1. Details of Module and its structure

Module Detail	
Subject Name	Geography
Course Name	Geography 01 (Class XI, Semester - 1)
Module Name/Title	Atmospheric circulation and weather systems – Part 2
Module Id	kegy_11002
Pre-requisites	Basic knowledge about the about the Atmosphere, the elements of weather and climate, climatic conditions
Objectives	After reading this lesson, learners will be able to know about: • Explain the factors affecting general air circulation, Describe the role of different factors, • Explain the atmospheric circulatory pattern, Explain different air circulatory cells, • Illustrate El Nino and La Nina as well as establish the relationship with global climatic events, • Describe local winds like land and sea breeze, mountain and valley winds and • Explain the mechanisms of the development of tropical and extra tropical cyclones.
Keywords	Atmospheric circulation, General circulation, Seasonal winds, Tropical cyclone, Extra-tropical cyclone

2. Development Team

Role	Name	Affiliation
National MOOC Coordinator (NMC)	Prof. Amarendra P. Behera	CIET, NCERT, New Delhi
Program Coordinator	Dr. Mohd. Mamur Ali	CIET, NCERT, New Delhi
Course Coordinator (CC) / PI	Prof. Aparna Pandey	DESS, NCERT, New Delhi
Course Co-Coordinator / Co-PI	Dr. Archana	CIET, NCERT, New Delhi
Subject Matter Expert (SME)	Arbind kumar pandey	RPVV, Raj Niwas Marg, New Delhi
Review Team	Dr. Ramashray Prasad	Bhim Rao Ambedkar College, New Delhi

Table of Content:

1. Introduction
2. Factors affecting general circulation
3. General atmospheric circulation and its effects on oceans
4. Seasonal wind local winds
5. Air masses fronts
6. Extra tropical cyclones tropical cyclones

Introduction

Circulation refers the movement of any substance. Any substance will not move unless some force is applied to it. The force is external. When it is applied to that substance, its impact is seen on that substance. Air is a substance. It has its mass. There are several external forces applying to it. Some of them are like – temperature of the air, distribution of insolation, altitude etc. Air is available everywhere on/ near the earth surface. But wind is the blowing of the gaseous form of air. Air blows because of pressure gradient. The circulation of gases (atmosphere) is mostly happens in the form of wind. The movement of air molecules are seen in both ways – horizontal and vertical.

Factors Affecting General Circulation

General circulation of atmosphere is affected by various factors. Important among them are:

(i) Latitudinal variation of atmospheric heating;

(ii) Emergence of pressure belts;

(iii) The migration of belts following apparent path of the sun;

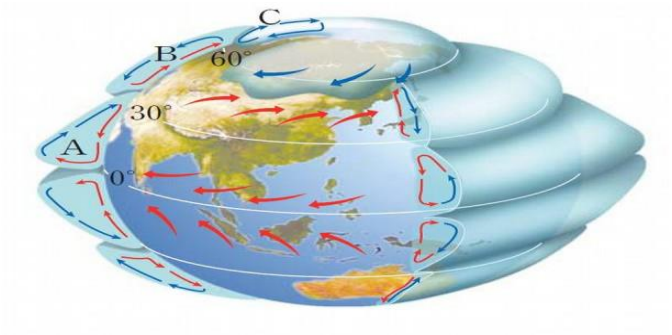
(iv) The distribution of continents and oceans;

(v) The rotation of earth.

Meaning of Pattern

Pattern is basically the laying down of some observable characteristics of something. It is a sort of rhythmic presentation of a phenomenon. When we talk about the pattern of atmospheric circulation, we mean by the appearance of the wind pattern over the globe. The pattern of the movement of the planetary winds is called the general circulation of the atmosphere. The general circulation of the atmosphere also sets in motion the ocean water circulation. It happens because the air has its mass. The mass of the air presses the ocean water. It possess a pressure of 1034gram per centimetre square. This much of huge pressure

of air on the fluid water of the ocean causes to bring dynamism. This dynamism in ocean water produces waves and currents. Waves and currents as well as the influence the ocean water affects the global climate. A three dimensional general atmospheric circulation is very clearly shown in Figure. Figure 1: Global Air Circulation



Source: http://koc.chunjae.co.kr/upload/606/B-T33-00-62-02-04.jpg

Latitudinal Variation of Atmospheric Heating

Atmospheric heating is the main cause of differential pressure belt existence. It leads to atmospheric circulation. The amount of insolation received on the earth surface varies with changing latitudes. In general, more heating is seen in the equatorial region. With increasing latitudes, the heating of the atmosphere is lowered, baring the seasonal changes.

Emergence of Pressure Belts

As per the insolation received on the earth surface, pressure belts are developed. The low pressure belts at equatorial region and high pressure in polar region is caused by this process. The subtropical high pressure and subpolar low is caused by dynamic factors. Thus, the emergence of these pressure belts leads to atmospheric circulation.

Migration of Pressure Belts

We very well observe that the atmospheric conditions of any area is not the same throughout the year. There is well marked and distinct seasons. These seasons are caused due to inclination of earth's axis and revolution on its orbit around the sun. In this process after March, the northern hemisphere receives vertical rays and sun's inclination is maximum by the end of third week of June. Reverse case is observed in southern hemisphere after September. By the end of third week of December, the southern hemisphere receives vertical rays and sun's inclination is the maximum. Due these reasons, the ITCZ also shifts. Shifting in the ITCZ causes the pressure belts to migrate accordingly, i.e., northward from March to September and southward from September to March. Since the pressure belts migrate, the air circulation is also modified accordingly.

Distribution of Continents and Oceans

The distribution of land and water is not the same proportion in both the hemispheres. Northern hemisphere is known as land hemisphere and the southern to be as water hemisphere. In northern hemisphere, land surface is about 39% whereas water surface is 61%. In southern hemisphere, land surface is only about 19% and 81%. Because of large land body in the northern hemisphere, the shifting of the ITCZ is more but in southern, it is less. Land is more and quickly heated in comparison to water and thus the circulation is also impacted.

Rotation of Earth

Earth is a rotating body. Due to rotation, the movement of any object/ air is affected. This effect produces a force in relation to the moving earth. This effect is greatest at the poles and lowest at the equator. It is termed as Coriolis Effect. According to this effect, any moving body will be deflected from its path to the right (clockwise) in northern hemisphere and to the left (anti-clockwise) in southern hemisphere.

Inter Tropical Convergence Zone

We do observe that the sun is moderate in March and September. We also know that on March 21 and September 22, sun shines exactly over equator. The low pressure is created because of more temperature in equatorial belt. The winds come to this low pressure areas. In this zone wind converges from both hemispheres. Therefore, it is called Inter Tropical Convergence Zone (ITCZ). Here, the air rises because of expanding air due to high temperature. It happens because air volume is increased. It leads to decrease in density of the air. Air becomes lighter. Lighter air lifts/ replaced by heavier air molecules. Hence, the low air pressure is the result.

The winds from the tropics converge at this low pressure zone. The converged air rises along with the convective cell. It reaches above and gets diverted towards the poles in both the hemispheres. But they are not pushed till poles. They climb down in the tropics between 20^0 to 35^0 north and south latitudes as they are sufficiently cooled. The descended air gets accumulated here. The accumulation causes the air pressure to rise. Therefore high pressure belt is developed.

Hadley Cell: Down below near the land surface, the air blows towards the equator. It is known as easterlies. The easterlies from either side of the equator converge in the Inter Tropical Convergence Zone (ITCZ). The circulation of air from the tropics to equator – convergence at ITCZ – upward draft – diversion towards poles from upper troposphere –

climbing down at the tropics makes a circulatory cell. This cell is known as Hadley Cell shown in Figure 2.

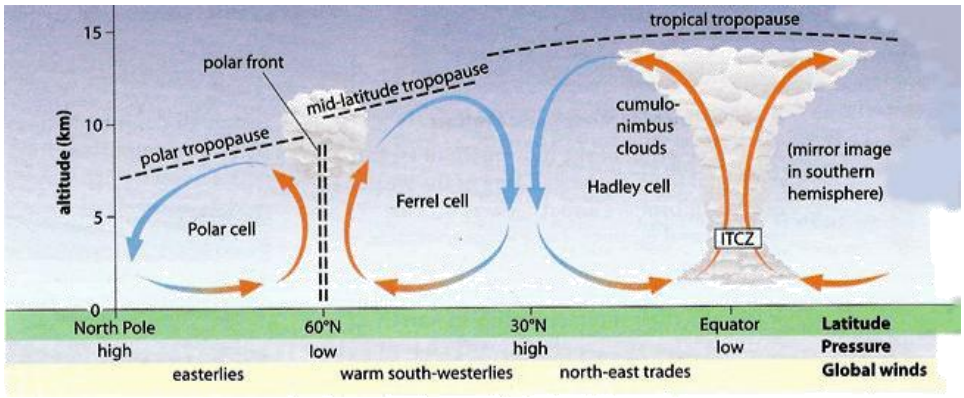


Figure 2: Circulatory Cells in the Troposphere

Source: http://www.mrgscience.com/uploads/2/0/7/9/20796234/9991763_orig.gif

Ferrel's Cell: The winds also blow towards pole from the high pressure belts of tropics. As mentioned before, poles are excessively cold and possess high pressure zones. From the polar high pressure, winds are coming towards tropics. The winds coming from both the high pressures converges at subpolar low pressure zone. It lays between 50^0 and 70^0 latitudes in both the hemispheres. This low pressure is dynamically induced. From this zone, the air is drafted upward. Upward moving air is diverted towards equator in both the hemispheres. Equatorward moving air descends at the subtropical zone. Therefore, the cell created by air moving from subtropical high to subpolar low to upward uplift and drifted towards subtropical high is known as Ferrel's Cell (Figure 2).

Polar Cell: Uplifted air from subpolar high also gets diverted towards poles from the upper troposphere in both the hemispheres. Near the poles, they subsides and comes to the polar highs from where the winds blow towards subpolar lows. In this way, a cell is created, popularly called as Polar Cell (Figure 2).

The general circulation of the atmosphere also affects the oceans. The large-scale winds of the atmosphere initiate large and slow moving currents of the ocean. Oceans in turn provide input of energy and water vapour into the air. These interactions take place rather slowly over a large part of the ocean.

General Atmospheric Circulation and its Effects on Oceans

Warming and cooling of the Pacific Ocean is most important in terms of general atmospheric circulation.

Normal Conditions: Normally the trade winds converge at the equatorial region (ITCZ) and blows towards west. It exerts pressure on the ocean water and the warm water is dragged towards west. The air over the warmer water gets sufficient moisture from the ocean surface. Since, the moisture rich air is lighter, it climbs up in the western Pacific and pours heavy convectional rain. Upper dry air moves eastward and climbs down in the eastern Pacific. This situation is normal/ neutral. This normal situation is also known as Walker circulation (Figure 3A).

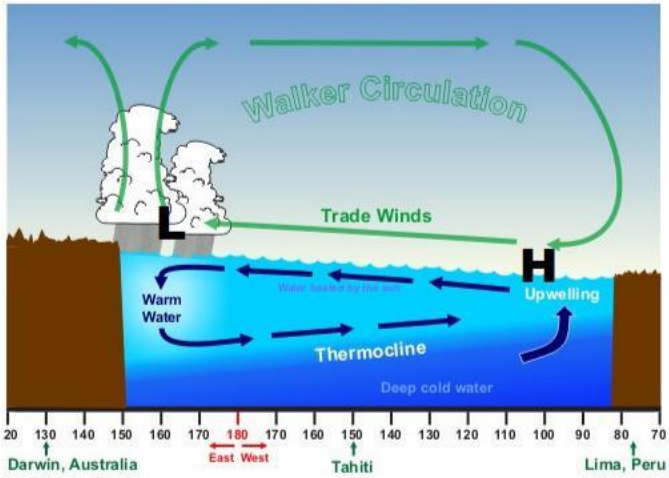


Figure 3A: Normal Conditions in the Pacific Ocean

El Nino: Along the ITCZ near equator or little south of it, the converged easterly air from both hemispheres drifts the warm water towards west. The depth of warm water becomes more in the western Pacific Ocean near New Guinea. The warm water of western part moves back towards the east under the water surface. So warm water is accumulated near the South American coast. The normal condition is reversed and a low pressure is developed off the coast of Peru. The normal convective precipitation in the western Pacific is altered to central and eastern Pacific. Therefore, the major rain zone migrates eastward. It is the root cause for prolonged dry period western Pacific. It known as El Nino. The El Nino event is closely associated with the pressure changes in the Central Pacific and Australia. This change in pressure condition over Pacific is known as the southern oscillation.

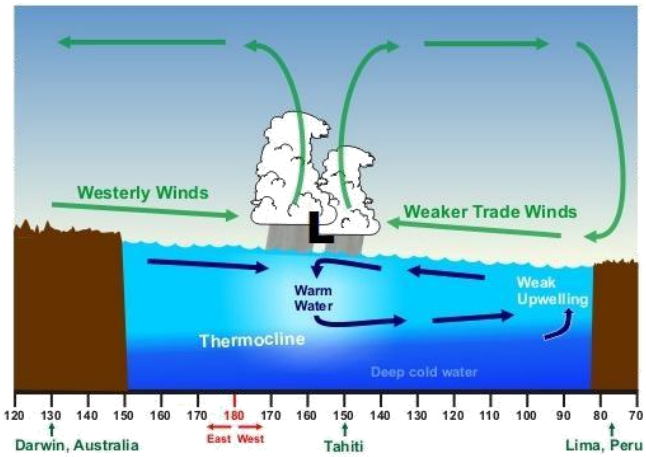


Figure 3B: El Nino Conditions in the Pacific Ocean

La Nina: When the up welling of the cold water is greater than the normal, the high pressure is very strong in the eastern Pacific. The air pressure in the western Pacific is excessively low. In this situation, the more rain is observed in the west. This causes very goon monsoon in south Asian countries (Figure 3C).

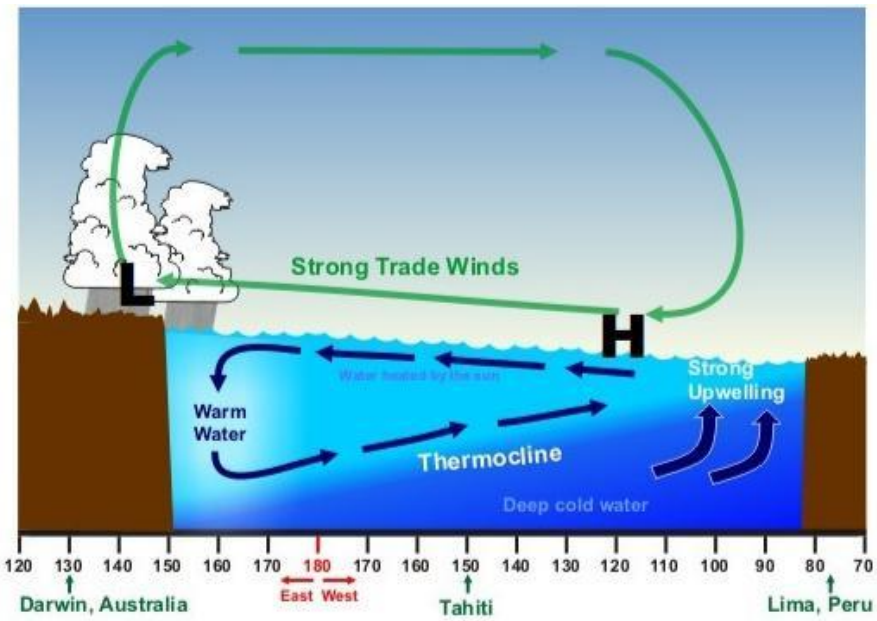


Figure 3C: La Nina Conditions in the Pacific Ocean

Seasonal Wind

Season is very unique characteristics that we observe in an annual cycle. Due to this, the wind pattern changes very significantly almost all over the globe. The pattern of wind circulation is modified in different seasons due to the shifting of regions of maximum heating, pressure and wind belts. The most pronounced effect of such a shift is noticed in the monsoons. Monsoon is a seasonal changing pattern of winds. It is very significant at a very large scale. The details about this is not given right now here. It will be discussed with reference to the study about our county. Hence, can study in another module. The other local deviations from the general circulation system are as follows.

Local Winds

Differences in the heating and cooling of earth surfaces cause changes in the wind patterns. These changes can be observed on daily or annual basis. Important among them are discussed below.

Land and Sea Breezes

The heating and cooling process of land and water is quite different. Land is heated very quickly with greater heat absorption within very thin layer of the earth. The effect of heating is very low on water. Due to evaporation, heat is transferred to the atmosphere by latent heat. Another reason is, the penetration of heat transfer is to a greater depth in water. Therefore, the water is cool in comparison to land, though the insolation is the same over both piece of surface. During the day, the land heats up faster and becomes warmer than the sea. Therefore, over the land the air rises giving rise to a low pressure area, whereas the sea is relatively cool and the pressure over sea is relatively high. Thus, pressure gradient from sea to land is created and the wind blows from the sea to the land. It is called the sea breeze, i.e., the air blowing from the sea (Figure 4A).

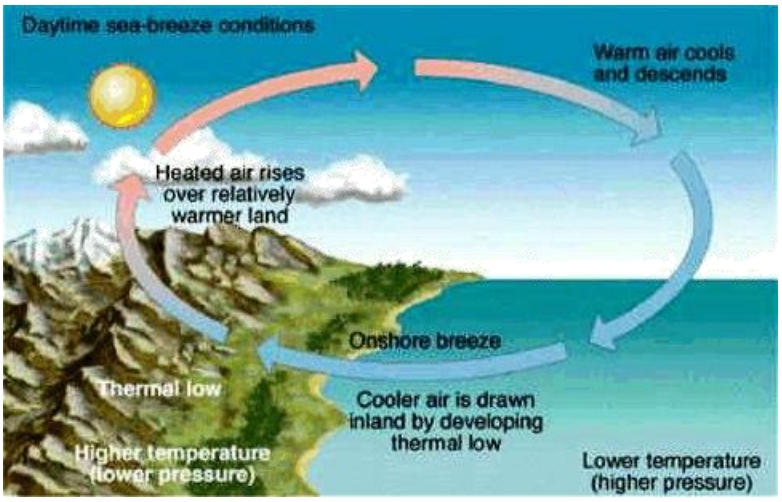


Figure 4A: Sea or Onshore Breeze

Source: http://www.rain.org/~mkummel/stumpers/28mar03b.gif

In the night, the land gets cool quickly than the water body of sea. Since, the land is cool and the sea water is warm, a low pressure is created over the sea. Hence, the wind starts blowing from land (high pressure) to sea (low pressure). This type of wind is called land breeze (wind blowing from land). It is illustrated in the Figure 4B.

Figure 4B: Land or Offshore Breeze

Source:https://laulima.hawaii.edu/access/content/group/2c084cc1-8f08-442b-80e8-ed89faa22c33/book/chapter_4/landbrez.jpg

Mountain and Valley Winds

In mountainous regions, during the day the slopes get heated up. The heated air moves upslope. To fill the temporary vacuum the air from the valley blows upward along the slope. This wind is known as the valley breeze (Figure 5). During the night the slopes get cooled. Cooled air is relatively denser. The dense air descends into the valley from the upslope. It is called as the mountain breeze (Figure 5).

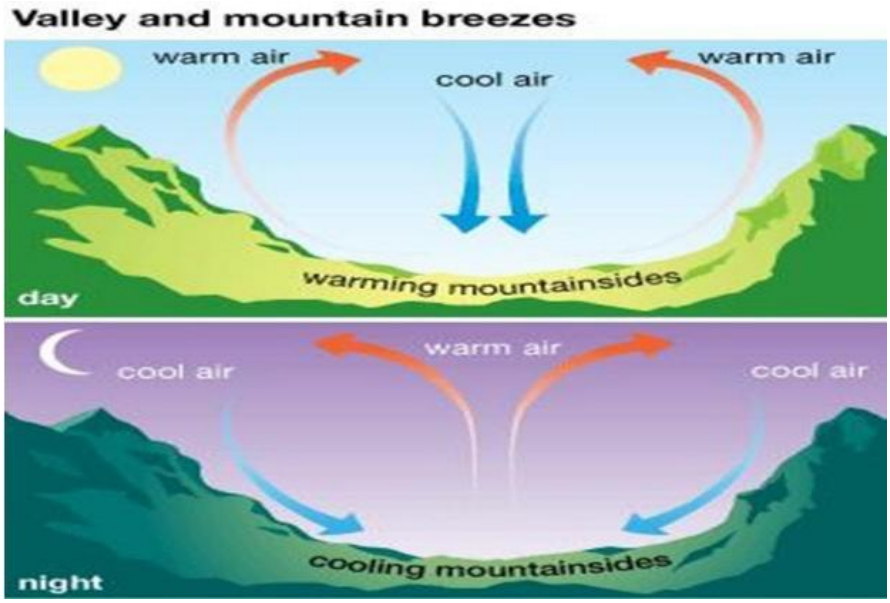


Figure 5: Valley and Mountain Breeze

Source: http://www.drishtiias.com/uploads/article-images/1430113385.Valley%20Breeze.jpg

The cool descending air from the mountain or plateau or from the mountain glaciers to the downslope is called katabatic wind. A parcel of warm air rising from the lower to the higher elevation is known as adiabatic wind. Another type of warm wind occurs on the leeward side of the mountain ranges. The moisture in these winds, while crossing the mountain ranges condense and precipitate. When it descends down the leeward side of the slope the dry air gets warmed up. It happens because of compression of the descending air. Compression leads to reduction in the intermolecular space. Due to this reason, this air is warmed up and does

not leave moisture. Therefore, the leeward side of the mountain slope is dry and semi-desert.

Air Masses

When the air remains over a homogenous area for a sufficiently longer time, it acquires the characteristics of the area. The homogenous regions can be the vast ocean surface or vast plains. The air with distinctive characteristics in terms of temperature and humidity is called an air mass. It is defined as a large body of air having little horizontal variation in temperature and moisture. The homogenous surfaces, over which air masses form, are called the source regions.

The air masses are classified according to the source regions. There are five major source regions. These are: (i) warm tropical and subtropical oceans; (ii) subtropical hot deserts; (iii) relatively cold high latitude oceans; (iv) very cold snow covered continents in high latitudes;

Permanently ice covered continents in the Arctic and Antarctica. Accordingly, following types of air masses are recognised: (i) maritime equatorial (mE) (ii) maritime tropical (mT);

Continental tropical (cT); (iv) maritime polar (mP); (v) continental polar (cP); (vi) continental arctic (cA). The nomenclatures are based on assigning the capital letters to the geometrical division of the earth, like equatorial (E), tropical (T), polar (P) and arctic (A). The area specific characteristics are denoted by small letters like maritime (m) and continental (c). Different types of air masses are shown in Figure 6. Tropical air masses are warm and polar air masses are cold as per the distribution of temperature over the globe.

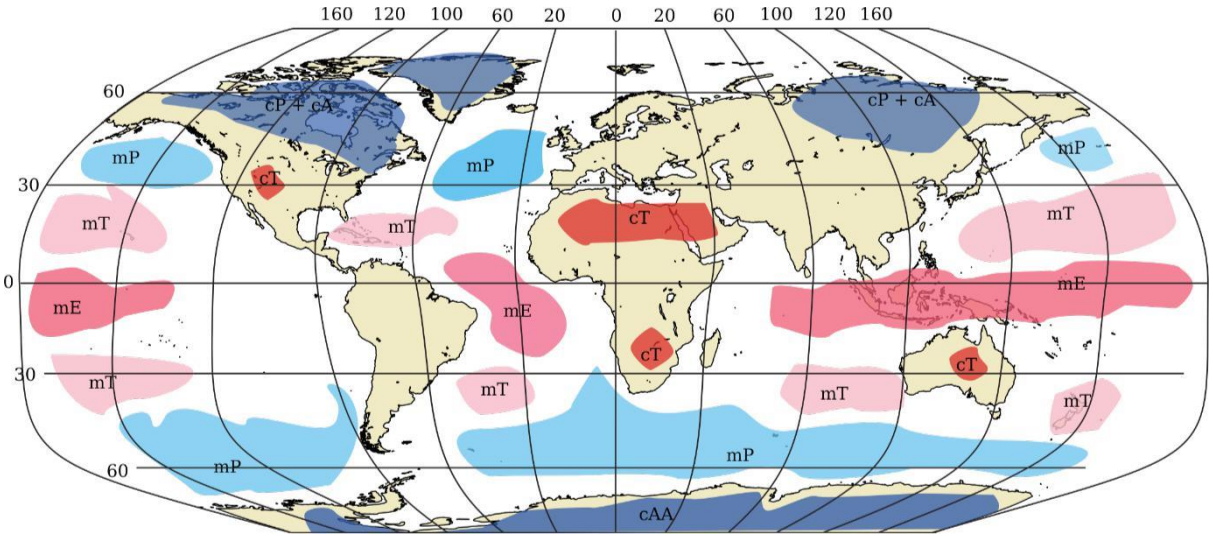


Figure 6: Source Regions of Global Air Masses

Source: https://openclipart.org/image/2400px/svg_to_png/182590/Air%20Masses.png

Arctic, Antarctic, and polar air masses are cold. The characteristics of arctic air is controlled

by the characteristics of the surface over which it develops. Since, the surface is icy/ snow-covered, the air bears its characteristics. Arctic air is deeply cold, colder than polar air masses. Arctic air moves equatorward in summer and modify the area from where it passes. Polar air masses develop over higher latitudes over the land or ocean, are relatively stable. Polar air over the ocean (maritime) loses its stability as it gains moisture over relatively warmer ocean surface.

Fronts

When two different air masses meet, the boundary zone between them is called a *front*. The process of formation of the fronts is known as *frontogenesis*. There are four types of fronts: Cold; (b) Warm; (c) Stationary; (d) Occluded (Figure 7). When the front remains stationary, it is called a *stationary front*. When the cold air moves towards the warm air mass, its contact zone is called the *cold front*, whereas if the warm air mass moves towards the cold air mass, the contact zone is a warm front. If an air mass is fully lifted above the land surface, it is called the *occluded front*.

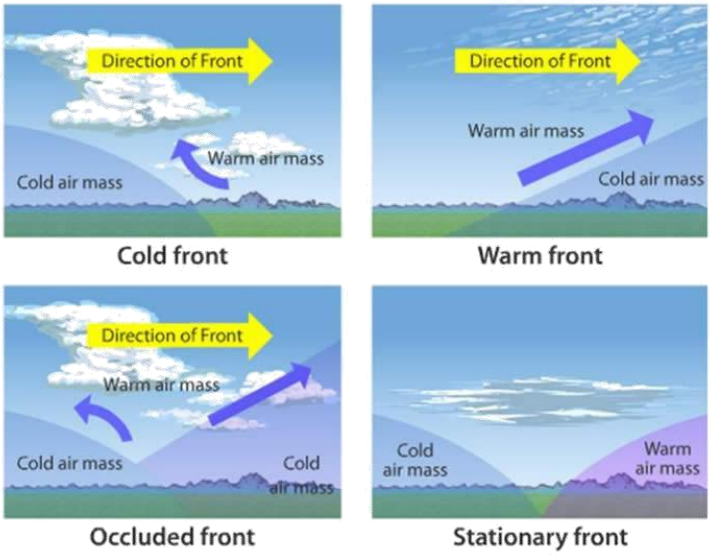


Figure 7: Types of Fronts

Source:https://s-media-cache-ak0.pinimg.com/originals/80/6d/36/806d36c0404d3afec7f55b24615a8092.jpg

The fronts occur in middle latitudes. In this zone, the subtropical air mass and polar air mass meet. Both of these air masses have different characteristics in terms of temperature and moisture. They bring abrupt changes in temperature and cause the air to rise to form clouds and cause precipitation.

Fronts are generally guided by winds aloft, but do not move as quickly. Cold fronts and

occluded fronts in the Northern Hemisphere usually travel from the northwest to southeast, while warm fronts move more poleward with time. In the Northern Hemisphere a warm front moves from southwest to northeast. In the Southern Hemisphere, the reverse is true; a cold front usually moves from southwest to northeast, and a warm front moves from northwest to southeast. Movement is largely caused by the pressure gradient force (horizontal differences in atmospheric pressure) and the Coriolis Effect, which is caused by Earth's spinning about its axis. Frontal zones can be slowed down by geographic features like mountains and large bodies of warm water.

Extra Tropical Cyclones

The cyclonic systems developing in the mid and high latitude, beyond the tropics are called the *middle latitude or extra tropical cyclones*. The passage of front causes abrupt changes in the weather conditions over the area in the middle and high latitudes (Figure 8).

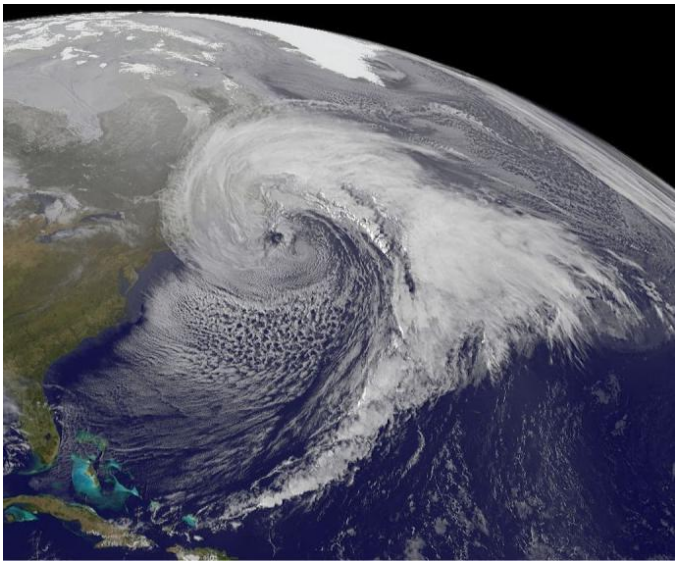


Figure 8: A Panoramic View of an Extratropical Cyclone over North-East USA
Source:https://upload.wikimedia.org/wikipedia/en/9/92/Intense_Nor%27Easter_over_the_N._Alantic_on_Mar_26%2C_2014.png

Extra tropical cyclones form along the polar front. Initially, the front used to be stationary. In the northern hemisphere, warm air blows from the south and cold air from the north. When the pressure drops along the front, the warm air moves northwards and the cold air move towards south. Due to this, anticlockwise cyclonic circulation sets in. The cyclonic circulation leads to a well-developed extra tropical cyclone, with distinct warm and cold fronts. The plan and cross section of a well-developed cyclone is given in Figures 9 and 10.

Figure 9: Development of Extratropical Cyclone

Source: https://www.pmfias.com/wp-content/uploads/2016/01/Temperate-Cyclone-polar-front-theory.jpg

There are pockets of warm air or warm sector wedged between the forward and the rear cold air or cold sector. The warm air glides over the cold air and a sequence of clouds appear over the sky ahead of the warm front and cause precipitation. The cold front approaches the warm air from behind and pushes the warm air up. As a result, cumulus clouds develop along the cold front. The cold front moves faster than the warm front ultimately overtaking the warm front (Figure 10, part a to part f). The warm air is completely lifted up and the front is occluded and the cyclone dissipates.

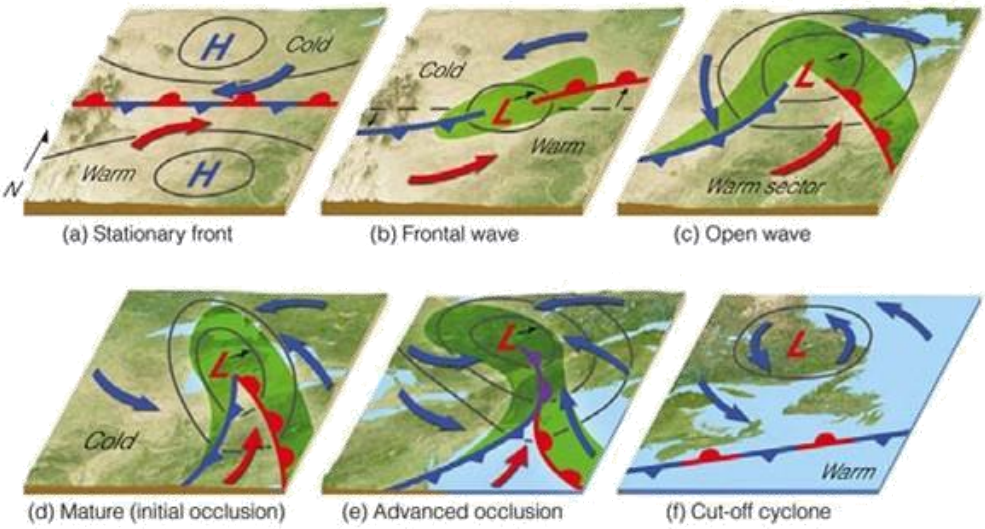


Figure 10: Successive Stages of the Development of Extratropical Cyclone

Source:https://classconnection.s3.amazonaws.com/487/flashcards/1587487/png/cyclogensis1352485600173.png

The processes of wind circulation both at the surface and aloft are closely interlinked. The extra tropical cyclone differs from the tropical cyclone in number of ways. The extratropical

cyclones have a clear frontal system which is not present in the tropical cyclones. They cover a larger area and can originate over the land and sea. Whereas the tropical cyclones originate only over the seas and on reaching the land they dissipate. The extratropical cyclone affects a much larger area as compared to the tropical cyclone. The wind velocity in a tropical cyclone is much higher and it is more destructive.

Tropical Cyclones

Tropical cyclones are violent storms that originate over oceans in tropical areas. They move over to the coastal areas and bring large scale destruction. It is caused by violent winds and very heavy rainfall along the track they follow. The coastal areas are subject to devastation due to huge surge of ocean waves as well which is caused by swiftly moving tropical cyclone. This is one of the most devastating natural calamities. They are known as *Cyclones* in the Indian Ocean, *Hurricanes* in the Atlantic, *Typhoons* in the Western Pacific and South China Sea, and *Willy-willies* in the Western Australia.

Conditions for the Development of Tropical Cyclone

Tropical cyclones originate and intensify over warm tropical oceans. The conditions favourable for the formation and intensification of tropical storms are: (i) Large sea surface with temperature higher than 27° C; (ii) Presence of the Coriolis force; (iii) Small variations in the vertical wind speed; (iv) A pre-existing weak low pressure area or low-level-cyclonic circulation; (v) Upper divergence above the sea level system. In this situation, the water vapour is generated quickly. A vapour laden air rises above. It is done so due to thermos-dynamism. This results in a cyclonic condition, popularly known as tropical cyclone. A schematic representation of the structure of a mature tropical cyclonic storm is shown in Figure 11.

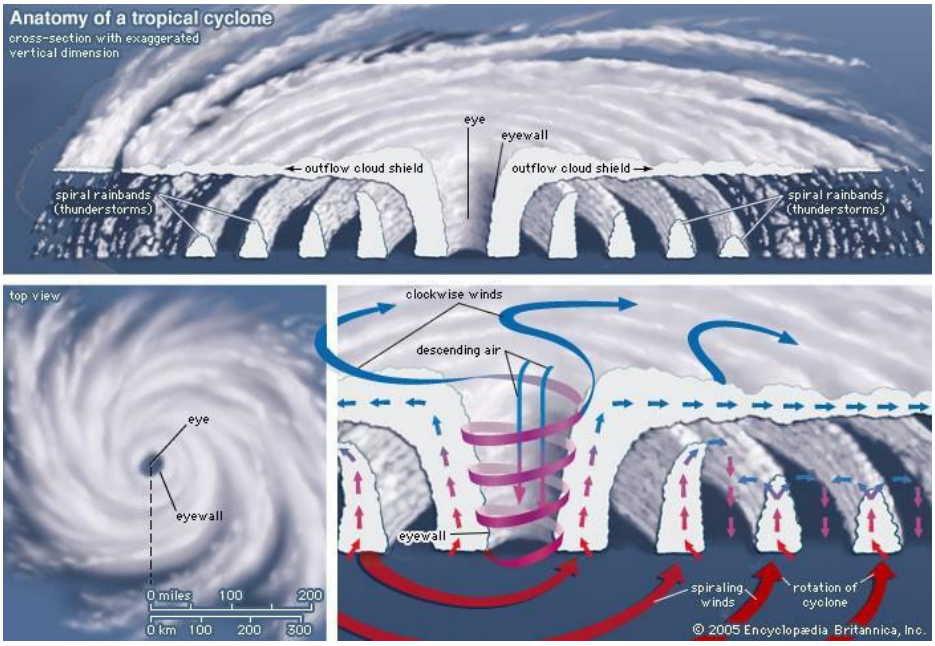


Figure 11: Structure of a Tropical Cyclone

Source: https://www.britannica.com/science/tropical-cyclone

The energy that intensifies the storm, comes from the condensation process in the towering cumulonimbus clouds, surrounding the centre of the storm. With continuous supply of moisture from the sea, the storm is further strengthened. On reaching the land the moisture supply is cut off and the storm dissipates. The place where a tropical cyclone crosses the coast is called the landfall of the cyclone. The cyclones, which cross 20° N latitude generally, recurve and they are more destructive. The tracks of both cyclones Tropical and Extratropical is shown in the Figure 12.

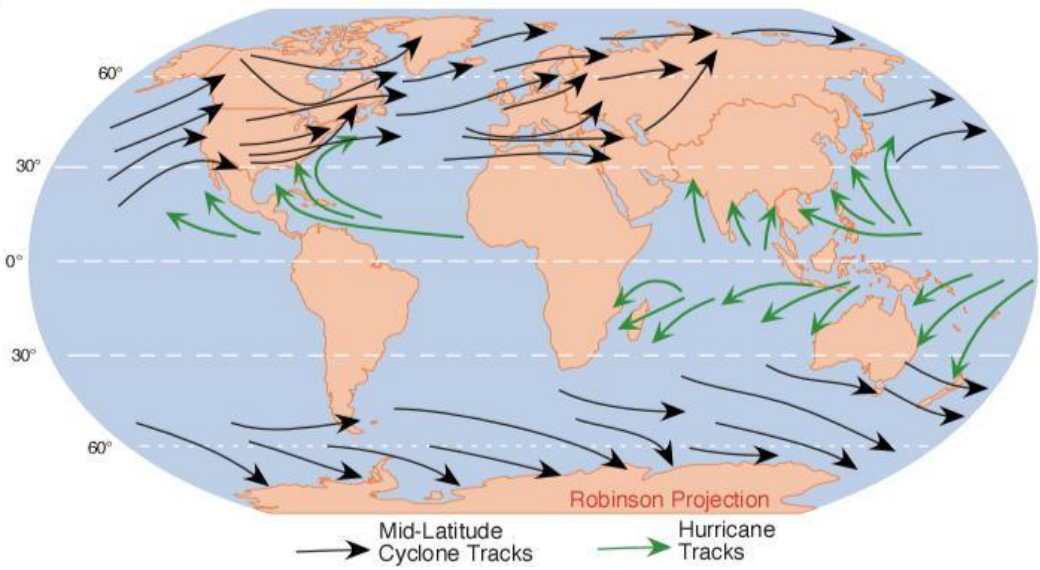


Figure 12: Tracks of Tropical and Extratropical Cyclone

Source: http://www.physicalgeography.net/fundamentals/images/midlatitudecyclonepaths.gif

A mature tropical cyclone is characterized by the strong spirally circulating wind around the centre, called the eye. The diameter of the circulating system can vary between 150 and 250 km.

The eye is a region of calm with subsiding air. Around the eye is the eye wall, where there is a strong spiralling ascent of air to greater height reaching the tropopause. The wind reaches maximum velocity in this region, reaching as high as 250 km per hour. Torrential rain occurs here. From the eye wall rain bands may radiate and trains of cumulus and cumulonimbus clouds may drift into the outer region. The diameter of the storm over the Bay of Bengal, Arabian Sea and Indian Ocean is from 600 to 1200 km. The system moves slowly about 300 - 500 km per day. The cyclone creates storm surges and they inundate the coastal low lands.

Thunderstorms and Tornadoes

Other severe local storms are thunderstorms and tornadoes. They are of short duration, occurring over a small area but are violent. *Thunderstorms* are caused by intense convection on moist hot days. A thunderstorm is a well-grown cumulonimbus cloud producing thunder and lightning. Lightning is a very rapid release of massing electrical discharge in the atmosphere. A part of it may even reach to the ground/ buildings and cause heavy local destruction.

Figure 13: Lightning from the Clouds

Source: http://images.indianexpress.com/2016/06/lioght.jpg

When the clouds extend to heights where sub-zero temperature prevails, hails are formed and they come down as hailstorm. Hailstorm is basically hardened ice produced by very low

temperature condition in certain situation. When this ice balls fall from the atmosphere, they are reduced in size as well due to friction (Figure 14). Therefore, hailstorm is associated by rainfall too. It is very disastrous for standing crops as it damage it almost completely.

Figure 14: Hails at the Ground

Source: https://redcrossdfw.files.wordpress.com/2016/04/hailstorm.jpg?w=648

A thunderstorm is characterised by intense updraft of rising warm air, which causes the clouds to grow bigger and rise to greater height. This causes precipitation. Later, downdraft brings down to earth the cool air and the rain. From severe thunderstorms sometimes spiralling wind descends like a trunk of an elephant with great force, with very low pressure at the centre, causing massive destruction on its way. Such a phenomenon is called a *tornado*. Tornadoes generally occur in middle latitudes. The tornado over the sea is called *water spouts*. Figure 15 shows the waterspout during a tornado at Auckland in February 2012.

Figure 15: Waterspout during a Tornado at Auckland

Source: http://w0.fast-meteo.com/system/images/8688/large/Auckland.jpg?1343397744

These violent storms are the manifestation of the atmosphere's adjustments to varying energy distribution. The potential and heat energies are converted into kinetic energy in these storms

and the restless atmosphere again returns to its stable state.

Conclusions

There are several factors which are affecting the circulation of the atmosphere. Important among them are distribution of insolation and pressure, land-water distribution and rotation of the earth. They are controlling the wind pattern and direction. They are studied in three dimensional perspectives. Hadley, Ferrel and Polar cells are important developments in the troposphere which ultimately give impetus to the air circulation system. El Nino and La Nino are also important for their roles in the climatic pattern of the globe. Since the season is a distinct feature of the climate of the earth, according to seasonal changes, a number of deviations are recorded. Local winds like land breeze, sea breeze, mountain wind and valley wind are some of the features at very small scale. Air masses have important bearing on the climate of the region where they are found and move. Cyclones, both tropical and extratropical, affect the region of their influence greatly. Extratropical cyclones are developed due to the interaction of the two air masses of different characteristics through the formation of fronts. Tropical cyclones develop on the ocean surface in the tropical region except the equatorial belt. Apart from all these thunderstorm, tornadoes, waterspout and lightning have their own significance.

Bibliography:

Barry, RG and RJ Chorley (2010) Atmosphere, Weather and Climate, Routledge: London.

Khullar, DR (2012) Physical Geography, Kalyani Publisher: New Delhi.

Lal, DS (2003) Climatology, Sharda Pustak Bhawan:

Lutgens, FK, EJ Tarbuck and D Tasa (2012) The Atmosphere: An Introduction to Meteorology, PHI Learning Pvt Ltd: New Delhi.

Menon, PA (1989) Our Weather, National Book Trust, India: New Delhi.

NCERT (2006) Fundamentals of Physical Geography, Class IX.

Oliver, JE and JJ Hidore (2011) Climatology: An Atmospheric Science, Pearson: New Delhi.

Siddharatha, K (2016) Physical Geography, Kitab Mahal: Allahabad.

Strahler, AN (1976) Physical Geography, John Wiley & Sons: New York.