from the Sun and is broken down into atomic oxygen (O) and diatomic oxygen (O2). Atomic oxygen is found prevalent in the upper stratosphere due to the bombardment of UV light and the destruction of both ozone and diatomic oxygen. The mid stratosphere has less UV light passing through it, O and O_2 are able to combine, and is where the majority of natural ozone is produced. It is when these two forms of oxygen recombine to form ozone that they release the heat found in the stratosphere. The lower stratosphere receives very low amounts of UV, thus atomic oxygen is not found here and ozone is not formed (with heat as the by-product). This vertical stratification, with warmer layers above and cooler layers below, makes the stratosphere dynamically stable: there is no regular convection and associated turbulence in this part of the atmosphere. The top of the stratosphere is called the stratopause, above which the temperature decreases with height.

Why aeroplanes cruise in Stratosphere?

The first reason is that the stratosphere is free from the violent weather changes which occur below. So, it is preferred by commercial airliners. The commercial airliners typically cruise at altitudes of 9–12 km in the lower reaches of the stratosphere. They do this to optimize fuel burn. It also allows them to stay above any hard weather (extreme turbulence) of the Troposphere. Please note that they don't do so to avoid the clouds or water vapour. There are occasions where clouds in the stratosphere and mesosphere are formed and have been observed. The stratosphere is very dry, because vertical transfer is limited by the high stability and because any transfer would have to occur through the tropopause, which is so cold that the saturation vapour pressure is negligibly small. Yet on occasion thin veils of clouds are observed above the tropopause. Presumably these clouds consist largely of ice, although their exact composition is not known. Cumulonimbus clouds are able to reach into the stratosphere for brief periods of time. So, the major reasons for preference of Jet liners of stratosphere are:

1. Optimize fuel burn
2. Avoid turbulence of Troposphere Jet liners,

However, we face another menace in stratosphere, namely jet streams. Jet streams are high velocity air currents. The main jet streams are located near the tropopause, the transition between the troposphere (where temperature decreases with altitude) and the stratosphere (where temperature increases with altitude). The location of the jet stream is extremely important for aviation. Please note that Jet streams are NOT always harmful for aviation. They are beneficial and used commercially as it reduced the trip time and fuel consumption. Commercial use of the jet stream began in 1950s when an aeroplane flew from Tokyo to Honolulu at an altitude of 7,600 meters cutting the trip time by over one-third. It also nets fuel savings for the airline industry.

OZONE LAYER

As discussed above, the **Ozone layer is contained within the stratosphere.** In this layer ozone concentrations are about 2 to 8 parts per million, which is much higher than in the lower atmosphere but still very small compared to the main components of the atmosphere. It is mainly located in the lower portion of the stratosphere from about 15–35 km, though the thickness varies seasonally and geographically. About 90% of the ozone in our atmosphere is contained in the stratosphere. The Ozone layer absorbs ultraviolet radiation from the sun and converts it into heat and chemical energy. It is this activity that is responsible for the rise in temperature. The layer, as we discussed in the environment is NOT of uniform thickness. Height at the equator is maximum and lowest at the poles.

MESOSPHERE

The mesosphere extends from the stratopause to 80–85 km. Please note that most meteoroids get burnt in this layer. Temperature decreases with height in the mesosphere. The mesopause, the temperature minimum that marks the top of the mesosphere, is the coldest place around Earth and has an average temperature around −85°C. At the mesopause, temperatures may drop to −100 °C. Due to the cold temperature of the mesosphere, water vapour is frozen, forming ice clouds. These clouds are called

NOCTILUCENT CLOUDS

Please note that these **noctilucent clouds** are the highest clouds in the Earth's atmosphere, located in the mesosphere at altitudes of around 76 to 85 kilometres (47 to 53 mi). They are normally too faint to be seen, and are visible only when illuminated by sunlight from below the horizon while the lower layers of the atmosphere are in the Earth's shadow. Noctilucent clouds are not fully understood and are a recently discovered meteorological phenomenon. Mesopause, a thin layer of extremely cold atmosphere, separates the mesosphere from the Ionosphere above.

IONOSPHERE

Ionosphere is called so because it is ionized by solar radiation. It plays an important part in atmospheric electricity and forms the inner edge of the magnetosphere. Ionosphere stretches from 50 to 1,000 km and typically overlaps both the exosphere and the thermosphere. It has practical importance because it influences, for example, radio propagation on the Earth. It is also responsible for auroras. Ionosphere is also known as THERMOSPHERE because of the high temperatures because of the high temperatures prevailing there as much as 870°C over the equator and 1427°C over the north pole, the temperature near the upper boundary of the thermosphere may become higher than 1000-1500°C. Along with temperature rise sharp changes caused by the corpuscular and ultraviolet solar radiation are observed in it. We note that the ionization depends primarily on the Sun and its activity. This means that the amount of ionization in the ionosphere varies greatly with the amount of radiation received from the Sun. This is the reason that there are changes in the Ionosphere and there are diurnal effect and seasonal effects. The activity of the Sun is associated with the position of earth in the revolutionary orbit, sunspot cycle, with more radiation occurring with more sunspots. Radiation received also varies with geographical location (polar, aurora zones, mid-latitudes, and equatorial regions). There are also mechanisms that disturb the ionosphere and decrease the ionization. There are disturbances such as solar flares and the associated release of charged particles into the solar wind which reaches the Earth and interacts with its geomagnetic field. It is called the ***Aurora Borealis*** (or northern lights) in the northern hemisphere and the **Aurora Australis** in the southern hemisphere. Occasionally the Aurora borealis is seen in England, but it is more common in northern Scotland, presents a magnificent spectacle in northern Scandinavia and northern Canada.

EXOSPHERE

The exosphere lies above the altitude of 800 kilometres and it needs further studies. Characteristic of exosphere is an extreme rarefaction of the air; gas particles, moving with tremendous velocities, nearly fail to meet one another and there takes place an outflow of gas particles into the interpreter space.

ATMOSPHERE AND INSOLATION

Sun is the major source of energy for the entire earth system. The earth does receive very small proportions of energy from other stars and from the interior of the earth itself (volcanoes and geysers provide certain amount of heat energy). However, when compared with the amount received from the sun, these other sources seem insignificant. The energy emitted by the sun which reaches the surface of the earth is called **Insolation**. The sun, a mass of intensely hot gases, with a temperature at the surface be 6000°C emits radiant energy in the form of waves, which consists of very short wave-length x-rays, gamma rays, and ultraviolet rays; the visible light rays and the longer infrared rays. The earth receives only about one **two thousand millionth** of the total insulation poured out by the sun, but this is vital to it; the amount received at the outer limit of the atmosphere is called **Solar Constant**. Thus **Solar Constant** is the rate per unit area at which solar radiation is received at the outer limit of the atmosphere.

EARTH'S ALBEDO

The ratio between the total solar radiation falling (incident) upon a surface and the amount reflected without heating the earth is called ALBEDO (expressed as a decimal or as a percentage). The earth's average albedo is about 0.4 (40 percent); that is, 4/10 of the solar radiation is reflected back into space. It varies from 0.03 for dark soil to 0.85 for a snow-failed. Water has a low albedo (0.02) with near-vertical rays, but a high albedo for low-angle slanting rays. The figure for grass is about 0.25. Over-pastured land and bare soil are more reflective of solar radiation than are crops and vegetation. A desert is much more reflective than a savannah or forest. If economic pressure on soil and vegetation increases, and drought then occurs, the effect overall is to increase the albedo of the surface.

Effects of the Atmosphere on Solar Radiation

When the sun's energy passes through the atmosphere several things happen to it. Around one fourth of this energy is directly reflected back to clouds and the ground. Around 8 percent is scattered by minute atmospheric particles and returned to space as diffuse radiation. Some 20 percent reaches the earth's surface as diffuse radiation after being scattered. Approximately 27 percent reaches the earth's surface as direct radiation and 19 percent is absorbed by the ozone layer and by water vapour in the clouds of the atmosphere. On an average, 47 percent of the solar energy arriving at the outer limits of the atmosphere eventually reaches the surface, and 19 percent is retained in the atmosphere. This 19 percent of direct solar radiation that is retained by the atmosphere is locked up in the clouds and the ozone layer and is thus not available to heat the troposphere. The warmth of the atmosphere is due to the 47 percent of incoming solar energy reaching the earth's surface (that is, both land and bodies of water) and in the transfer of heat energy from the earth back to the atmosphere through such physical processes such as long-wave Radiation, Conduction and convection. Some related phenomena such as advection and Latent Heat of Condensation also contribute to the warmth of the atmosphere.

Radiation as method of Heat Energy Transfer

Radiation is the process by which most energy is transferred through space from the sun to the earth. Radiation is given off by all bodies including earth and human being. The hotter is the body, shorter are the waves. We can simply say that the radiation from Sun comes to earth in the form of smaller waves and earth being cooler body, gives off energy in the form of long-wave. These are then radiated back to the atmosphere. This Long-Wave Radiation from the earth's surfaces heats the lower layers of the atmosphere.

Conduction as Method of Heat Transfer

Conduction is the means by which heat is transferred from one part of a body to another or between two touching objects. Heat flows from the warmer to the cooler (part of a) body in order to equalize temperature. Conduction actually occurs through molecular movement, with one molecule bumping into another. The Atmospheric conduction occurs at the interface of (zone of contact between) the atmosphere and the earth's surface. However, it is actually a minor method of heat transfer in terms of warming the atmosphere since it affects only the layers of air closest to the earth's surface. This is because air is a very poor conductor of heat.

Convection as Source of Heat Transfer

When the pockets of air near the surface are heated, they expand in volume, become less dense than the surrounding air, and therefore rise. This vertical transfer of heat through the atmosphere is called convection, and is the same type of process by which heated water circulates in a pan while heating. The currents set into motion by the heating of a fluid (liquid or gas) make up a convectional system. Most vertical transfer of heat within the atmosphere & Oceans occurs via Convection and is a major cause of clouds and precipitation.

Advection as Source of Heat Transfer

Advection is the horizontal heat transfer within the atmosphere. Obviously the wind is the transfer agent of advection. Wind brings about the horizontal movement of large portions of lower atmosphere. This advection transports warmer or accounts for a major proportion of the lateral heat transfer that takes place within the atmospheric system.

Latent Heat of Condensation

A proportion of the solar energy is used to change liquid water from rivers, lakes, and oceans to water vapour. The solar energy used to do this is then stored in the water-vapour as latent or potential energy. Later the water-vapour in the atmosphere may change to form liquid water again through a process called CONDENSATION. The energy released through this process is known as the **Latent Heat of Condensation**. Like other means of heat transfer in the earth system, latent heat of condensation plays a major role in warming of the atmosphere and in addition, is a source of energy for STORMS. All the above process now would help us to understand the concept of Earth's Heat Budget **Earth's Energy Budget.**

Incoming Heat Energy Outgoing Heat Energy

1. Solar radiation (99.97%)
2. Geothermal energy (0.025%)
3. Tidal energy (0.002%)
4. Fossil fuel consumption (about 0.007%)

5. Minor Sources: remains part of the average albedo (reflectivity) of the Earth is about 0.3, which means that 30% of the incident solar energy is reflected into space, while 70% is absorbed by the Earth and reradiated as infrared. This 30% of the incident energy is reflected, consisting of 6% reflected from the atmosphere, 20% reflected from clouds and 4% reflected from the ground (including land, water and ice). The remaining 70% of the incident energy is absorbed, out of 51% is absorbed by land and water, and then emerges in the following ways:
6. 23% is transferred back into the atmosphere as latent heat by the evaporation of water, called latent heat flux
7. 7% is transferred back into the atmosphere by heated rising air, called Sensible heat flux
8. 6% is radiated directly into space
9. 15% is transferred into the atmosphere by radiation, then reradiated into space
10. 19% is absorbed by the atmosphere and clouds, including:
    a. 16% reradiated into space
    b. 3% transferred to clouds, from where it is radiated back into space.

The above figures are the averages for the whole earth over a year's time. For any particular location, the factors discussed may not be balanced, and adjustments must be made within the entire earth system. Some places have a surplus of incoming solar energy over outgoing energy loss in their budget, while others have a deficit. The main cause of these variations is the differences in latitude, and the seasonal fluctuations. We know that the amount of insolation received is directly related to the latitude. The tropical zone where insulation in high throughout the year more solar energy is received at the earth's surface and in the atmosphere than can be emitted back into space. In the arctic and Antarctic zones there is so little insulation during the winter, when the earth is still emitting long-wave radiation, that there is a large deficit for the year. Places in the mid-latitude zone have lower deficits or surpluses, but only at about latitude 38° is the budget balanced. It is the heat energy transfer within the atmosphere that prevents a situation whereby the tropical zones get hotter and hotter and the arctic and Antarctic zone get colder and colder.

DISTRIBUTION OF TEMPERATURE

As we discussed above, the most important cause of atmospheric temperature is the energy received from the sun. The atmosphere of the earth does not heat up directly as solar radiation is in the form of short waves and air cannot absorb the short waves. The earth absorbs the short wave energy and then radiates in the form of long wave terrestrial radiation that can be absorbed by the air. So, air heats up when comes in contact with the surface of the earth. This was the general description. We also know that the temperature differs from one part of the world to the other. Since Insolation is the basic source of energy for the atmosphere, the distribution of insolation would determine the temperature of the earth. Thus latitude, altitude, distance from sea, features of the surface, nature of the landscape are some important factors that affect the distribution of temperature. Since, the insolation is highest at equator; temperature is highest at the equator and lowest near the poles. Altitude is the second major control of temperature of a place. The temperature depends upon albedo of the surface as mentioned above. One more important factor affecting the distribution of the temperature of Earth is distribution of Land and Oceans. We all know that there is more land in Northern Hemisphere and more waters in Southern hemisphere. There is a big difference between the specific heat of land and water. This means that the loss of heat from the continents is bigger than the oceans. The continents get heated faster and get cooled faster in comparison to the Oceans. This is the reason that the temperatures of the Oceans are moderate while that of continents is extreme. The moderating effect on temperature of the land due to proximity of the seas is called **Maritime influence**. The increasing effect on temperature of the land at interior of the continents is called **Continental Influence**.

Three Broad Temperature Zones

The earth can be generally divided into three broad temperature zones.

1. **Torrid Zone**

   Torrid Zone is the tropical region. The temperature remains high. Sun is directly overhead at least once during the year. In the Northern Hemisphere, the overhead Sun moves north from the equator until it reaches 23.5 °North (Tropic of Cancer) for the June solstice after which it moves back south to the equator. In the Southern Hemisphere, the overhead Sun moves south from the equator until reaches 23.5 ° South (Tropic of Capricorn) for the December solstice after which it moves back north to the equator. The Sun crosses the equator 99 times a year in it moves through June super to September solstice and when it moves from December solstice to June solstice. The days when the Sun crosses the Equator are known as the Equinoxes. The Torrid Zone forms the hottest region of the world with two annual seasons namely a dry and a wet season. This zone includes most of Africa, southern Asia, Indonesia, New Guinea, northern Australia, southern Mexico, Central America and northern South America.

2. **Temperate Zones:**

   Temperate zones are the mid latitudinal areas, where the temperature is moderate. There are two temperate areas viz. North and South. In the two Temperate Zones, consisting of the tepid latitudes, the Sun is never directly overhead, and the climate is mild, generally ranging from warm to cool. The four annual seasons, spring, summer, autumn and winter occur in these areas. The North Temperate Zone includes Great Britain, Europe, northern Asia, North America and northern Mexico. The South Temperate Zone includes southern Australia, New Zealand, southern South America and South Africa.

3. **Frigid Zones**

   The two Frigid Zones, or polar regions, experience the midnight sun and the polar night for part of the year - the cliff of the zone experiences one day at the solstice when the Sun doesn't rise or set for 24 hours, while in the centre of the zone (the pole), the day is literally one year long, with six months of daylight an d six months of night. Please note that the Frigid Zones are not the coldest parts of the earth, and are covered with ice and snow.

INVERSION OF THE TEMPERATURE

In the mountain valleys, the temperature of the air is found increasing with increasing altitude. Thus there is an inversion of the temperature. This is because during the night, the quick radiation from the upper exposed slopes of the mountains causes the surface and air over it to cool rapidly. This cooler air is denser and gets drained by the valley slopes and displaces the warmer air toward up. So, when we go up in a valley, the temperature seems to getting increased. This phenomenon is also called drainage inversion.

MEAN THERMAL EQUATOR

Thermal equator is a **global isotherm having the highest mean annual temperature at each longitude around the globe.** The first thing we should note that thermal equator is general taken coinciding with the geographical equator. But this is not correct. The highest absolute temperatures are recorded in the Tropics but the highest mean annual temperatures are recorded at equator. But because local temperatures are sensitive to the geography of a region, and mountain ranges and ocean currents ensure that smooth temperature gradients (such as might be found if the Earth were uniform in composition and devoid of surface irregularities) are impossible, the location of the thermal equator is not identical to that of the geographic Equator. Further, we know that the Earth reaches perihelion (the minimum distance from the Sun in its orbit) in early January and is at aphelion (maximum distance) in early July. During winter season of the respective hemispheres, the angle of incidence of the sun's rays is low in tropics. The average annual temperature of the tropical regions is therefore lower than the observed near the equator, as the change in the angle of incidence is minimum at equator. Please note that the thermal equator shifts towards north and south with north south shift in the position of vertical rays of the sun. However, annual average position of the Thermal equator is 5° N latitude. The reason is that highest mean annual temperature shifts towards northwards during the summer solstice to a much greater extent than it does towards south at the time of winter solstice.

Why highest temperature is NOT recorded at 12.00 PM noon?

Sun is at the highest point at noon but the highest temperature does not occur at 1200 hours because the atmosphere does not get the heat directly from the Sun. It receives heat from the earth's surface slowly and that is why maximum temperature is generally attained by 1400 hours (2.00p.m.). The daily minimum temperature at a place does not occur at about 0400 hours (4.00 p.m.) in the morning because radiation of heat continues up to the sun rise. Réaumur scale was also used to measure the temperature. It is the scale in which the freezing and boiling points of water are set to 0 and 80 degrees respectively.

Some Notes on daily temperature ranges

1. Daily temperature range is **low in clouded areas** because the clouds obstruct the receipt and loss of insolation.
2. The sky is clear in hot desert's areas. Insolation is received without obstruction in the day and most without obstruction in the night. This causes high temperature range in deserts.
3. Ice or snow absorbs less and reflects the insolation more. Hence, the daily temperature range is low is snow bound areas.
4. The air is thin in areas of high altitude. There is great loss of insolation in the night. There is no obstruction in the receipt of insolation in the day. Such places have a high temperature range.
5. There is a higher temperature range in than interior areas of continents than at seas because the sea heats and cools slowly but the land heats and cools rapidly.
6. Warm and cool winds also disturb the temperature range.

Notes on Annual temperature range

1. The duration of the day or night is the same in equatorial countries. The sun's rays are vertical all through the year. Hence, there is no worthwhile difference between the summer and winter seasons. This is the reason that the lowest annual temperature range is found in equatorial areas.
2. Towards the poles, the duration of the day and the inclination of the sun rays go on increasing. It causes a lot of difference between the temperatures of the two seasons. Hence, towards the poles, the annual temperature range goes on increasing.
3. Near the seas and oceans, the equalizing effect of sea water makes the winter less cold and the summer less hot. This reduces the annual range of temperature near the seas.
4. The equalizing effect of the sea water cannot reach land areas, away from the seas. The countries like Mongolia and Tibet which are situated far into the interior of the continent have a high annual range of temperature.
5. The ocean currents near the coasts also affected the temperature range. Due to the warm Gulf Stream, the winter of Western Europe is less cold than what it Europe is less cold than what it should have been without the Gulf Stream. This reduces the annual temperature range.
6. The shifting attitude of ocean currents has a lot of effect on the annual temperature range. For example, the weather and seasons have to undergo greater changes on the eastern coasts of Indian and Australia due to the shifting of ocean currents. It increases the annual temperature range on these coasts as compared to that on the opposite side coasts.
7. The prevailing winds also have a greater effect on the annual temperature range. Winds from the land blow in Arabian countries and therefore increase the annual range of temperature. Winds from the oceans and seas blow into Western Europe and reduce the annual temperature range. The variation in the annual temperature range in west and east European countries is due to land and sea winds. The effect of winds from the ocean has a far smaller effect in Eastern Europe than in Western Europe. It is why the annual temperature range is higher in eastern than in Western Europe.

Some Iso Words

1. Isallobars, isanomal, isobar (pressure);
2. Isobase (elevation or depression of land);
3. Isochrones (travelling time);
4. Isogon, or isogonic lines (magnetic variation),
5. Isohaline (salinity);
6. Isohel (sunshine);
7. Isohyets (rainfall);
8. Isomer (the mean monthly rainfall as a percentage of the average annual amount).
9. Isoneph (cloudiness);
10. Isophene (flowering dates and other botanical and biological occurrences);
11. Isoryme (frost);
12. Isoseismal (earthquake intensity);
13. Isotope (significant dates);
14. Isotherm (temperature);
15. Isotach (equal wind-speed);

PRESSURE AND WINDS

When air moves in a definite direction, it is called wind. If the winds move in west, they are called **Westerlies**. If they move in east they are called **easterlies.** There are winds because there are differences in pressures. The direction of wind is also affected by Coriolis force or Coriolis affect. This affect is caused by the rotation of earth. The rotation of the earth on its axis from west to east results in the genesis of deflective force or **Coriolis force** which deflects the general direction of ocean currents as well as winds. For example, the winds flowing from equator towards the North Pole and from North Pole towards the equator are deflected to their right while the winds flowing north-south and south-north in the southern hemisphere are deflected towards their left. Please note that the magnitude of the deflection, or "Coriolis effect," varies significantly with latitude. The **Coriolis Effect is zero at the equator** and **increases to a maximum at the poles**. The effect is proportional to wind speed; that is, deflection increases as wind strengthens. The resultant balance between the pressure force and the Coriolis force is such that, in the absence of surface friction, air moves parallel to isobars (lines of equal pressure). This is called the geotropic wind. The Coriolis force explains why winds circulate around high and low pressure systems as opposed to blowing in the direction of the pressure gradient. The following figure shows how wind is deflected in each hemisphere. The core philosophy of the Coriolis force is that when the earth rotates from west to east, it produces the centrifugal force and due to this force, there is a change in the direction of the wind. There is **Ferrel's law** derived from Coriolis Effect, which says that in northern hemispheres, wind deflects towards the right and in southern hemisphere wind deflects towards left. This means that in northern hemisphere, wind deflects clockwise, while in southern hemisphere, wind deflects anti-clockwise.

Trade winds and Hadley cells

There are three primary circulation cells on earth known as the Hadley cell, Ferrel cell, and Polar cell. The Hadley cell mechanism provides an explanation for the trade winds. Hadley cell is a closed circulation loop, which begins at the equator with warm, moist air lifted aloft in equatorial low pressure areas (the Intertropical Convergence Zone, ITCZ) to the tropopause and carried pole ward. At about 30°N/S latitude, it descends in a high pressure area. Some of the descending air travels equatorially along the surface, closing the loop of the Hadley cell and creating the Trade Winds. Hadley Cells is described to be lying on equator but it follows sun's zenith point, or what is termed the "thermal equator".

HOW TRADE WINDS ORIGINATE?

We now know that Trade winds are part of the Hadley cell circulation. At the equator, a low-pressure area of calm, light variable winds is known Intertropical Convergence Zone as we discussed above. The air lifts from here and at around 30° North and South, the air begins to descend toward the surface in subtropical high-pressure belts known as subtropical ridges. At the surface, the air flows from these subtropical high-pressure belts toward the Equator but is deflected toward the west in both hemispheres by the Coriolis Effect. Thus, these winds blow predominantly from the northeast in the Northern Hemisphere and from the southeast in the Southern Hemisphere. Because winds are named for the direction from which the wind is blowing, these winds are called the northeast trade winds in the Northern Hemisphere and the southeast trade winds in the Southern Hemisphere. The trade winds meet at the doldrums.

WESTERLIES

The directions of the Westerlies are opposite to trade winds and that is why they are also called **antitrade winds**. Westerlies blow in the middle latitudes between 30 and 60 degrees latitude, and originate from the high pressure area in the horse latitudes towards the poles. Under the effect of the Coriolis force, they become the south westerlies in the northern hemisphere and Northern westerlies in the southern hemisphere. Please note that in the southern hemisphere, there is more of ocean and less of land in comparison to the northern hemisphere. Due to this reason, the westerlies blow with much greater force in southern hemisphere in comparison to northern hemisphere. This also has implications in the Ocean currents. The currents in the Northern Hemisphere are weaker than those in the Southern Hemisphere due to the differences in strength between the Westerlies of each hemisphere. Generally, Westerlies are strongest in the winter hemisphere and times when the pressure is lower over the poles, while they are weakest in the summer hemisphere and when pressures are higher over the poles. Please note the westerlies are also associated with the "extra tropical" cyclones which refer to the fact that this type of cyclone generally occurs outside of the tropics, in the middle latitudes of the planet, where the Westerlies steer the system generally from west to east. Whenever there is a convergence of the cold and denser polar winds and warm and light westerlies, there is much variation in the weather. The velocity of the westerlies increases southward and they become stormy. When we move towards poles, the velocity of the westerlies is given different terms as follows:

1. Roaring Forties between the 40-50°S
2. Furious Fifties at the 50°S and Shrieking Sixties at 60°S.

POLAR EASTERLIES

Polar easterlies blow from the polar high pressure belts towards the temperate low pressure belts. These are extremely cold winds that come from the Tundra and Icecap regions of the poles. The Polar Easterlies are more regular in the southern hemisphere in comparison to the northern hemisphere. These polar cold winds converge with the warm easterlies near 60° latitudes and form the Polar front or Mid Latitude front. This mid-latitude front becomes the centre of the origin of the Temperate Cyclones.

LOCAL WINDS

The Local winds around the world are formed through the heating of land. In coastal regions, the sea breezes and land breezes are important factors in a location's prevailing winds. The sea is warmed by the sun more slowly because of water's greater specific heat compared to land. As the temperature of the surface of the land rises, the land heats the air above it by conduction. The warm air is less dense than the surrounding environment and so it rises. This causes a pressure gradient of about 2 millibar from the ocean to the land. The cooler air above the sea, now with higher sea level pressure, flows inland into the lower pressure, creating a cooler breeze near the coast. At night, the land cools off more quickly than the ocean because of differences in their specific heat values. This temperature change causes the daytime sea breeze to dissipate. When the temperature onshore cools below the temperature offshore, the pressure over the water will be lower than that of the land, establishing a land breeze, as long as an onshore wind is not strong enough to oppose it. There is a different explanation for local winds near mountains. Over elevated surfaces, heating of the ground exceeds the heating of the surrounding air at the same altitude above sea level, creating an associated thermal low over the terrain and enhancing any thermal lows that would have otherwise existed, and changing the wind circulation of the region. In areas where there is rugged topography that significantly interrupts the environmental wind flow, the wind circulation between mountains and valleys is the most important contributor to the prevailing winds. The mountains and valleys are capable to distort the airflow by increasing friction between the atmosphere and landmass by acting as a physical block to the flow, deflecting the wind parallel to the range just upstream of the topography, which is known as a barrier jet. This barrier jet can increase the low level wind. Wind direction also changes because of the contour of the land. If there is a pass in the mountain range, winds will rush through the pass with considerable speed because of the Bernoulli principle that describes an inverse relationship between speed and pressure. The airflow can remain turbulent and erratic for some distance downwind into the flatter countryside. These conditions are dangerous to ascending and descending airplanes.

Major Local Winds

1. Abrolhos → squall frequent wind that occurs from May through August between Cabo de Sao Tome and Cabo Frio on the East Coast of Brazil
2. Amihan →north-easterly wind across the Philippines
3. Bayamo →violent wind on Cuba's southern coast
4. Bora →north-easterly from eastern Europe to north-eastern Italy
5. Calima →dust-laden south to south-easterly wind blowing in the Saharan Air Layer across the Canary Islands
6. Cape Doctor →dry south-easterly wind that blows on the South African coast in summer
7. Chinook →warm dry westerly off the Rocky Mountains
8. Elephanta →strong southerly or south-easterly wind on the Malabar coast of India
9. Föhn →or Foehn is a type of warm dry southerly off the northern side of the Alps and the North Italy. The name gave rise to the fén-fēng ('burning wind') of Taiwan.
10. Fremantle Doctor →afternoon sea breeze from the Indian Ocean which cools Perth, Western Australia during summer
11. Gregale →north-easterly from Greece
12. Habagat →south-westerly wind across the Philippines
13. Harmattan →dry northerly wind across central Africa
14. Karaburan → "black storm", a Spring and Summer Katabatic wind of central Asia
15. Khamsin →south-easterly from north Africa to the eastern Mediterranean
16. Khazri →cold north wind in the Absheron Peninsula of the Azerbaijan Republic
17. Kona →southeast wind in Hawaii, replacing trade winds, bringing high humidity and often rain
18. Košava → strong and cold south-easterly season wind in Serbia
19. Lodos → south-westerly towards Turkey. Strong "Lodos" events occur 6 - 7 times a year bringing 35kt winds into Marmara Sea. The winds are funnelled SE from the Mediterranean and through the Dardanelles Strait.
20. Loo →hot and dry wind which blows over plains of India and Pakistan.
21. Mistral →cold northerly from central France and the Alps to Mediterranean
22. Monsoon →mainly south westerly winds combined with heavy rain in various areas close to the equator
23. North wind →northern cold winds blowing from the Gulf of Mexico to the Isthmus of Tehuantepec
24. Nor'easter →strong storm with winds from the northeast in the eastern United States, especially New England

25. Nor'wester → wind that brings rain to the West Coast, and warm dry winds to the East Coast of New Zealand's South Island, caused by the moist prevailing winds being uplifted over the Southern Alps, often accompanied by a distinctive arched cloud pattern
26. Pampero → very strong wind which blows in the Pampa.
27. Simoom →strong, dry, desert wind that blows in the Sahara, Israel, Jordan, Syria, and the desert of Arabia
28. Sirocco →southerly from north Africa to southern Europe
29. Sundowner →strong offshore wind off the California coast
30. Zonda wind →on the eastern slope of the Andes in Argentina

MONSOON

The word monsoon derived from the Arabic word *mausim* means seasonal winds. In this system, the direction of the winds reverses seasonally. The first thing we note is that Monsoon is typically considered a phenomenon of tropical south Asia, but it is also experienced over parts of North America and Africa.

Origin of Monsoon: Traditional View

Traditionally, monsoon has been considered a result of the differential heating of land and sea. In summer, southern Asia develops a low pressure while the pressure over the sea is relatively higher. As a result the air starts flowing towards land from the Indian oceans. The winds coming from ocean carry moisture and thus cause rainfall in summer reason. This is known as the southwest monsoon or summer monsoon. In winter, the pressure over land is higher than over the sea and consequently the air starts flowing from land to sea. The air coming from land being dry, these winds do not cause rainfall. The above explanation is known as the thermal theory of monsoon. This theory explains monsoon as a regional phenomenon but fails to explain the total amount of energy / processes involved in the global monsoon circulation.

Origin of Monsoon: Modern View

The modern meteorologists seek explanation for the phenomenon of monsoon on the basis of seasonal shift in the position of the global belts of pressure and winds. This is also known as Dynamic Theory. According to the dynamic theory, monsoons are a result of the shift of the inter-tropical convergence zone (ITCZ) under the influence of the vertical sun. Though the average position of the ITCZ is taken as the equator, it keeps shifting vertical sun towards with the migration of the vertical sun towards the tropics during the summer of the respective hemisphere.

During summer in the northern hemisphere in the months of May and June, the sun shines vertically over the tropic of cancer. Due to the northward shift of the zone of maximum heating and low pressure at this time the ITCZ also shifts northwards and approaches, the tropic of cancer. The ITCZ being the zone of the lowest pressure in the tropical region is the destination of the trade winds blowing from both the hemispheres. With ITCZ situated close to the tropic of cancer the northeast trade winds are confined to an area extending to its north while the southeast trade winds blowing from the southern hemisphere have to cross the equator to reach this area of low pressure. However as the winds blowing from the southern hemisphere cross the equator their direction is altered due to Coriolis effect, i.e. they are direction is their right and thus it give rise to the formation of a belt of equatorial westerlies in t he months of many of June northeast and they are called the southwest monsoon. As the ITCZ again moves southwards at the end of the summer of the northern hemisphere the areas north of the equator which experienced the equatorial westerlies during the summer season come under the influence of the northeast trade winds. These north-easterly winds are called the northeast monsoons. The onset of winter season the ITCZ shifts south of the equator and reaches as far south at this time. in this season the northeast trades blowing towards the ITCZ have to cross the equator towards south and as a result they get deflected giving rise to the equatorial westerlies in the southern hemisphere. These westerlies blow form the northwest to the southwest, replacing the trade winds of the southern hemisphere between the ITCZ and the equator. They form the summer monsoon of the southern hemisphere. We can say that due to the seasonal shift of the wind belts under the influence of the north-south migration of the vertical sun the areas situated in the tropical zone in the both the hemisphere come under the influence of the trade winds during the respective winter and the equatorial westerlies during the respective summer season. The direction of the winds is thus reversed seasonally and it makes up the monsoon system of these regions. Please note that though, dynamic theory provides a much better explanation of the system of monsoon as a global phenomenon, it does not negate the influence of differential heating of land and sea. Differential heating still plays an important role in making monsoon much stronger in certain of the south-west monsoon factor that explains the extension of the southwest monsoon even to the north of the tropic of cancer in northern India.

RAINFALL

How it occurs?

The amount of moisture in air is also commonly recorded as relative humidity; which is the percentage of the total water vapour air can hold at a particular air temperature. The presence of warm, moist and unstable air and sufficient amount of the hygroscopic nuclei is a prerequisite condition for rainfall. The warm and moist air after being lifted upwards becomes saturated and clouds are formed after condensation of water vapour around the hygroscopic nuclei such as dust particles. How much water vapour a parcel of air can contain before it becomes saturated (100% relative humidity) and forms into a cloud (a group of visible and tiny water and ice particles suspended above the Earth's surface) depends on its temperature. Warmer air can contain more water vapour than cooler air before becoming saturated. The process of condensation begins only when the relative humidity of the ascending air becomes 100% and air is cooled through four main mechanisms to its dew point: adiabatic cooling, conductive cooling, Radiative cooling, and evaporative cooling.

1. **Adiabatic cooling** occurs when air rises and expands. The air can rise due to convection, large-scale atmospheric motions, or a physical barrier such as a mountain (orographic lift).
2. **Conductive cooling** occurs when the air comes into contact with a colder surface, usually by being blown from one surface to another, for example from a liquid water surface to colder land.
3. **Radiative cooling** occurs due to the emission of infrared radiation, either by the air or by the surface underneath.
4. **Evaporative cooling** occurs when moisture is added to the air through evaporation, which forces the air temperature to cool to its wet-bulb temperature, or until it reaches saturation.

Further, we note that the very small rain drops are almost spherical in shape. As drops become larger, they become flattened on the bottom, like a hamburger bun. Very large rain drops are split into smaller ones by air resistance which makes them increasingly unstable. When water droplets fuse to create larger water droplets, it is called Coalescence. When water droplets freeze onto an ice crystal, which is known as the Bergeron process, air resistance typically causes the water droplets in a cloud to remain stationary. When air turbulence occurs, water droplets collide, producing larger droplets. As these larger water droplets descend, coalescence continues, so that drops become heavy enough to overcome air resistance and fall as rain. Coalescence generally happens most often in clouds above freezing, and is also known as the warm rain process.

Features of Convectional Rainfall

The convectional rainfall occurs due to the thermal convection currents caused due to the heating of ground due to insolation. The convectional rainfall is prevalent in equatorial regions. In these, the warm air rises up and expands then, reaches at a cooler layer and saturates, then condenses mainly in the form of cumulus or cumulonimbus clouds. Please note that in the equatorial regions, the precipitation due to convectional rainfall occurs in the afternoon. The rainfall is of very short duration but in the form of heavy showers.

Features of Cyclonic of Frontal Rainfall

Frontal rainfall occurs due to the upward movement of the air caused by the convergence of different air masses with different temperatures. The warm air rises over the cold air and cyclonic rain occurs. The cold air pushes up the warm air and sky gets clear again.

Features of orographic Rainfall

The orographic rainfall occurs due to the ascent of air forced by the mountain barrier. The mountain barrier should be across the wind direction, so that the moist air is forced in obstruction to move upward and get cooled. In Rajasthan, the Aravallis is not an obstructing barrier to the highly moist air coming from Arabian Sea and that is why they don't play very important role in rainfalls. Thus they produce a Rain shadow area. A rain shadow is a dry area on the lee side of a mountainous area. The mountains block the passage of rain producing weather systems, casting a "shadow" of dryness behind them. In south India, the Mangalore is with different density (temperature and/or moisture) characteristics. Once an air mass moves away from its source region, underlying vegetation and water bodies can quickly modify its character.

FRONTOGENESIS AND FRONTOLYSIS

The boundary between the two air masses is called the **front.** A temperature difference is essential in the definition of a front because it implies a density difference. The air masses of different densities don't mix readily and tend to retain their identity as far as we care for the moisture. The front represents a transition zone between two air masses of different density. Generally, an air mass from one region moves to the other region which is occupied by some other air mass. When a warmer and lighter air mass moved against a cold and denser air mass, the former rides over the other and it is called **warm front.** If the cold air mass forces its way under a warm air mass, it is called **cold front.** When new fronts are created or old fronts are regenerated, it is called Frontogenesis. Please note that fronts don't appear all of a sudden. They appear only after a process of Frontogenesis which is there in place for quite some time. When winds converge towards a point it would lead to **Frontogenesis**.

Frontogenesis takes place only when two conditions are met. First, two air masses of different densities must exist adjacent to one another; and second, a prevailing wind field must exist to bring them together. There are three basic situations, which are conducive to Frontogenesis and satisfy the two basic requirements. The wind flow is cross isothermal and flowing from cold air to warmer air. The flow must be cross isothermal, resulting in a concentration of isotherms (increased temperature gradient). The flow does not have to be perpendicular; however, the more perpendicular the cross isothermal flow, the greater the intensity of Frontogenesis. On the other hand, the dying of a front is called **Frontolysis.** Frontolysis also does not happen all of a sudden. The process of Frontolysis must happen for quite some time to destroy the existing front.

Types of Fronts

Cold Front: When a cold air invades the warm air, it remains at the ground and forcibly uplifts the warmer and lighter air mass. This is known as Cold front. This upward motion causes lowered pressure along the cold front and can cause the formation of a narrow line of showers and thunderstorms when enough moisture is present. Cold fronts can move up to twice as fast as warm fronts and can produce sharper changes in weather. Since cold air is denser than warm air, it rapidly replaces the warm air preceding the boundary. Cold fronts are usually associated with low-pressure areas. Cold front usually causes a shift of wind from southeast to northwest and in the southern hemisphere a shift from northeast to southwest.

Warm front: When a warmer and lighter air mass moved against a cold and denser air mass, the former rides over the other and it is called **warm front.** Being lighter, the warm air mass is unable to displace the cooler air mass and instead is forced upward along the upper boundary of the colder air in a process known as overrunning. The boundary between the two air masses has a gradual slope of 130 and lifting is slow but persistent. As the air mass rises into regions of lower pressure, it expands and cools. As it cools, water vapour condenses and forms extensive cloud coverage. The first clouds to form along the sloping surface of the cold air are high cirrus, which thicken to cirrostratus and altostratus.

Occluded front: An occluded front is a front that is formed when a cold front overtakes a warm front. The cold front moves rapidly than the warm front. Ultimately, the cold front overtakes the warm front and completely displaces the warm air at the ground.

CYCLONES

Cyclone is a system of low atmospheric pressure in which the barometric gradient is steep. Cyclones represent circular fluid motion **rotating in the same direction as the Earth.** This means that the inward spiralling winds in a cyclone rotate anticlockwise in the Northern Hemisphere and clockwise in the Southern Hemisphere of the Earth. Most large-scale cyclonic circulations are centred on areas of low atmospheric pressure. The cyclones can be tropical cyclones or temperate cyclones (extra-tropical cyclones).

Tropical Cyclones

The tropical cyclone is a system of low pressure occurring in tropical latitudes characterized by very strong winds. The tropical cyclones are mainly found in Indian Ocean, Indonesia and Australia. Please read the following points carefully:

Formation in Low Pressure areas: All tropical cyclones are formed in areas of low atmospheric pressure in the Earth's atmosphere.

Minimum Pressure at centre: The pressures recorded at the centres of tropical cyclones are among the lowest that occur on Earth's surface at sea level.

Driver is the Large Heat of Condensation: Tropical cyclones are driven by the release of large amounts of latent heat of condensation, which occurs when moist air is carried upwards and its water vapour condenses. This heat is distributed vertically around the centre of the storm. Thus, at any given altitude, environment inside the cyclone is warmer than its outer surroundings.

Eye is the sinking air: There is an area of sinking air at the centre of circulation, which is known as Eye. Weather in the eye is normally calm and free of clouds, although the sea below it may be extremely violent. Eye is normally circular in shape, and is typically 30–65 km in diameter.

Stadium Effect: The mature tropical cyclones sometimes exhibit an outward curving of the eye wall's top, making it resemble an arena football stadium. It is called Stadium Effect.

Greatest Wind speeds are at eye walls: Greatest wind speeds in a tropical cyclone is found at the eye wall, which is a circle of strong thunderstorms that surrounds the eye. Here, the clouds reach the highest, and precipitation is the heaviest. The heaviest wind damage occurs where a tropical cyclones eye wall passes over land.

Source of the huge Energy:

The Primary energy source is the release of the heat of condensation from water vapour condensing, with solar heating being the initial source for evaporation. So a tropical cyclone can be visualized as a giant vertical heat engine supported by mechanics driven by physical forces such as the rotation and gravity of the Earth. Inflow of warmth and moisture from the underlying ocean surface is critical for tropical cyclone strengthening.

Impact of Earth's Rotation: The rotation of the Earth causes the system to spin (Coriolis Effect) giving it a cyclonic characteristic and affecting the trajectory of the storm. In Northern Hemisphere, where the cyclone's wind flow is counter clockwise, the fastest winds relative to the surface of the

Earth occur on the eastern side of a northward-moving storm and on the northern side of a westward-moving one; the opposite occurs in the Southern Hemisphere, where the wind flow is clockwise.

Movement of Clouds: In Lower troposphere, motion of clouds is toward the centre. At upper-level, there is outward flow of clouds.

Formation in Northern Atlantic Ocean: Northern Atlantic cyclone season occurs from June 1 to November 30, sharply peaking from late August through September. The statistical peak of the Atlantic hurricane season is 10 September.

Formation in North East Pacific: The Northeast Pacific Ocean has a broader period of activity, but in a similar time frame to the Atlantic.

Formation in North West Pacific: The Northwest Pacific sees tropical cyclones year-round, with a minimum in February and March and a peak in early September.

Formation in North Indian basin: Storms are most common from April to December, with peaks in May and November.

Formation in Southern Hemisphere: Tropical cyclone year begins on July 1 and runs all year-round and encompasses the tropical cyclone seasons, which run from November 1 until the end of April, with peaks in mid-February to early March.

Requirements for formation

1. Water temperatures of at least 26.5 °C down to a depth of at least 50 m, so that it may cause the overlying atmosphere to be unstable enough to sustain convection and thunderstorms.
2. Rapid cooling with height, so that it may cause release of the heat of condensation that powers a tropical cyclone.
3. High humidity
4. Low amounts of wind shear as high shear is disruptive to the storm's circulation.
5. A distance from the Equator, which should be at least 555 km or 5 degrees of latitude, so
6. That it allows the Coriolis Effect to deflect winds blowing towards the low pressure centre and creating a circulation. Because the Coriolis effect initiates and maintains tropical cyclone rotation, tropical cyclones rarely form or move within about 5 degrees of the equator, where the Coriolis effect is weakest.
7. A pre - existing system of disturbed weather.

Movement: The Earth's rotation imparts an acceleration known as the Coriolis Effect, which causes cyclonic systems to turn towards the poles in the absence of strong steering currents. The pole ward portion of a tropical cyclone contains easterly winds, and the Coriolis Effect pulls them slightly more pole ward. The westerly winds on the Equator ward portion of the cyclone pull slightly towards the equator, but, because the Coriolis Effect weakens toward the equator, the net drag on the cyclone is pole ward. Thus, tropical cyclones in the Northern Hemisphere usually turn north (before being blown east), and tropical cyclones in the Southern Hemisphere usually turn south (before being blown east) when no other effects counteract the Coriolis Effect.

High speed of rotation: It is caused by Coriolis effect as well as energy released by heat of condensation.

Fujiwhara effect: When two cyclones approach one another, their centres will begin orbiting cyclonically about a point between the two systems. The two vortices will be attracted to each other, and eventually spiral into the centre point and merge. When the two vortices are of unequal size, the larger vortex will tend to dominate the interaction, and the smaller vortex will orbit around it. This phenomenon is called the Fujiwhara effect.

Impact on passing over land: We should note that the deep convection is a driving force for tropical cyclones. The convection is strongest in a tropical climate; it defines the initial domain of the tropical cyclone. This is a major difference between the Tropical cyclones with other mid-latitude cyclones as the later derive their energy mostly from pre-existing horizontal temperature gradients in the atmosphere. To continue to drive its heat engine, a tropical cyclone must remain over warm water, which provides the needed atmospheric moisture to keep the positive feedback loop running. When a tropical cyclone passes over land, it is cut off from its heat source and its strength diminishes rapidly. The moving over land deprives it of the warm water it needs to power itself, quickly losing strength. Thus, most strong storms lose their strength when the pass on to land, but if it manages to move back to ocean, it will regenerate.

Impact of passing over cold water: When a tropical storm moves over waters significantly below 26.5°C, it will lose its strength. This is because of losing its tropical characteristic of the warm core.

Project Storm fury: The United States Government attempted in 1960s and 1970s to artificially weaken the Cyclones. During this project, Cyclones were seeded with silver iodide. It was thought that the seeding would cause super cooled water in the outer rain bands to freeze, causing the inner eye wall to collapse and thus reducing the winds. The Hurricane Debbie lost as much as 31% of its strength, when seeded with Silver Iodide in this project but Debbie regained its strength after each of two seeding forays. So, it was not a good idea. There were some more ideas applied which were as follows:

1. Cooling the water under a tropical cyclone by towing icebergs into the tropical oceans and covering the ocean in a substance that inhibits evaporation
2. Dropping large quantities of ice into the eye at very early stages of development (so that the latent heat is absorbed by the ice, instead of being converted to kinetic energy that would feed the positive feedback loop)
3. Blasting the cyclone apart with nuclear weapons.
4. A Project called **Project Cirrus** involved throwing dry ice on a cyclone.
5. None of the idea was very much practical because the tropical storms are too large and too momentary.

Naming of Cyclones: Tropical cyclones are classified into three main groups, based on intensity: tropical depressions, tropical storms, and a third group of more intense storms, whose name depends on the region.

1. If a tropical storm in the North-western Pacific reaches hurricane-strength winds on the Beaufort scale, it is referred to as a **typhoon**
2. If a tropical storm passes the same benchmark in the Northeast Pacific Basin, or in the Atlantic, it is called a **hurricane**.
3. Neither “hurricane” nor “typhoon” is used in either the Southern Hemisphere or the Indian Ocean. In these basins, storms of tropical nature are referred to simply as “cyclones”.

Types: There are three kinds of Tropical cyclones:

1. **Tropical Depression:** A tropical depression is a system with low pressure enclosed within few isobars and with the wind speed of 60 Kmph. It lacks marked circulation
2. **Tropical Storm:** It is a system with several closed isobars and a wind circulation of 115 Kmph.
3. **Tropical Cyclone:** It is a warm core vortex circulation of tropical origin with small diameter, circular shape and occurs in oceanic areas.

Anticyclones

An ‘anticyclone’ is opposite to a cyclone, in which winds move into a low-pressure area. In an anticyclone, winds move out from a high-pressure area with wind direction clockwise in the northern hemisphere, anticlockwise in the southern hemisphere. Such a high pressure area is usually spread over a large area, created by descending warm air devoid of moisture. The absence of moisture makes the dry air denser than an equal quantity of air with moisture. When it displaces the heavier nitrogen and oxygen, it causes an anti-cyclone.

TORNADO

Basically, hurricanes and typhoons form over water and are huge, while tornados form over land and are much smaller in size. A tornado is a violent windstorm characterized by a twisting, funnel-shaped cloud. In the United States, twister is used as a colloquial term for tornado.

What is it?

Technically, a tornado is a rotating column of air that is in contact with both the surface of the earth and a cloud, which is generally cumulonimbus and occasionally cumulus. Most tornadoes have wind speeds less than 110 miles per hour and travel several kilometres before dissipating.

How it is formed?

First the rotating cloud base lowers. This lowering becomes a funnel, which continues descending while winds build near the surface, kicking up dust and other debris. Finally, the visible funnel extends to the ground, and the tornado begins causing major damage.

Where they are seen?

Tornadoes have been observed on every continent except Antarctica.

How they are detected?

Tornadoes can be detected before or as they occur through the use of Pulse Doppler radar by recognizing patterns in velocity and reflectivity data.

What is Fujita Scale?
Fujita scale rates tornadoes by damage caused and have been replaced in some countries by the updated Enhanced Fujita Scale. An F0 or EF0 is the weakest tornado, while F5 or EF5 is the strongest tornado.

What is Torro Scale?
TORRO scale ranges from a T0 for extremely weak tornadoes to T11 for the most powerful known tornadoes.

Funnel Cloud as predecessor: Tornadoes often begin as funnel clouds with no associated strong winds at the surface, although not all evolve into a tornado. However, many tornadoes are preceded by a funnel cloud. Most tornadoes produce strong winds at the surface while the visible funnel is still above the ground, so it is difficult to discern the difference between a funnel cloud and a tornado from a distance.

Infrasonic signature: Tornadoes produce identifiable inaudible infrasonic signatures. Due to the long distance propagation of low-frequency sound, efforts are ongoing to develop tornado prediction and detection devices with additional value in understanding tornado morphology, dynamics, and creation.
Electromagnetic Spectrum: Tornadoes emit on the electromagnetic spectrum. There are observed correlations between tornadoes and patterns of lightning.

When they occur? 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. Worldwide, most tornadoes occur in the late afternoon, between 3 pm and 7 pm local time, with a peak near 5 pm.