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Component-I (B) - Description of Module

Items	Description of Module
Subject Name	Geography
Paper Name	Climatology
Module Name/Title	**GENERAL ATMOSPHERIC CIRCULATION: VERTICAL AND HORIZONTAL**
Module Id	CL-11
Pre-requisites	
Objectives	
Keywords	

Module 11

GENERAL ATMOSPHERIC CIRCULATION: VERTICAL AND HORIZONTAL

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Contents

Introduction

You have already studied about the composition and structure of atmosphere. You very well know it is composed of a variety of gases, aerosols and water in all three states, therefore, it has mass. A book laid on your table would stay till the time some force shifts it or removes it. The mass of air is not at all static for all times,it is dynamic. You must have observed blowing winds, seen the plant's leaves or thin twigs of trees or crops in the field bowing to one side and coming back. Have you ever thought of this event, as to why it all happens? It is the law of nature, nothing happens out of nothing. Events or something happens due to some reasons. This natural law also prevails with the movements of air. Generally, the horizontal motion of air is represented by winds and vertical motion of air by currents.

The winds and currents are the function of several associated phenomena which govern their movements. Therefore, discussion on the circulation of the atmosphere is the prime concern in this module.

Learning Objectives

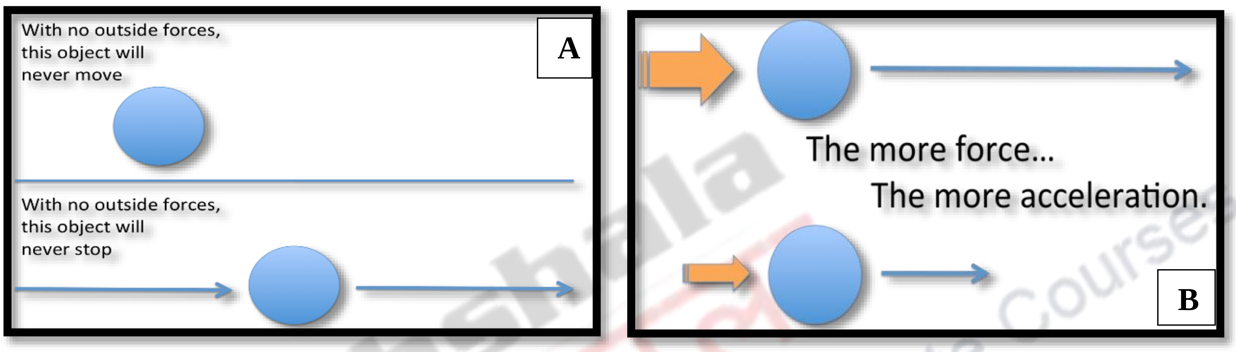
After studying this module, you will be able to:

- define general atmospheric circulation;
- enlist factors affecting atmospheric circulation;
- explain different scales of atmospheric circulation;
- describe single-cell and three-cell atmospheric circulation;
- explain the mechanisms of Hadley cell, Ferrel cell and polar cell;
- discuss the vertical atmospheric movement, and
- describe the regional atmospheric circulations such as Walker circulation (sir you have added this also, later on)

Atmospheric Circulation

As stated above, there has to be some reasonsfor something to happen. The first law of motion as explained by Newton is concerned with inertia. It states that "an object at rest stays at rest and an object in motion stays in motion with the same speed and direction unless acted upon by an unbalanced force". From the first law of motion, it is quite obvious that any mass would be at its original motion (rest or moving, Figure 1A) until and unless some force is applied from outside. It is also noteworthy that the acceleration/ velocity would be determined by the quantum of force applied (Figure 1B) and the mass of the object to be accelerated.

Figure 1: Force and Motion



Source A: https://d2gne97vdumgn3.cloudfront.net/api/file/rvzhdyfMQPWBGoyvp53T

Source B: http://organizationalphysics.com/wp-content/uploads/2011/12/Newton2.png

Factors Affecting Atmospheric Circulation

The acceleration or the velocity of the wind is determined by the following forces (Table 1):

Wind affecting force	**Operating cause**
Pressure gradient	Spatial differences in pressure
Coriolis	Rotation of the earth
Centripetal	Curvature of the air blowing
Friction	Surface roughness interaction acting against direction of motion

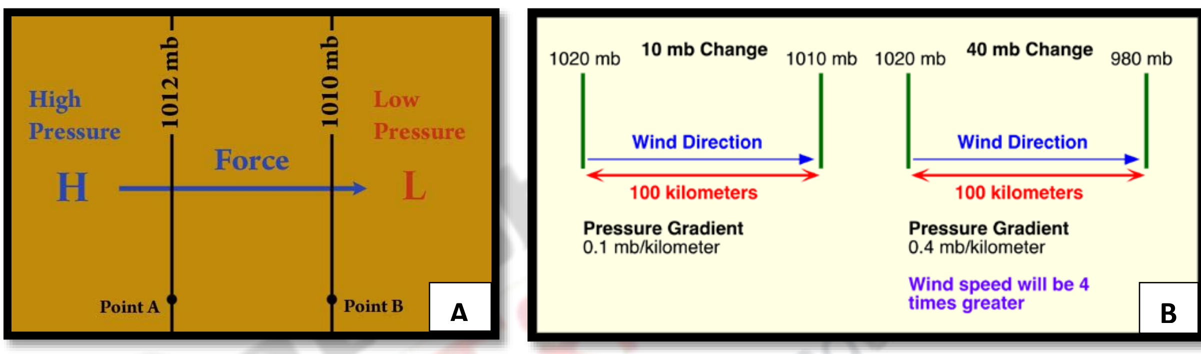
Let us discuss them in brief.

Pressure Gradient Force

Pressure gradient is the change in the air pressure per unit of distance travelled along a certain line. In another words, it is an average change in barometric pressure per unit of distance along a certain linear direction in a given region. Refer the Figure 2. From this figure, it is obvious that the pressure gradient determines the direction as well as the intensity of the wind blow. The winds always blow from the high pressure areas to the low pressure areas (Figure 2A). Apart from the direction, its velocity is the product of the pressure gradient.

Pressure gradient can be calculated by the change in the isobaric values (barometric pressure generally in milibars per km (distance)). For example, suppose the two places X and Y are 100 km away from one another. At X, suppose, the air pressure is 1020 mb and at Y, it is 1010 mb. Therefore, the pressure gradient can becalculated by dividing 10 (difference between 1020 mb and 1010 mb) by 100 km. Itgives a value of 0.1 mb/km. Take another example, when at A, the air pressure is 1020 mb and at Y, it is 980 mb. Get the difference between 1020 mb and 980 mb. It comes to 40 mb. Divide it by 100 km. The result would be 0.4 mb/km. Out of these two examples, the second one is four times greater than the first one, hence, the wind speed would be four times more in comparison to the first.

Figure 2: Air Pressure Gradient and Wind Speed



Source A: http://www.hurricanescience.org/images/hss/Illustration1.jpg

Source B: http://www.physicalgeography.net/fundamentals/images/pressuregradient.GIF

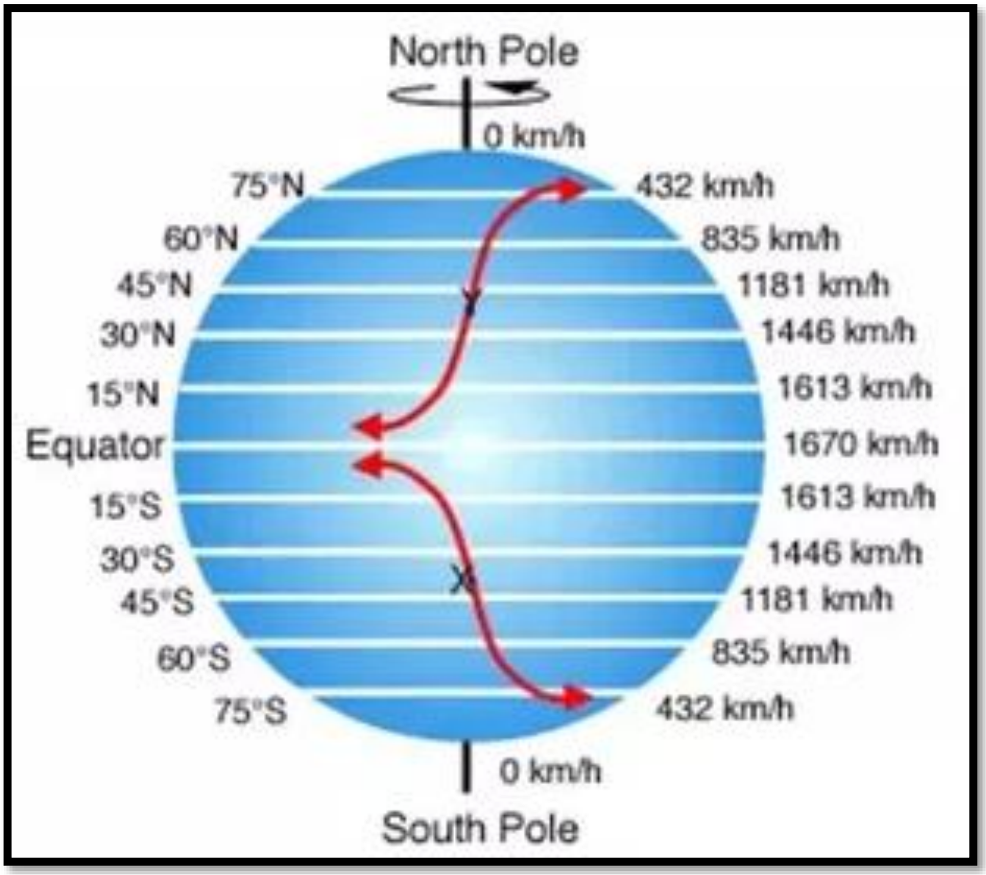
On the basis of your knowledge of Module 9 and 10 on pressure belts and wind patterns, you understand that temperature and moisture are the prime factors associated with atmospheric pressure. You also very well know that temperature distribution depends on insolation and various factors controlling its distribution. Therefore, insolation, temperature and pressure are interlinked.

Coriolis Force

Coriolis, practically speaking is not a force but it an effect which is observed on a mass of body in a rotating system. It results from the rotational movement of the earth and the movement of air in relation to the earth. It acts perpendicular to the axis of the earth.It is determined by the mass of the body and its rate of rotation. The earth rotates from west to east on its axis. Hence, the Coriolis force operates in north-south direction. The Coriolis force is zero at the equator and maximum at the poles. This concept was first explained by French engineer G. G. Coriolis in 1835, thus it is known by his name.

The earth is rotating on its axis. Equator has the maximum bulge. One rotation takes about 24 hours. The velocity of the rotation of the earth is 1670 km/hour (the circumference is about 40000 km) along the equator which comes down to half (835 km/hour) along 60^0 north and south latitudes(Figure 3). Since the pole is a point and it does not have any circumference, the rotational velocity at pole is zero.

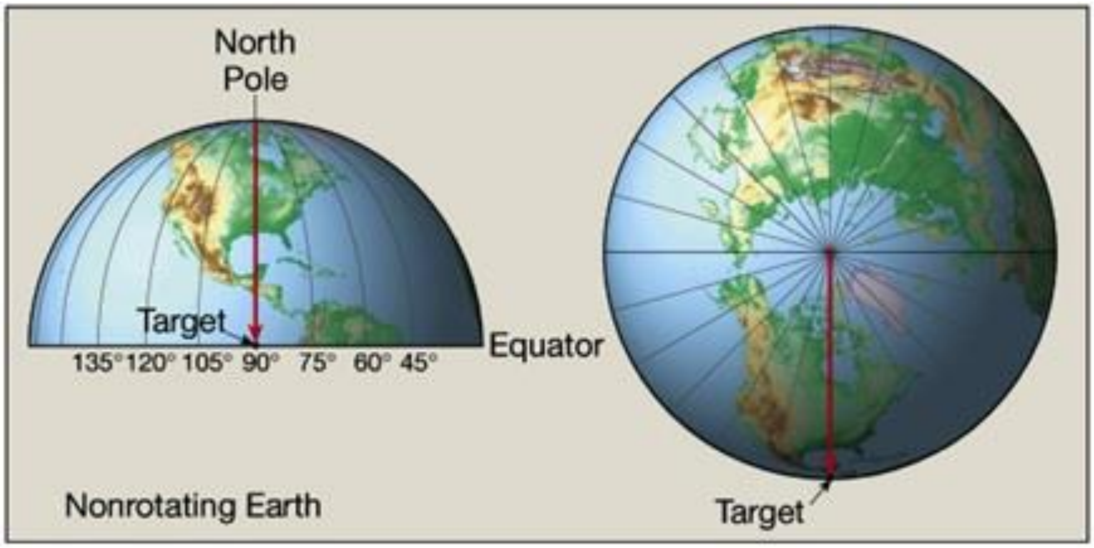
Figure 3: Earth's Rotational Velocity along Selected Latitudes



Source:https://qph.ec.quoracdn.net/main-qimg-6d6f839923b3355e5929b6ede6779150

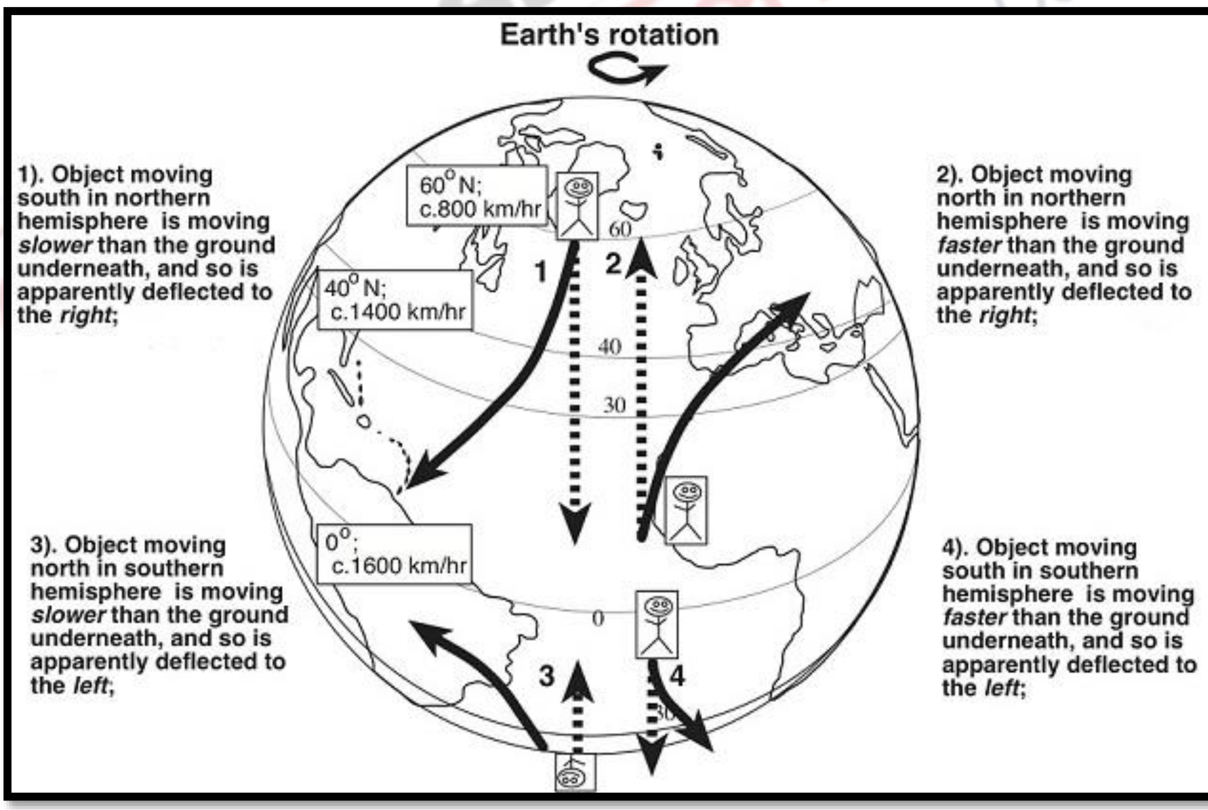
When an air moves equatorward in the northern hemisphere on a non-rotating earth it reaches to the destination along the designated path (Figure 4A). We know that the earth is not a non-rotating body but, it rotates on its axis. When the air moves equatorward on the spinning earth in the northern hemisphere, the air is deflected to the right as the surface itself moves forward. The same thing also happens when the air is moving from equator to pole, i.e., rightward turning in the northern hemisphere. When you take the case of southern hemisphere, leftward turning of the moving air is observed. The turn is explained by the relative motion/ velocity of the earth along different latitudes. The Figure 4B explains the Coriolis Effect very clearly. Its effect is more visible on the moving objects like the winds, ocean currents or aero planes/ fighter planes.

Figure 4A: Movement of Air on Non-Rotating Earth



Source: http://www.ux1.eiu.edu/~cfjps/1400/FIG06_011.jpg

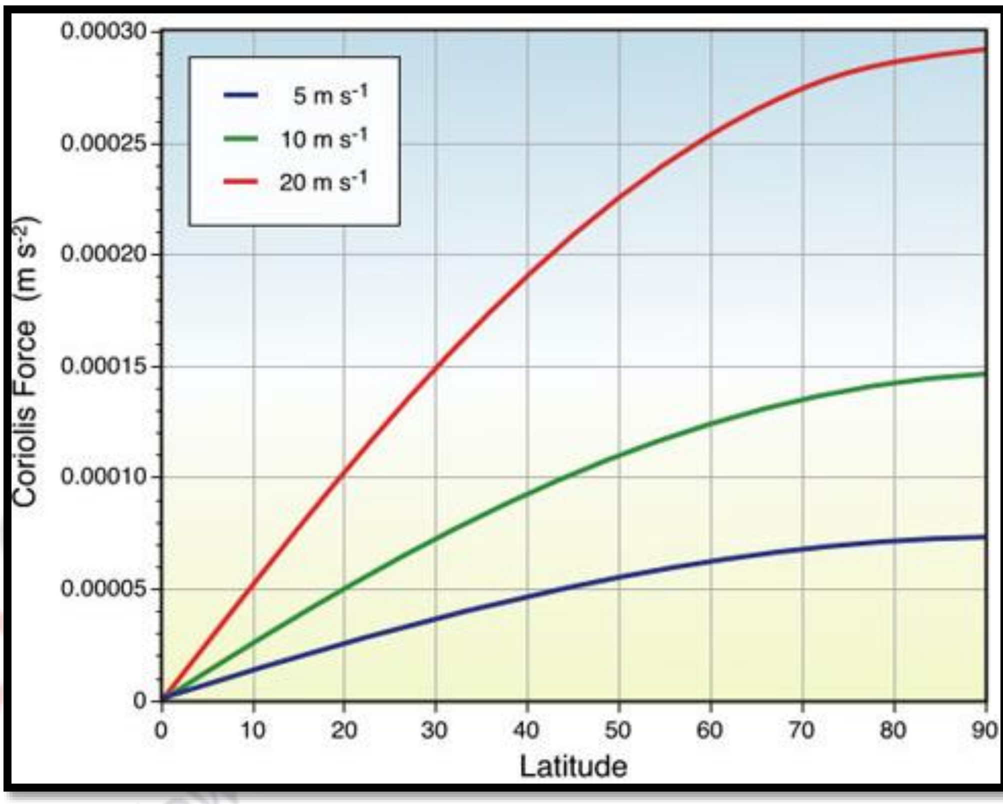
Figure 4B: Movement of Air on Rotating Earth



Source: http://www.offshoreengineering.com/images/Courses/Oceanography/coriolis-force-deflection-to-right.jpg

The Coriolis Effect does not affect the wind speed, but affects the direction. But the wind speed definitely affects the Coriolis Effect. The Coriolis Effect is stronger when the moving air mass is huge and have greater velocity. Therefore, the greater velocity wind is deflected more in comparison to the less strong (Figure 5). All the three lines representing different velocities of the wind are merged together at equator. The violet line shows the wind speed of 5 meter/second (18 km/hour) while the red line shows 20 meter/second (72 km/hour). It is obvious that the difference among these lines are great at the poles. The highest velocity is associated with highest Coriolis force.

Figure 5: Wind Velocity and Coriolis Effect



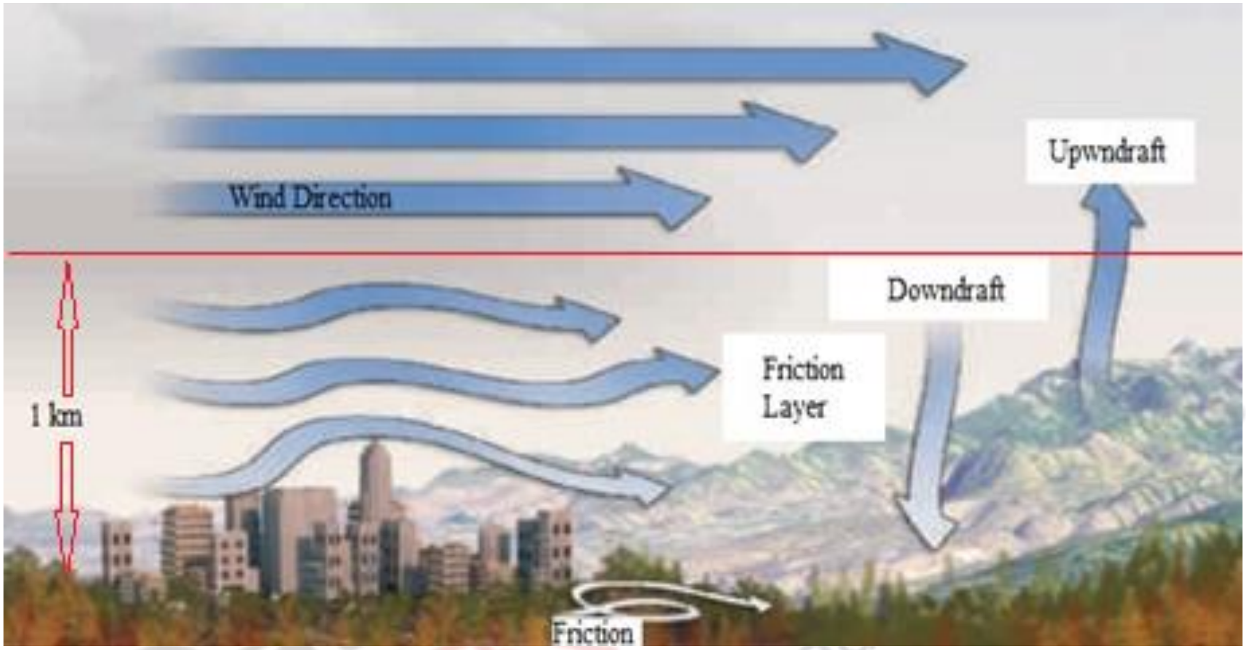
Source: http://www.physicalgeography.net/fundamentals/7n.html

Frictional force

In simple terms, air friction is the resistance to motion of air in relation to the surface roughness and irregularity through which the wind is blowing. Frictional force reduces the velocity of the wind near the ground. Therefore, wind is most affected by the friction and it is maximum near the ground. As long as we keep on going above the ground, the friction is reduced very drastically.

From Figure 6, it is obvious that the surface irregularity and undulation is impacting the blowing winds. Within a height of about one km from the ground, the wind is creating eddies and straight blow is heavily affected. After that the velocity is increasing. Right moving arrows shows the direction as well as the velocity of the winds. Bigger arrow show the greater speed, the smaller one indicate lesser velocity. On the land surface, the friction is greater but on the sea surface due to uniformity, it is less.

Figure 6: Friction and its Impact on Winds

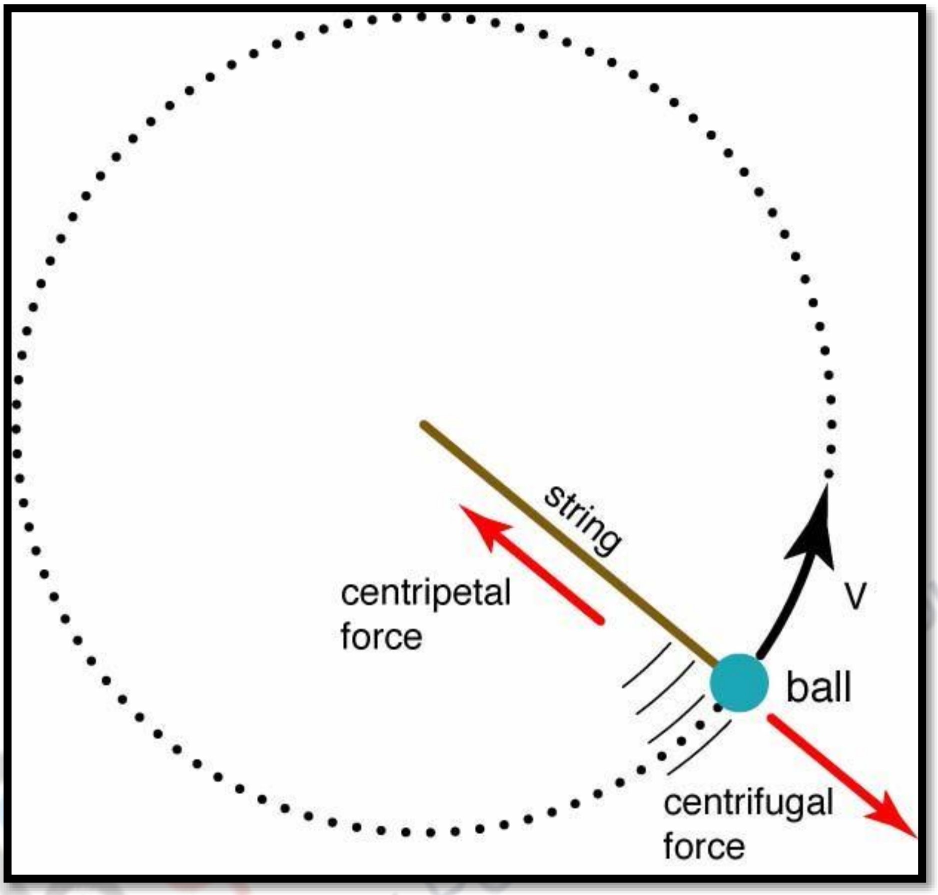


Source: http://highered.mheducation.com/sites/dl/free/0078095166/1030553/Chapter3.pdf

Centripetal Force

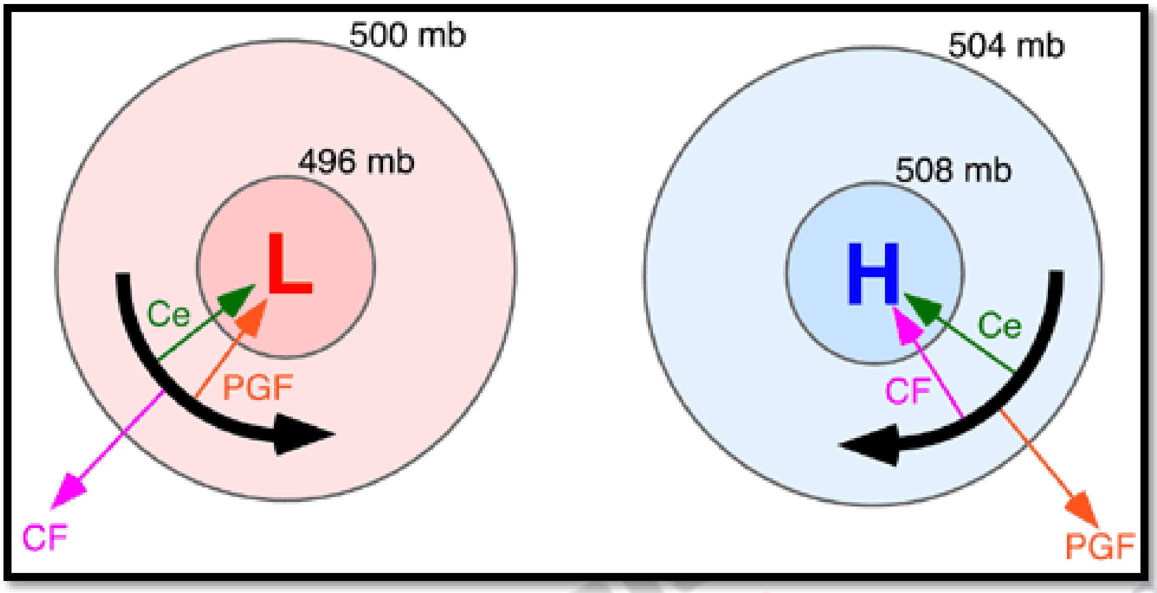
Centripetal force operates at right angles to the blowing wind. It is the inward pulling force i.e. towards the centers of rotation. You must be very well aware that what the centripetal forceis. Suppose you fix a ball with a string and you rotate by holding the other side of the string. The resultant forces are centripetal and centrifugal which is very visiblyshown by the Figure 7.

Figure 7: Diagrammatic Presentation of Centripetal and Centrifugal Forces



Generally, the winds are blowing in a curved paths. The curvature is still more when the isobaric circular patterns are developed around high pressure or low pressure (anticyclone and cyclone). It is very well developed above the friction layer. Vertically above about a height of around 5.5 km, the air pressure is approximately 500 mb. By this height, the friction force is almost terminated except over the highlands and mountains. Refer to the Figure 7, which shows that the winds above the friction layer are blowing in a circular manner. Since the friction is over, in case of low pressure, Coriolis force is equal to centripetal force plus pressure gradient force. But in case of high pressure where anticyclone is developed in upper troposphere, pressure gradient force is equal to Coriolis force plus centripetal force. In these conditions, the winds are blowing parallel to the isobars. It is called geostrophic winds by which the jet stream is developed about which you would study in another module.

Figure 7: Balancing Forces



Source: http://www.physicalgeography.net/fundamentals/7n.html

Scales of Atmospheric Circulation

The atmospheric circulation happens at a varied scales of operation starting from a very small local scale to the global one. The circulation is classified on the basis of spatial extension as well as its temporal duration. The classification of the atmospheric circulation has been presented in Table 2.

Table 2: Scales of Atmospheric Circulation

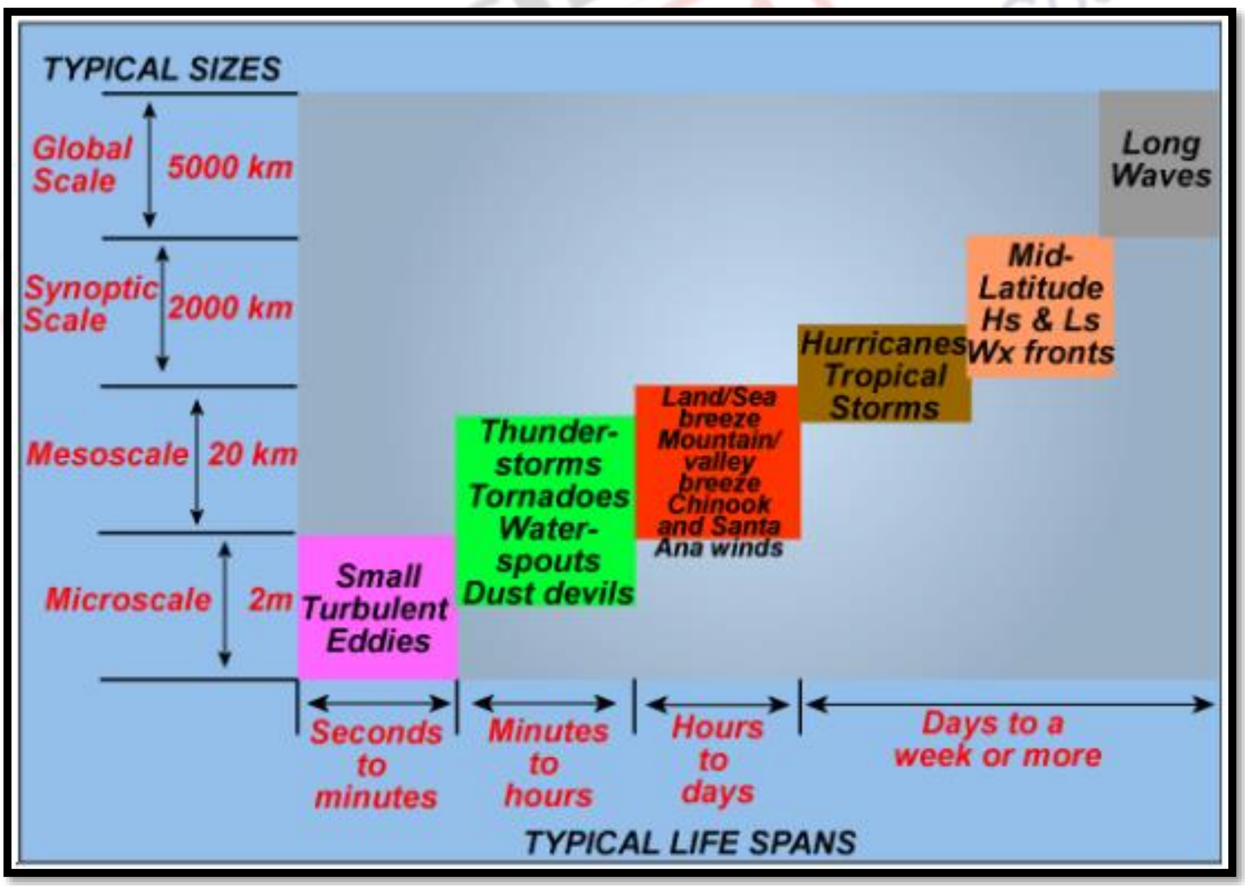
Category of Scale	**Duration**	**Spatial Extension**	**Examples**
Micro scale	Minutes and seconds	Meters to km	Turbulence, small cumulus clouds, eddies
Meso scale	Minutes to hour and to one day	Km to 100s of km	Thunderstorms sea breezes, mountain circulation
Synoptic scale	Days to weeks	1000s of km	Fronts, cyclones, anticyclones
Planetary scale	Weeks to months	Global	Planetary winds or permanent winds

The planetary scale atmospheric as well as ocean circulation are redistributing the thermal energy on the earth surface and atmosphere. The atmospheric circulation varies from one year to another, but the large scale patterns remain almost alike. The synoptic scale movements like frontal development, cyclones etc. have a certain duration of occurrence but not very definitely pinpointed one. Their variations are sometimes randomly associated with certain conditional fulfillment. That variation might be of hundreds of km. They develop in a specific belts in both the hemispheres.

The meso scale weather events and movements are associated with further small areas and their occurrences are of less than a day. Greater degree of variation is associated with these events. Some of them are directly associated with the heat received from the sun and are most commonly found at a regular diurnal interval. Some are not very predictive and appear randomly, but require fulfillment of certain conditions.The micro scale events are still at further minute level and they are mostly the product of the local variations.

The above table information is very vividly presented in Figure 8 which gives an idea to make a mental map of it. The atmospheric circulation at micro and meso scales have been discussed in Module 12 concerning periodic and local winds. Synoptic scale of circulation is taken care in various modules related to air masses, and cyclones, monsoon, atmosphere-ocean interaction etc. in this module, planetary scale circulation is discussed below.

Figure 8: Spatio-Temporal Atmospheric Circulation



Source: https://aesnotes.files.wordpress.com/2012/12/scale-of-atmospheric-motion1.png?w=594

Planetary Atmospheric Circulation

At the planetary scale, the atmospheric circulation is divided into two groups. They are:

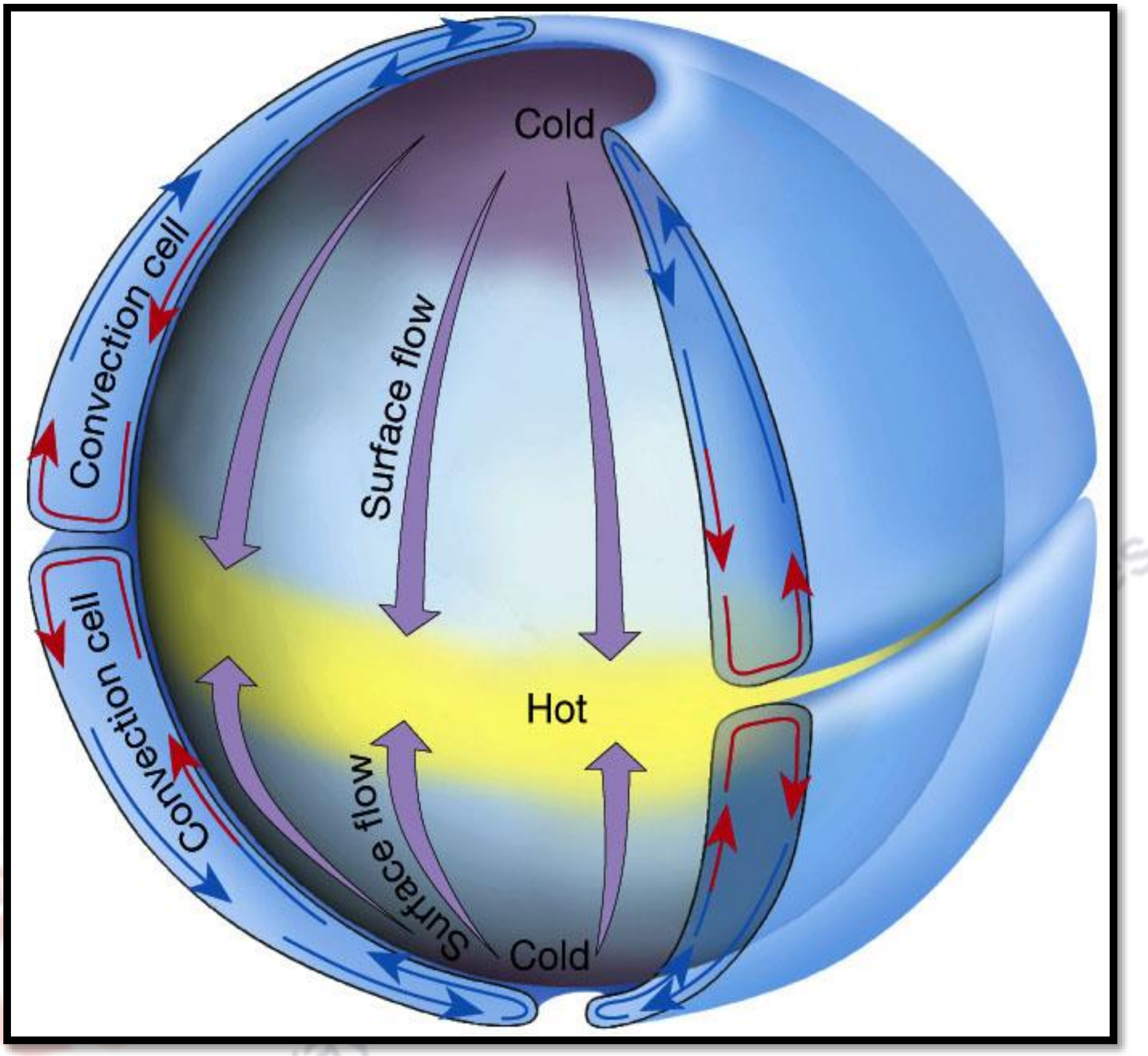
- Single-Cell Atmospheric Circulation Model
- Three-Cell Atmospheric Circulation Model

Single-Cell Atmospheric Circulation Model

The term “cell” refers to the cycling of the air. Here, we are calling it a single-cell, it means that it is operating at a global scale, but divided atthe equator. Hence, in both the hemisphere one cell is found,its occurrence is now debatable.The single-cell atmospheric circulation model was proposed by George Hadley in 1735. At that time scanty information was available about the atmospheric science. Based on his personal experience about more heat in the equatorial belt and very cold polar region, he proposed that the air in the equatorial region is expanded due to more temperature. In expanded air, the air molecules are widely spaced. Therefore, the density is reduced. Reduction in density causes the air to be lighter. Lighter air gets uplifted and moves aloft with upper limit at tropopause.

By that height, it becomes very cool. Since, there is continuously uprising air is existing, the uplifted air is being pushed towards north and south in both the hemispheres. Both the poles are very cold, hence, the air over the poles is very dense and heavier. This leads to create high pressure belts surrounding the poles. According to this concept, cold air sinks at the poles and warm and heated air rises at equator. It results into the formation of Hadley cell which is named after its inventor.

Figure 9: Single-Cell Atmospheric Circulation Model



Source: http://www.ux1.eiu.edu/~cfjps/1400/FIG07_005.jpg

Is Single-Cell Model in Operation

George Hadley proposed the single-cell model, but it would develop only when the sun is overhead at equator and the earth is static, which is not the reality. While proposing this model, he did not consider other factors like apparent shift of the sun's position in an annual cycle. Earth's rotation and Coriolis effect were also not taken into account by Hadley. The distribution of land and water also play a very significant role in the heat transfer, heating of the surface and the air in their contact. Therefore, the idea of single-cell was well accepted long time back but now the researches have proved that the single-cell in not in operation rather it is three-cell atmospheric circulation.

Three-Cell Atmospheric Circulation Model

By now, you must have read about the planetary pressure belts and winds in Module 10. The distribution of pressure belts and winds is fairly well established and their seasonal variations are also well known. The pressure belts are result of interplay of various factors. The pressure variations give genesis to horizontal motion of air i.e. winds.

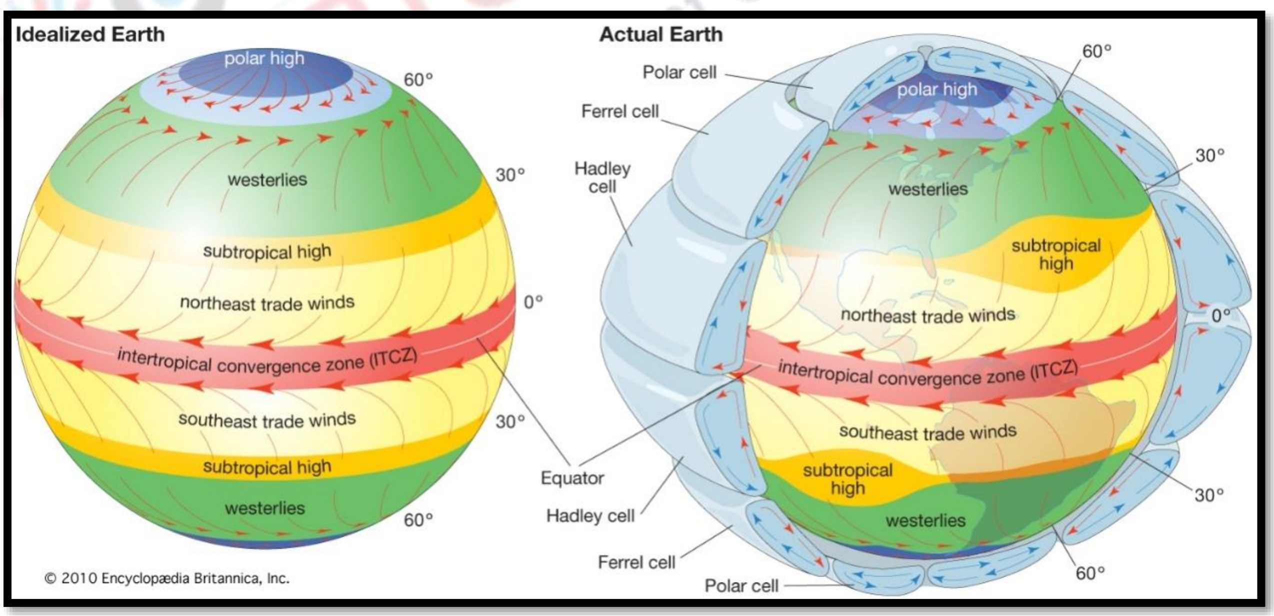
It is well known fact that the maximum sun energy is received in the equatorial region and this energy is redistributed by the winds and ocean currents as mentioned earlier also. But this energy redistribution is not directly from the high energy zone to the low energy zone in a single cell. This redistribution is performed through well-developed distinct three cells. Three-cell formation and their relative regulation is in a sequential manner. These cells divide the troposphere into three separate, distinct and almost closed atmospheric circulations. The three cells are:

- Tropical cell
- Mid-latitude cell
- Polar cell

Tropical Cell

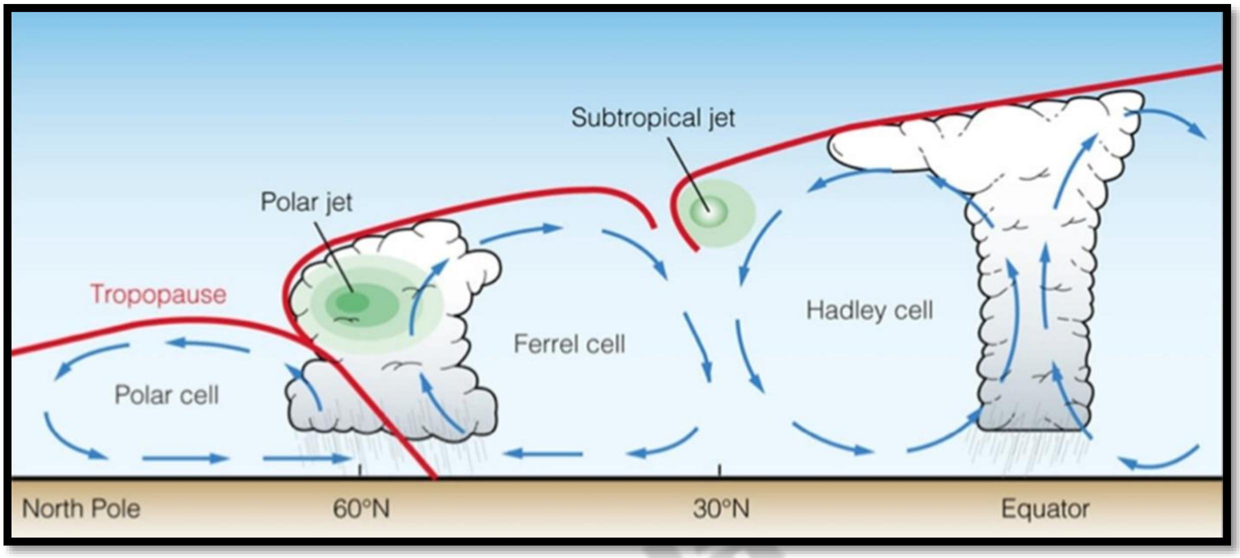
Tropical cell exists between equator and 30^0 north and south latitudes (Figure 10A and B).It is thermally induced cell. The upper limit of the cell is demarcated by the tropopause. First of all, it was explained by George Hadleyin 1735 and so it is named after him.

Figure 10A: Three-Cell Atmospheric Circulation on the Globe



Source: https://www.britannica.com/media/full/204996/107938

Figure 10B: Cross Sectional Three-Cell Atmospheric Circulation



Source: http://geophile.net/Lessons/atmosphere/images/circulationcells_xsection.fw.png

Mechanism: The maximum heat is received in equatorial region. Due to high heat, the air expands and it becomes light and rises up. This ascending air cools gradually and starts descending down over around 30 north and south latitudes due to rotation of earth. This descending cool and denser air increases atmospheric pressure in these belts which are also known as horse latitudes.The winds blow from these subtropical high pressure belts to equatorial low pressure belt as trade winds and complete circulation develops in the tropics of both the hemispheres.

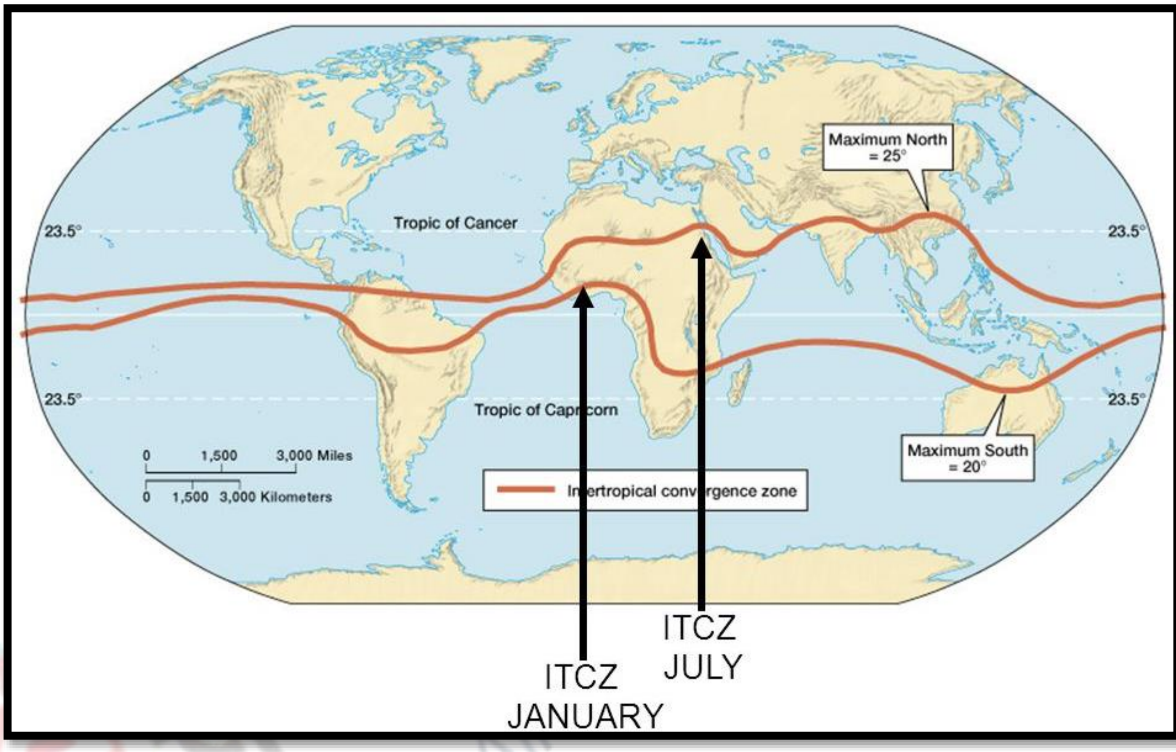
It is termed as Hadley cell. It has three distinct characteristics

i. The Hadley cell exists throughout the year and is always in operation with slight north and south shifting depending upon seasons.
ii. The upper air movement poleward conserves its axial angular momentum, but the equatorward moving air faces surface friction and finally loses velocity.
iii. The balance is achieved between warm upward moving air and the wind converging at the ITCZ.

The rising air in the equatorial region helps in developing cumulonimbus clouds to extensive height. After condensation and precipitation, great amount of latent heat is released there, and it gives impetus to drive the tropical/ Hadley cell equatorward. The direction of the movement of air in the upper troposphere is from southwest to northeast in northern hemisphere. At the ground level or near the surface, the general direction of wind is from northeast to southwest as trade winds of northern hemisphere, baring the seasonal changes. The air movement at upper troposphere and ground level is opposite to each other of which the reason is very well explained in Module 10. In general, the principle is that whatever is wind blowing direction there at the ground, its direction aloft is reverse.

Inter-tropical Convergence Zone: The trade winds coming from the sub-tropical highs from both hemisphere converges near equator during equinox. It is this zone from where the air rises and it is generally termed as doldrums. It is a zone of almost no horizontal air movement. With the changing seasons, the departure in the Hadley cell and ITCZ is also observed (Figure 11).

Figure 11: Seasonal Shift of ITCZ



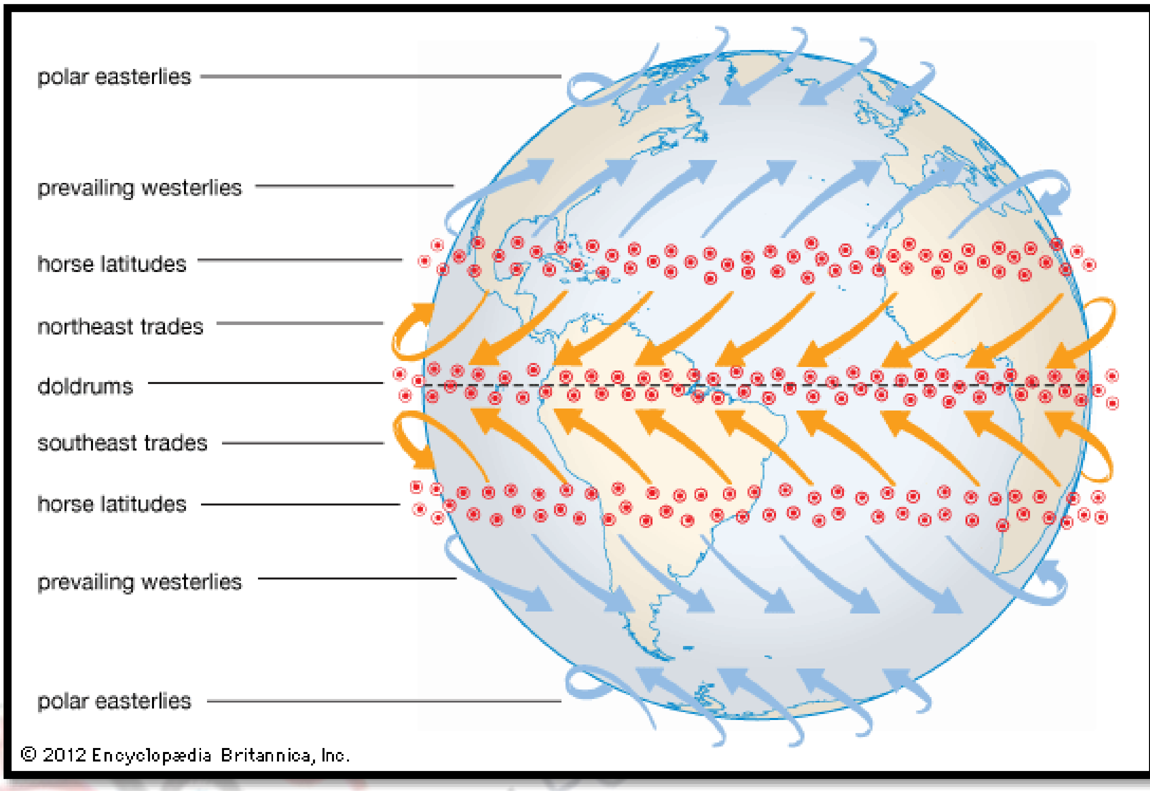
Source: http://slideplayer.com/slide/7741637/25/images/8/ITCZ+JULY+ITCZ+JANUARY.jpg

Mid-Latitude Cell

Mid-Latitude cell exists between 30 to 60 north and south latitudes (Figure 10A and B).It is found between Hadley cell and polar cell. It is developed due to dynamic conditions prevailing between the two cells bordering it. This cell is operating just reverse to tropical cell. First of all, it was explained by William Ferrel in 1856 and so it is named after him.

Mechanism: The low pressure around equator is thermally induced. The high pressure at sub-tropical zone is dynamically created by subsiding air from above coming from the ITCZ. From this high pressure, winds are blowing in both the directions – towards equator and towards poles (Figure 12). But before reaching the pole, another low pressure is bound to develop and it appears at around 60^0 north and south latitudes. It happens so, because the pole is excessively cold. It is quite natural to be a high pressure around poles. Therefore, two highs – subtropical and polar, the low pressure development is quite obvious. At this low pressure belt, rising air reaches near to the tropopause and gets diverted towards pole as well as sub-tropical direction. Hence, cell created by the circular motion from sub-tropical high to subpolar low, again upward, diverted to sub-tropical high and finally sinking is known as Ferrel cell (Figure 10A and B).

Figure 12: Lower Tropospheric Wind Patterns



Source: http://media1.britannica.com/eb-media/04/110604-004-2CDA5DF5.gif

The mid-latitude cell or Ferrel cell is also termed as polar front cell. You might be knowing that in the higher latitudes the temperature contrast is greater. Polar areas are occupied by cold air mass while on the southern areas warm air mass develops. When both of the air masses come closer and interacts with each other, the fronts are created. At the ground surface or near the surface the winds are blowing from southwest to northeast. Generally, these are known as westerlies. But aloft air circulation is opposite to it.

Polar Cell

The polar cell develops between $60^0$and poles in both hemisphere (Figure 10A and B). Polar areas are thermally induced high pressure belts as it is developed because of the excessively cold conditions. Temperature is very low, air is dry, intermolecular space of the air is very less and hence, the density is very high. This air has the tendency to lay near the surface. Along the surface, cold winds blow towards the sub-polar low as easterlies. From sub-polar low, it is lifted up due to convergence with westerlies at polar fronts. From near the tropopause, it is diverted towards pole and finally completes a circulationcalled polar cell.

In brief, the three-cell atmospheric circulation model is symmetrical in shape and character with seasonal asymmetrical appearance. The best symmetry is during equinox and the maximum asymmetry is during solstice.

Vertical Atmospheric Circulation

Earth has strong gravitational pull, as we all know very well. In spite of the gravitation pull, the question arises as to what causes the air to rise and what happens when the air moves upward. To get the answers of these two questions, you must have got some ideas from the discussion about different atmospheric cells. You have studied that the condensation and precipitation release latent heat and it generates additional energy to boost the diversion process from equatorial zone. You would study about the condensation and precipitation in Modules 17 to 19. Most of the condensation and precipitation processes are related to the vertical atmospheric circulation. Vertical rise of air is characterized by:

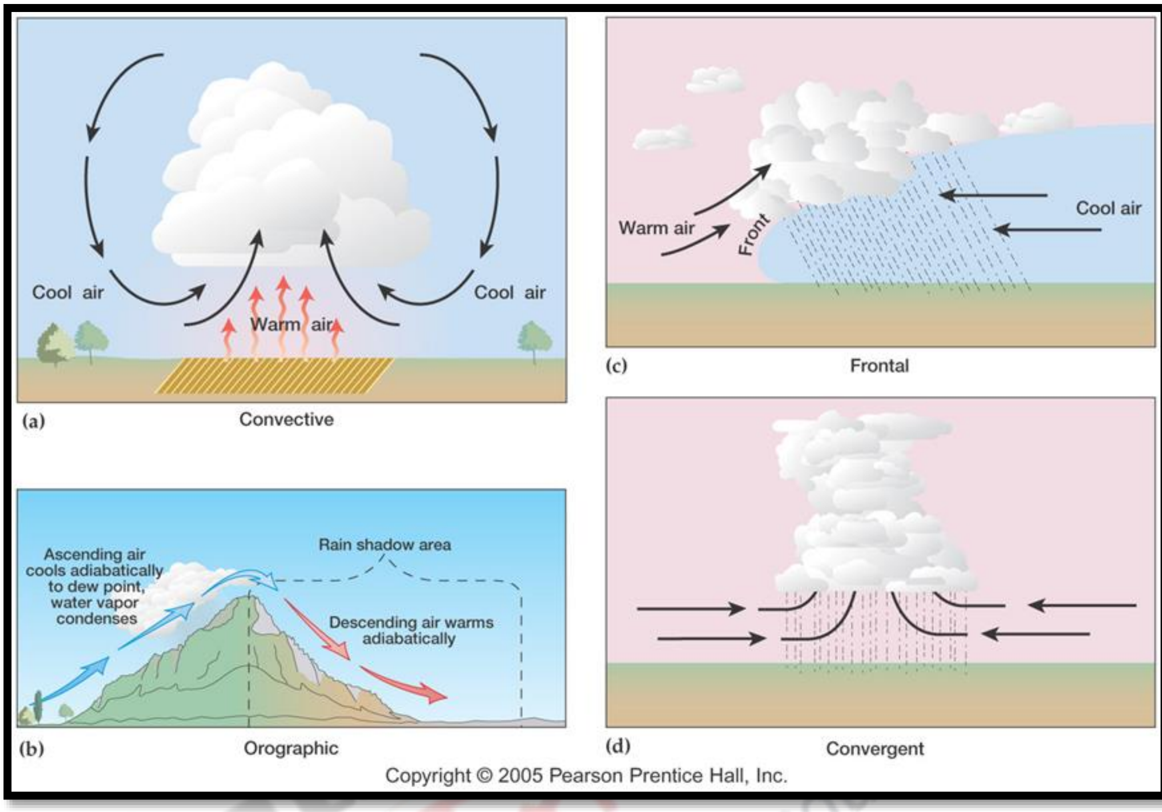
- Decrease in temperature with elevation
- Decrease in density of airwith elevation
- Decrease in pressurewith elevation
- Increase in intermolecular space of the air with elevation
- Decrease in temperature is due to expanding air mass
- Temperature, density and air pressure are highly correlated

Under above mentioned conditions, the upward moving air mass is bound to get altered and modified. The modification is seen in terms of air temperature, density and pressure. Most of the time, if moisture is available, condensation and precipitation are the natural outcomes. You would study about the forms and types of precipitation in Module 19 in detail. But in brief here, uplifting or vertical motion in the air is caused by:

- Convective lifting,
- Orographic lifting,
- Frontal/cyclonic lifting, and
- Convergent lifting.

In all these four cases, rising of the air cools. Relative humidity increases. Water holding capacity of the mass of air reduces. Dew level reaches by cooling of the air. In the presence of hygroscopic nuclei water vapour turns into tiny droplets. Through collision and coalescence process, the water droplets becomes bigger and fall down in numerous forms of precipitation (Figure 13). In other words, the vertical motion in the air causes cooling of the rising air as well as precipitation.

Figure 13: Mechanisms of Vertical Atmospheric Circulation



Source:http://web.gccaz.edu/~lnewman/gph111/topic_units/moisture/moisture_stabil_prec/4_lifting.jpg

Regional Vertical Atmospheric Circulation

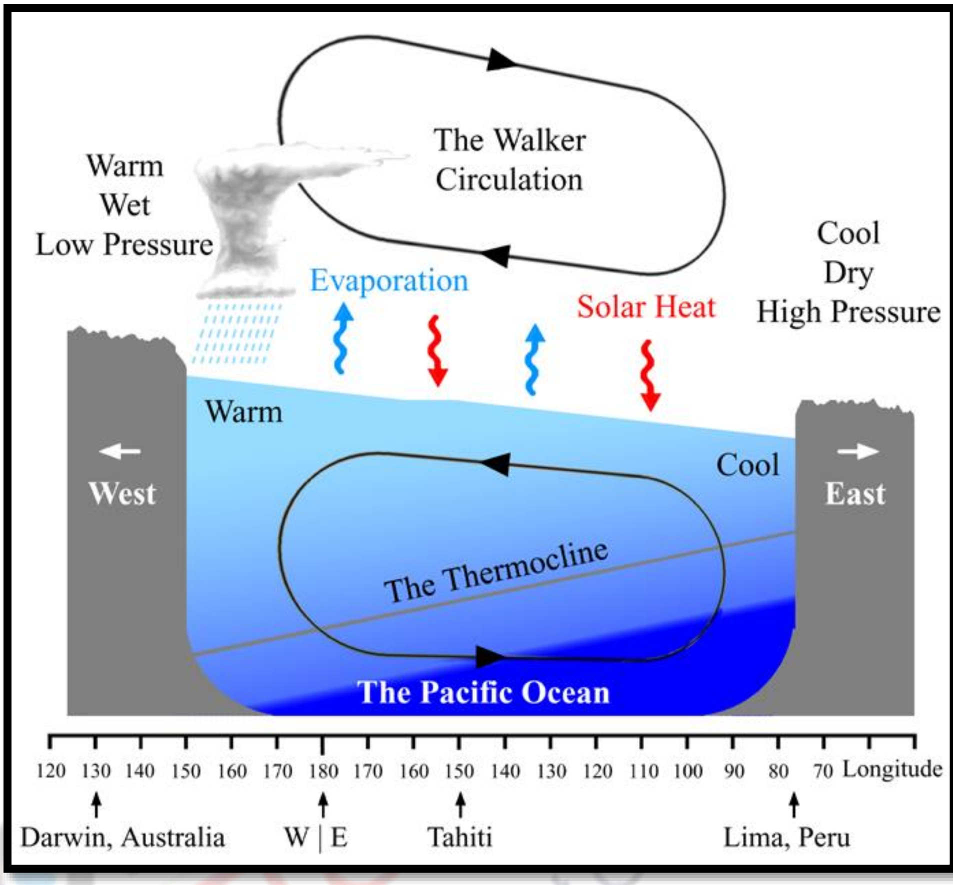
Apart from the above mentioned vertical motion of the air, some other vertical circulations also occurat regional level, but they are not confined to an annual cycle. Their development is related to the regional synoptic changes. They are mainly:

- Walker circulation
- Southern Oscillation and El Nino
- Southern Oscillation and La Nina

Walker circulation

The concept of Walker Circulation was proposed by Sir Gilbert Walker. It is based onthe difference in surface pressure and temperature over tropical western and eastern Pacific Ocean (Figure 14). Normally, tropical western Pacific is warm and humid with low pressure. Opposite to it, the tropical eastern Pacific is cool and dry with high pressure over the area. Therefore, in western part warm and humid air rises and give rain and aloft it goes to eastern Pacific and sinks there and enhances the high pressure. This is the normal affair associated with general weather conditions.

Figure 14: Walker Circulation

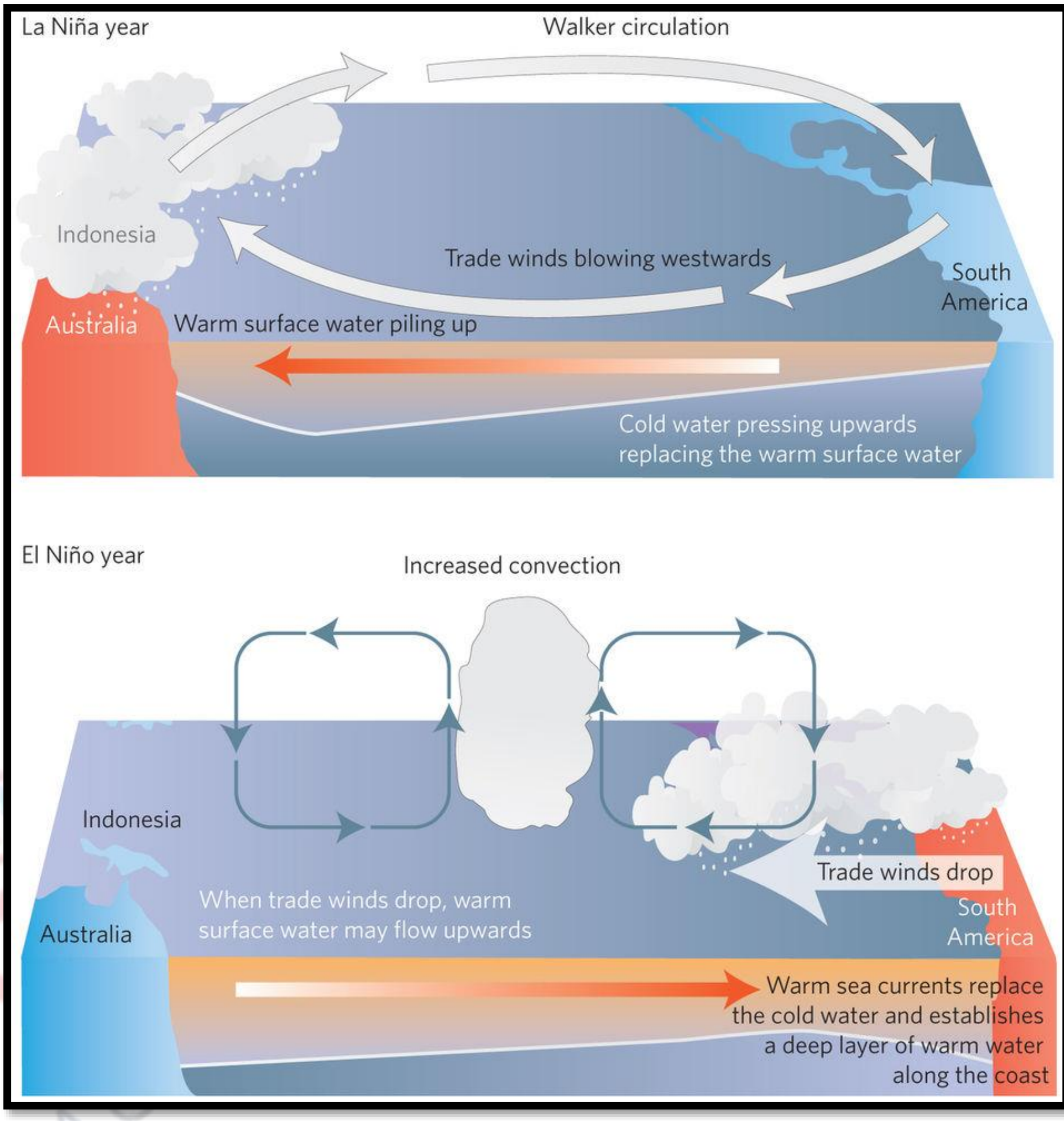


Source: https://upload.wikimedia.org/wikipedia/commons/6/68/LaNina.png

Southern Oscillation and El Nino

This normal condition reverses after few years and it is termed as El Nino and Southern Oscillation. In this case, Walker Circulation weakens and warm water is spread to the eastern Pacific where low pressure develops (Figure 15). Warm and moist air rises, gives rain there and diverges towards west and subsides in the western Pacific. It is completely opposite to the Walker Circulation, and it is termed as El Nino.

Figure 15: El Nino and La Nina



Source: https://images.nature.com/full/nature-assets/nclimate/journal/v4/n3/images/nclimate2149-f1.jpg

Southern Oscillation and La Nina

When the western Pacific is excessively warm and humid and the low pressure is intense, it is called La Nina (Figure 15). La Nina is opposite to El Nino. Keeping the Walker Circulation in the centre, both of these conditions are the two extremes of the events. All these are affecting the larger regional weather. These are also included in the vertical motion of the atmosphere. You will study about them in details in Module 15 on ocean-atmosphere interaction.

Summary and Conclusions

A huge envelop of air is surrounding the earth. It is made up of several gases, minute solid substances, smoke and water vapour. The atmospheric circulation is governed primarily by four forces. The first one is pressure gradient which is the change in the difference of isobar per unit distance along a line. This line may be horizontal or vertical. Horizontal pressure gradient is gentle while the vertical pressure gradient is much steep. In spite of steep pressure gradient in vertical case, the wind in not that strong as the gravitation of the earth pulls everything centreward. The second is Coriolis force, which is the effect of rotation of earth on the moving air/ wind In northern hemisphere, the wind is deflected to the right direction from its designated direction. Centripetal force is the third one which is resultant of the curvature of the air blowing. It is most deflected when the wind velocity is more but it less when the velocity is less. The third is the friction of the earth which is the function of the irregularity and undulation of the earth surface. Generally, the friction is negligible above 5.5 km height baring the highlands and mountains. It is quite natural that the acceleration is more when the applied force increases.

The scales of the atmospheric circulation is very wide. It starts with the appearance of small turbulence or eddies at a very minute scale lasting for a few minutes to the global scale like planetary system of wind circulation. In between lies the meso scale and synoptic scales. Large scale phenomena are more reliable, predictive and have major patterns almost in a symmetrical manner with the pivotal point along the equator. The decrease in the scale lead to less pre-designed prediction and more variation in the pattern. Therefore,at the smallest scale, it completely seems to be random.

The planetary atmospheric circulation can very well be explained by three cells in each hemisphere. They are tropical or Hadley cell, Ferrel or temperate cell, and polar cell.Tropical or Hadley cell explains that the converging air along ITCZ rises up. Condensation and precipitation lead to release of latent heat and it gives impetus to the convective cell and further divergence from the upper tropospheric level. The diverged air sinks around sub-tropical high. The second cell develops between 30^0 to 60^0 north and south latitudes. It is known as Ferrelcell. The polar cell is formed between 60^0 north and south to poles. Vertical motion in the air is associated with the lifting of the air. It is performed in four ways. They are convective, orographic, frontal and convergent.