Indira Gandhi National Open University
School of Sciences

MGG 005

CLIMATOLOGY

BLOCK

3

ATMOSPHERIC DISTURBANCES

BLOCK 3: ATMOSPHERIC DISTURBANCES

In Block 3, we enquire into the dynamic processes occurring within earth's atmosphere, exploring various atmospheric disturbances and their implications. We will unravel the complexities of humidity, precipitation, monsoon systems, air masses, fronts, and cyclones.

Unit 8 on Humidity and Precipitation delves into the fundamental concepts of moisture in the atmosphere, understanding the mechanisms behind condensation and the diverse forms and types of precipitation.

Unit 9 on Monsoon embarks on a journey to comprehend the complex phenomenon of monsoon, with a special focus on its origin, particularly in the Indian context.

Unit 10 on Air Masses unravels the characteristics and classifications of air masses, exploring their sources and distribution patterns across the globe.

Unit 11 Fronts and Cyclones Dive into the dynamics of fronts, examining their types, formation processes (frontogenesis), and dissipation (frontolysis). Explore the characteristics and impacts of both temperate and tropical cyclones, as well as the opposing phenomena of anticyclones.

After studying this Block, you should be able to:

- describe the fundamental concepts of humidity and precipitation, including the processes of condensation and the various forms of precipitation, and apply this knowledge to interpret global precipitation patterns and the hydrological cycle;
- analyse the intricate mechanisms behind monsoon systems, including their origin and the factors influencing their variability, such as El Nino, La Nina, Walker Circulation, and the Indian Ocean Dipole System, with a specific focus on the Indian context;
- identify and classify different types of air masses, discerning their characteristics and sources, and evaluate their influence on regional weather patterns and climate variability;
- discuss the formation, characteristics, and dynamics of fronts, including the processes of frontogenesis and frontolysis, and analyse their role in shaping weather phenomena such as cyclones and anticyclones; and
- evaluate the impacts of both temperate and tropical cyclones on various geographic regions, assessing their potential hazards and implications for human societies and ecosystems, and explore strategies for mitigating their effects.

Our best wishes are with you in this endeavour.

We suggest for any assistance regarding this course, you can contact satyaraj@ignou.ac.in

MGG 005 CLIMATOLOGY

UNIT 8

HUMIDITY AND PRECIPITATION

Structure

8.1 INTRODUCTION

In the previous blocks we have studied about fundamentals of climatology and atmospheric processes. So now you are acquainted with elements of weather and climate in greater detail. You have studied about insolation and temperature as well as pressure systems. You have also learnt about general atmospheric circulation in the form of winds. So now you are aware how differences in air pressure causes movement of winds. You can also differentiate between prevailing winds, seasonal winds and local winds and explain their importance. You have also learnt how onshore winds bring rain towards the areas they blow. Now in this unit, you will get acquainted with atmospheric moisture which has a tremendous bearing on the weather and climatic conditions of a place and which is an important determinant of humidity, cloudiness, precipitation and visibility.

Humidity refers to water vapour content of air at a particular time and place. Our planet earth is unique in the sense that water exists on it and that too in all the three phases, that is, solid, liquid and gas. An introduction to moisture in the atmosphere, process related to phase changes of water is discussed in Sec. 8.2. In Sec. 8.3, you will get a brief description of distribution of this moisture content. In Sec. 8.4 you will study about hydrological cycle and get acquainted how water in its different forms moves around the earth-atmosphere system through the process of evaporation, condensation, precipitation etc. Condensation and the various forms of condensation is discussed in Sec. 8.5 and 8.6 respectively. Lastly, Sec. 8.7 will acquaint you with different forms and types of precipitation.

Sudeshna Bhattacharya

In the next unit, you will learn about Indian monsoons.

Expected Learning Outcomes

After completing the study of this unit, you should be able to:

- define humidity and explain its importance in earth-atmosphere system;
- describe hydrological cycle;
- analyse the processes leading to condensation;
- compare the processes leading to stability and instability of the atmosphere;
- describe different types of fogs and clouds; and
- describe precipitation and different forms and types of precipitation.

8.2 MOISTURE IN THE ATMOSPHERE

Significance of Moisture in the Atmosphere

There are some interesting facts about moisture present in the atmosphere which is important for you to know. Moisture in the atmosphere is present mainly in the form of water vapour. The existence and distribution of atmospheric water vapour is of fundamental importance to climate. It condenses to form cloud and later precipitates. It absorbs radiation, mainly terrestrial and some solar radiation. The amount of water vapour present in the air varies only from 0-4% by volume. However even this small amount influences the rate of evaporation. Now let us learn about processes involved during phase changes of water.

Phase Changes of Water

Water is the only substance that exists on earth in all the three states, that is, solid, liquid and gas. Ice is the solid state of water and is composed of molecules tightly bound together in a crystalline structure. The change of state from solid to liquid is called melting. During the process of melting, energy is used to breakdown the crystalline structure. As a result, molecules move freely as liquid water. With the addition of more energy the molecules of liquid water become even more widely separated forming unconstrained molecules of water vapour which is the gaseous state of water. The process of conversion of liquid water to water vapour is called evaporation.

Reverse of evaporation is called condensation that marks a change from gaseous to liquid state. Sometimes there is a direct change of state from solid ice to water vapour. This process is called sublimation. Reverse of sublimation is called the deposition. Further change of state from liquid to solid is called freezing. The processes of evaporation, sublimation and melting consume energy while condensation, deposition and freezing release energy. Refer to Fig. 8.1 to get an idea of the entire process. This never ending release and consumption of energy drives the weather engine.

A- Freezing

B- Evaporation

C- Sublimation

D- Condensation

E- Melting

F- Deposition

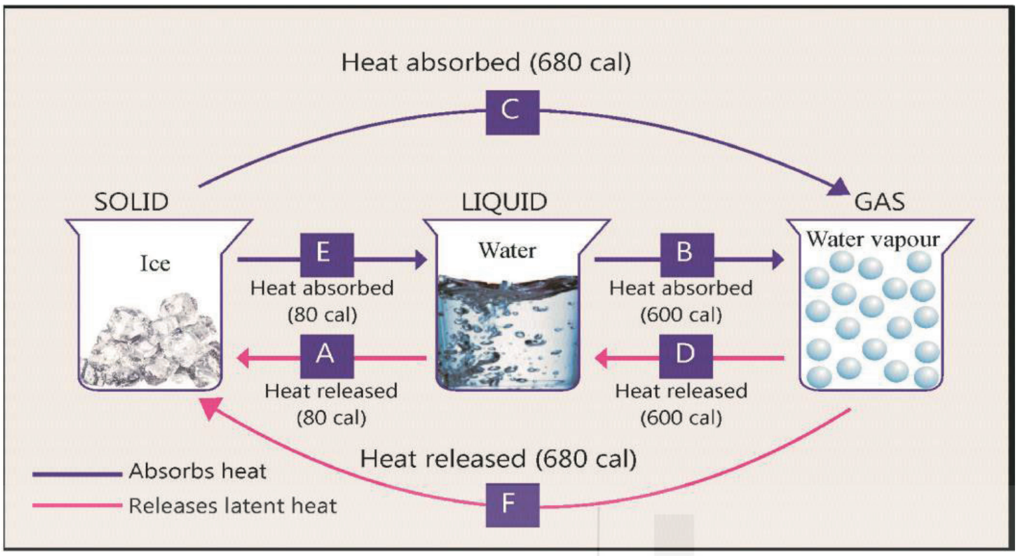

Fig. 8.1: Phase Changes of Water.

Vapour Pressure

We have already studied about atmospheric pressure in the previous unit. Now let us know about vapour pressure. Vapour pressure is the pressure exerted by water vapour in the atmosphere, which is a very small component in comparison to the other gases. The pressure exerted by water vapour may be only about 15/1000th part of the air pressure at a given time and place. There another term called Saturation Vapour Pressure which is the vapour pressure when the air cannot hold anymore water and it is saturated. At this moment evaporation stops. Saturation vapour pressure depends only on the temperature of the air. If the temperature increases, then vapour pressure also increases and evaporation goes on.

Evaporation

You have read that evaporation is the process where liquid water is transformed into gaseous state. It can only occur when water is available. Also the humidity of the atmosphere should be less compared to that of the surface undergoing evaporation. The process of evaporation requires large amounts of energy, for example, the evaporation of one gram of water requires 600 calories of heat energy.

The water vapour content of the atmosphere is in fact maintained by evaporation from oceans, rivers, lakes and other small water bodies. Along with it, transpiration from vegetation and evaporation from moist soil also adds water vapour to the atmosphere. Evaporation and transpiration together is known as 'evapotranspiration'. This is calculated by the formula:

$$ET = P-(R+ dS)$$

Where, 'ET' is evapotranspiration, 'P' is precipitation, 'R' is run-off, and 'dS' is the gain or loss of stored water in soil or water bodies.

Thus we can conclude that the rate of evaporation depends on the following factors:

- The availability of surface moisture,
- water vapour content of the atmosphere,
- temperature of air and the surface from where evaporation occurs, and
- the strength of the wind.

Evaporation occurs as molecules of water escapes into the air and at the same time molecules of gas return to the water. Equilibrium is reached when the number of escaped molecules equals the number of returning molecules. At this point the air is said to have reached saturation. The vapour pressure at this point is known as saturated vapour pressure.

The rate of evaporation depends on source of energy. Thus the potential for evaporation decreases from equator to the poles. But 'actual' evaporation also depends on the availability of water. For example, the Sahara desert has high potential for evaporation as it is in the subtropical region, but it is very low in actual evaporation due to little availability of water there. Therefore, actual evaporation is greater over oceans than over continents. Refer to Fig. 8.2 to understand better. More than two thirds of actual evaporation takes place in the region between 30° North and South latitudes. There is abundant supply of surface water in these regions, along with huge amount of evapotranspiration from equatorial rainforests. Refer to Table 8.1 to get a general picture of mean annual evaporation along different latitudinal zones.

SAQ I

What is evaporation and how does it occur?

Table 8.1: Zonal Distribution of Actual Mean Annual Evaporation in cm

Northern Hemisphere (Latitudes)						
	60°-50°	50°-40°	40°-30°	30°-20°	20°-10°	10°-0°
Continents	36	33	38	50	79	115
Oceans	40	70	94	115	120	100
Mean	38	51.5	66	82.5	99.5	107.5
Southern Hemisphere (Latitudes)						
	60°-50°	50°-40°	40°-30°	30°-20°	20°-10°	10°-0°
Continents	20	50	51	41	90	122
Oceans	23	58	89	112	120	114
Mean	21.5	54	70	76.5	105	118

Now let us get acquainted with some indices of moisture.

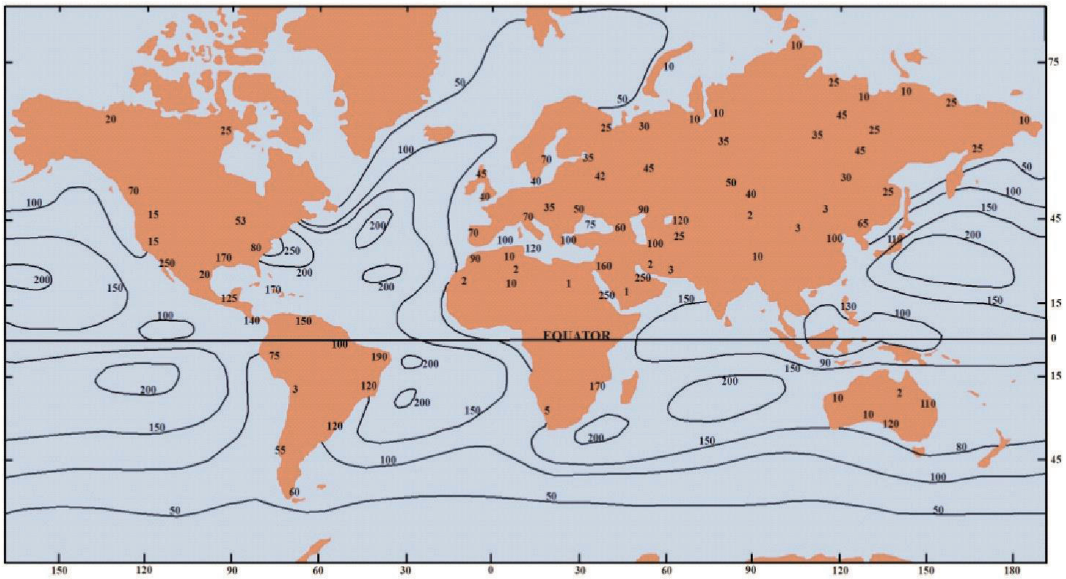

Fig. 8.2: Global Distribution of Mean Annual Evaporation.
(Redrawn from Source: Brittanica.com)

Indices of Moisture

The water vapour content of the atmosphere can be expressed in different ways. They are discussed below.

a) **Specific Humidity:** By Specific humidity, we mean, the ratio of the mass of water vapour present in a unit mass of moist air. This is expressed as gram of water vapour per kilogram of moist air (gm/kg). So if 56 gm of water vapour is present in a kilogram of air then specific humidity of that air is 56gm/kg.

b) **Relative Humidity (R.H):** It is the ratio of the amount of water vapour actually present in a parcel of air at a particular temperature to the maximum amount of water vapour that air could hold. So, it measures how close a given parcel of air is to saturation at a given temperature. It is also expressed as a ratio or percentage of vapour pressure (V.P.) to saturation vapour pressure (S.V.P).

$$R.H = (V.P/S.V.P)*100$$

Relative humidity is highly variable, and changes with variations in temperature. Maximum relative humidity is reached during the morning hours and it decreases as the day proceeds. If the early morning relative humidity is about 100% then it may be 40-50 % in the afternoon. This is basically due to change in temperature, although the actual amount of water vapour in the air may or may not have increased or decreased. Refer to Fig. 8.3 to get a clear picture where the rightmost parcel of air shows 100% R.H. while in the second and third parcel from right, it is seen that though water vapour content is same but R.H. decreases with the increase in temperature. This is because, the parcels are not saturated and their water holding capacity is increased with the temperature increase.

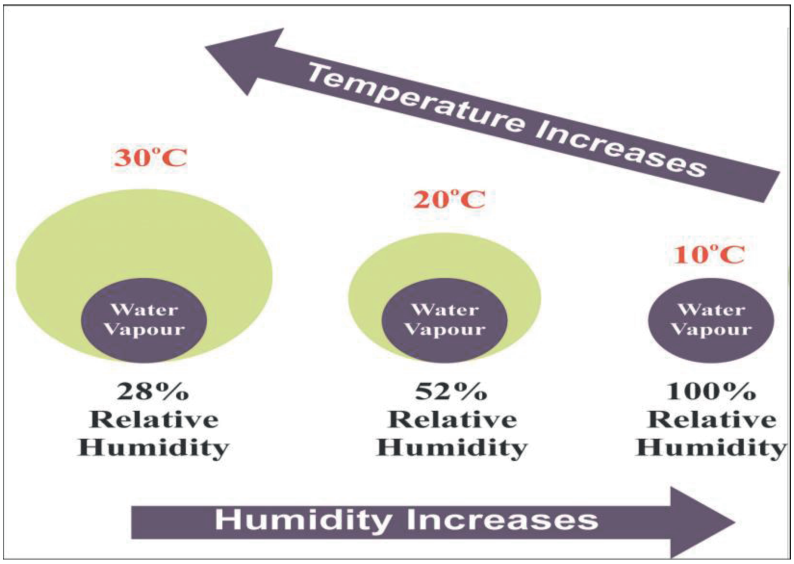

Fig. 8.3: Relative Humidity and Temperature.

Sometimes Absolute Humidity varies with the contraction of air in spite of mass of water vapour being constant. So it is not a precise measure of humidity and thus not preferred by meteorologists.

c) **Absolute Humidity:** It is expressed as the mass of water vapour per volume of air at a given temperature.

d) **Dew Point Temperature:** It is the temperature beyond which air is unable to hold any more water. At this temperature air is saturated or its vapour pressure is equal to saturation vapour pressure. Dew point temperature is expressed in Celsius or Fahrenheit.

e) **Precipitable Water:** It is the measure of water vapour content of the atmosphere, expressed in terms of its equivalent liquid content and so expressed in millimeters.

SAQ 2

If a kilogram of air has the capacity to hold 32 gram of water vapour at 34°C and its relative humidity at this temperature is 25 per cent. Calculate how much water vapour is present in that air at the same temperature.

Measuring the Atmospheric Water Vapour

Those who study climates are more interested in measuring the Relative Humidity of air than any other atmospheric variable as it gives them the clue as to what the weather is going to be in the near future. There are several instruments to measure relative humidity. They are Hygrometer, Psychrometer, Hygrograph and Infra-Red Hygrometer.

Of the names mentioned above, Hygrometer is the most popular instrument which uses a bunch of human hair to measure Relative Humidity. The bunch of hair expands with moisture and contracts when moisture reduces. The reading on a dial is compared to an accompanying table to read Relative Humidity.

Hygrograph is similar to hygrometer but it is can also plot a graph to show relative humidity.

Psychrometres are a pair of thermometers. One records the dew point temperature and the other records normal air temperature. The dew point temperature is recorded on the thermometer which has a piece of cloth tied to its bulb which is kept constantly wet. The ratio between the two readings gives relative humidity.

8.3 DISTRIBUTION OF WATER VAPOUR

Do you know the source of water vapour in the atmosphere? It is from the earth's land-sea surface. Let us now study the distribution of water vapour, both vertical (altitudinal) and horizontal (latitudinal).

A. Altitudinal Distribution

Most of the water vapour is found in troposphere. About half the total amount of water vapour is present within two kilometers from the earth's surface. Above 10 km there is very little water vapour.

B. Latitudinal Distribution

Going by latitudes, water vapour content in the atmosphere is highest near the equator and decreases polewards from equator. This follows the latitudinal distribution of temperature, as the capacity of air to 'hold' moisture depends on air temperature.

During summer temperatures are high and specific humidity, at any latitude, is also higher than in winter. However, in the same latitude there may be variation in specific humidity due to land- sea differences, as well as differences between different land surfaces. Water vapour content of air also varies during the twenty-four hours day and night cycle which is called diurnal variation. During night, the water vapour content over oceans follow temperature variations very closely. Over land, water vapor content rises and dips in twenty- four hours (two maxima and two minima). The specific humidity is at a minimum near sunrise as the temperature is lowest at this time. Water Vapour condenses to form dew, frost or fog. After sunrise, temperature rises, evaporation takes place and water vapour is added back (maximum) to the air. As a result, specific humidity rises. Near midday a secondary dip (minimum) in specific humidity occurs. This is due to heating of the land surface resulting in vertical movement of air and turbulence, which carries away the surface moisture. Later on as the day progresses, turbulence weakens and the water vapour content again increases producing early evening maximum.

Now let us focus on the movement of this water in different realms on earth through hydrological cycle.

8.4 HYDROLOGICAL CYCLE

Hydrological cycle, also known as water cycle, is the continuous movement of water on, above and below the surface of earth through physical processes of evaporation, condensation, precipitation, infiltration, surface run-off and sub- surface flow. During the process there is also change in the form of water from solid (ice) to liquid or gas (water vapour).

Let us understand this from Fig 8.4. In strong sunlight, water evaporates from the oceans and other water bodies. This is taken to be the beginning of hydrologic cycle. Solar radiation also heats the surface of the earth. This in turn heats the air above it, which becomes lighter and rises. Air cools when it reaches the cooler layers of troposphere and its capacity to 'hold' moisture reduces. At one point the air is cooled enough to reach saturation. The water vapour in the air condenses to form clouds. Moisture in the form of clouds is then transported around the world until it returns to the earth's surface as precipitation. When water reaches the ground, some of it may evaporate back into the atmosphere or may go below the surface and become groundwater. Groundwater flows into the oceans, rivers, and streams, or it is goes back to the atmosphere through evaporation from soil and transpiration from vegetation. Some of the water remains on the earth's surface as runoff, which flows into lakes, rivers and streams and is carried back to the oceans, where the cycle begins again.

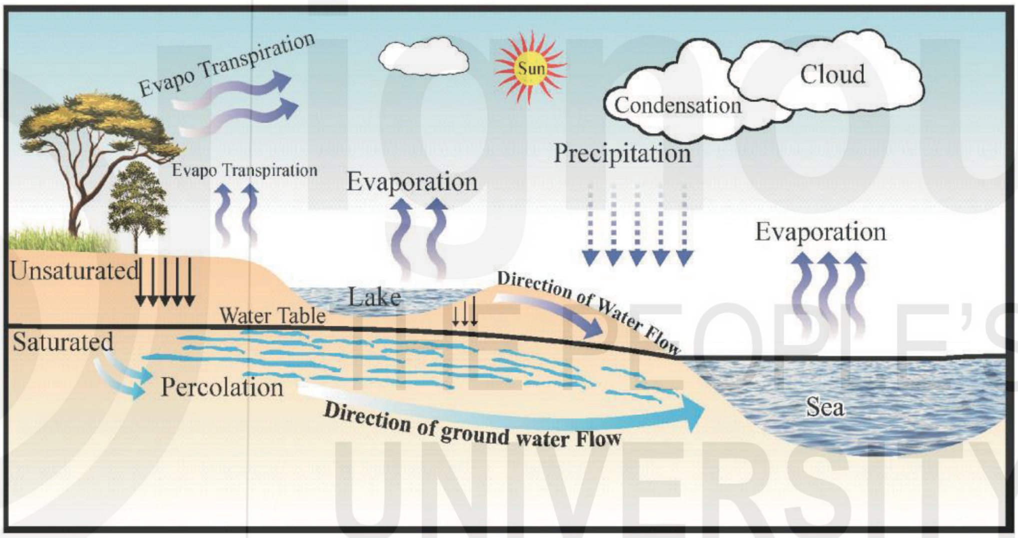

Fig. 8.4: Hydrological Cycle.

Now let us study the process of condensation and precipitation in the coming sections.

8.5 CONDENSATION

Condensation is the process of change of water vapour to liquid state. You have already studied that it occurs when air is unable to 'hold' any more moisture and is cooled to its dew-point temperature. The cooling needed to produce condensation can occur in a number of ways. Let us get a brief idea about them. It may happen:

- when relatively warm, moist air moves over a colder surface;
- when warm moist unsaturated air mixes with colder unsaturated air thus lowering the temperature of the air below its dew-point;
- during cold and long winter nights due to outgoing long wave terrestrial wave terrestrial radiation which cools the land surface and also air in

contact which becomes even colder than the air above it and condensation begins (fog, dew, rime may form in this way); and

- due to upward motion of air, its temperature can fall.

Rime is a coating of ice on grass or trees formed when extremely cold water droplets freeze almost instantly on a cold surface.

When condensation occurs heat is released. This is known as the latent heat of condensation. Let us get acquainted with some other terms related to condensation.

Hygroscopic Nuclei

Condensation does not take place automatically in air even if the air is totally saturated and relative humidity reaches 100%. For the condensation process to begin there must be some kind of a surface on which water can accumulate. The atmosphere contains tiny solid particles on which cloud droplets form. These solid particles are called 'hygroscopic' as they have the affinity to accumulate water around them. Sources of these hygroscopic particles can be both natural and human-caused. Natural sources include volcanic dust, sea spray salt, and bacteria. Human beings release solid particles into the air through fossil fuels, industrial effluents, automobiles etc. Water vapour condenses around them to form photochemical smog.

Surface air heated by the sun expands and becomes light and rises. At higher altitudes it cools and becomes heavy and comes down. On reaching the surface it gets warmed up and rises again and the process continues.

In the mid-latitude frontal zones two air streams of different temperature characteristics come together. The warmer air which is lighter is pushed up by the cooler and denser air. The warm air, which has been forced to rise, cools to its dew point temperature and condensation begins.

Adiabatic Warming and Cooling

When air is said to be warmed or cooled adiabatically, it means that the air does not lose or gain heat by any process. Rather, it gets heated or cooled due to atmospheric pressure changes associated with changing altitudes. An increase in pressure heats up the air adiabatically, while a fall in pressure allows the air to expand and get cooled adiabatically.

So adiabatic cooling occurs when air rises, expands and there is a decrease of barometric pressure. The reasons for air to rise above the surface may be due to convection, convergence of winds along fronts or orographic lifting.

As opposed to the adiabatic process, the ***diabatic processes*** are those in which heat enters or leaves the system. Examples are evaporation, condensation, turbulent mixing, heat conduction, emission and absorption of radiation. For this the established equivalent term **non-adiabatic** is generally preferred because it better emphasises the nature of the processes involved. Diabatic cooling occurs when there is loss of heat by radiation, contact with a cold surface through conduction or mixing with colder air.

Cooling of air due to lifting is a very important climatological process. The **Adiabatic Lapse Rate** is the rate at which unsaturated air cools adiabatically due to fall in air pressure while rising up. It is 10°C /km. At a particular altitude the air would reach its dew point temperature and condensation would begin. With condensation latent heat is released and it further reduces the rate of cooling. This reduced rate of cooling is known as **Moist Adiabatic Lapse Rate.**

Now you need to study about stability and instability of atmosphere because on it depends the weather conditions of a place, especially forms of precipitation etc.

Stability and Instability of the Atmosphere

The air which has a tendency to return to the surface when forced to rise is said to be stable air. Unstable air will go on rising when it is lifted from the surface. Stable and unstable conditions depend on the relationship between the normal lapse rate and adiabatic lapse rate of temperature change, of which the former varies but the latter is always constant.

Normal Lapse Rate is an estimation of the rate of temperature decrease with elevation and it is 6.5°C/1000 m of ascent. The Normal Lapse Rate changes with height, time of day, season etc. This is compared with Adiabatic Lapse Rates to conclude whether the air parcel is stable or unstable.

Air is considered to be stable when the adiabatic lapse rate of air is higher than the normal lapse rate. Take for example, if a parcel of air at ground level has a temperature of 25°C and the dry adiabatic lapse rate is 10°C/km and normal lapse rate is 6.5°C/km. After ascending to an altitude of 1km (1000m), the air will have a temperature of 15°C (25-10= 15°C) while the temperature of the surrounding air and that altitude would be 18.5°C (25 -6.5= 18.5°C). You can see that the temperature of ascending air in this case becomes less than the temperature of the surrounding air. So the ascending air would now descend and become stable. Sometimes normal lapse rate is even less than the moist adiabatic lapse rate that is about 4.6°C (this also has a range {4 -9° C /km} depending on latitude). In such cases all vertical movement of air is stopped and the air becomes absolutely stable.

Instability of atmosphere results when the conditions are quite reverse to the one discussed above. So you can now guess that when normal lapse rate is higher than dry adiabatic lapse rate of ascending air then the air is unstable. For example if a parcel of air at ground level has a temperature of 25°C and the dry adiabatic lapse rate is 10°C/km and normal lapse rate is 11°C/km, then after ascending to an altitude of 1km (1000 m), air will have a temperature of 15°C (25-10= 15°C) while the temperature of the surrounding air and that altitude would be 14°C (25-11 14°C). You can see that the temperature of ascending in air in this case is still higher than the temperature of the surrounding air. So the ascending air would continue to ascend and remain unstable. If the normal lapse rate is more than the moist adiabatic lapse rate, then the air becomes absolutely unstable and the air parcel continues to ascend. Sometimes normal lapse rate is very high. Under such abnormal conditions the upper layers of atmosphere becomes exceptionally cold and dense and starts descending. Such a condition is also called **mechanical instability** and gives rise to **tornadoes** (like cyclones but they are violently rotating column of air, one end of which is attached to the surface of earth the other end to a **supercell** thunderhead). We will study in detail about tornadoes and cyclones at higher levels.

An ascending parcel of air reaches a state of equilibrium when its temperature becomes equal to the temperature of the surrounding air. Now let us get familiar with different forms of condensation.

8.6 FORMS OF CONDENSATION

When condensation occurs due to saturation of air, the condensed water droplets take different forms. The most prominent of these are fog and clouds. The other forms are dew, frost, etc. Let us study about fog and clouds.

8.6.1 Fog and their Types

Fog and clouds both form in a similar manner. The only difference being, that fog forms closer to earth's surface while clouds form at a minimum height of about 200 meters. Fog may be considered as a natural hazard as it disrupts traffic, especially during winters (late nights and early mornings). Due to fog, we often hear of trains running late, aircrafts unable to fly or land on time and various road accidents taking place. Fog is a regular occurrence in and around cities where there is a lot of particulate matter in air from automobile exhausts and domestic fossil fuel consumption which acts as condensation nuclei.

Fog forms when air pressure and water vapour content are constant but the temperature drops below dew-point. Effectively, at this temperature the air is saturated with water vapour which condenses to form water droplets in the presence of hygroscopic nuclei. By definition fog exists when visibility is less than 1000 m and is classed as 'thick fog' when visibility is becomes less than 100 m.

Let us now study different types of fog and their distribution.

a) Radiation Fog

This type of fog forms during long winter nights under clear skies with slight winds. The duration of sunlight hours are shorter during winter. Clear nights help the heat to escape readily from the earth's surface, with the result that the air adjacent to the surface of the earth cools. If a thick layer of moist air is present near the earth's surface, the humidity will reach 100% and fog will form. Slight wind is necessary to raise the fog to some elevation above the surface. Radiation fog varies in depth from a meter to about 300 meters and is always found at ground level. This type of fog can reduce visibility to near zero at times and makes driving very hazardous.

b) Valley Fog

This type of fog is very common in mountainous regions. The air along the ridge tops and upper slopes of mountains begins to cool after sunset, and becomes so dense and heavy that it descends into the valley floors. The descending cold air reduces the temperature of the valley floor where the air becomes saturated and fog forms (see Fig. 8.5). Valley fog can be very dense at times and make driving very hazardous due to reduced visibility. However, it dissipates very quickly once the sun comes up and there is rise in air temperature.

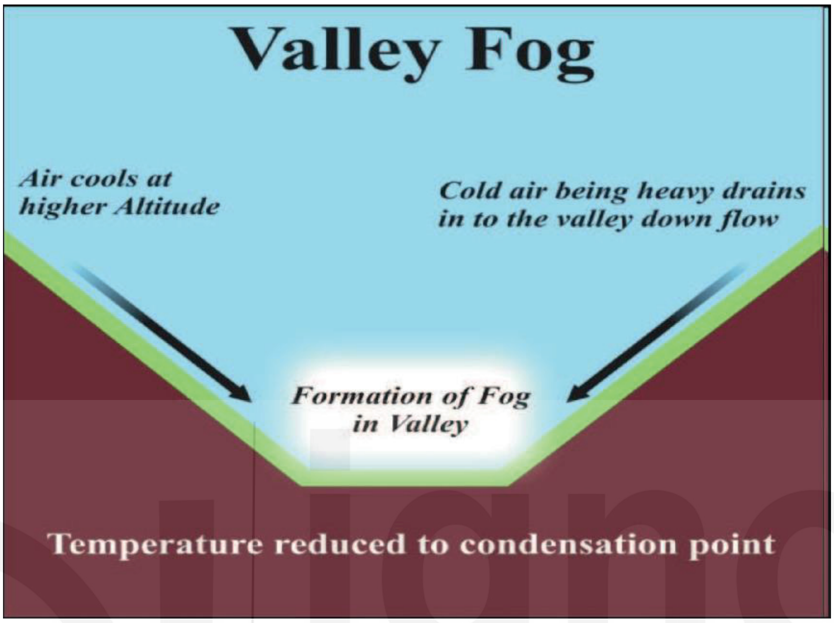

Fig. 8.5: Valley Fog.

c) Advection fog

Advection Fog is also like radiation fog. However, condensation in this case is caused not by a reduction in surface temperature but by horizontal movement of warm moist air over a cold surface. So, advection fog can also be distinguished from radiation fog by its horizontal motion along the ground (Refer Fig. 8.6).

This frequently happens when warm moist maritime or oceanic air drifts over a cold inland area during nights when the temperature of the land drops due to radiational cooling.

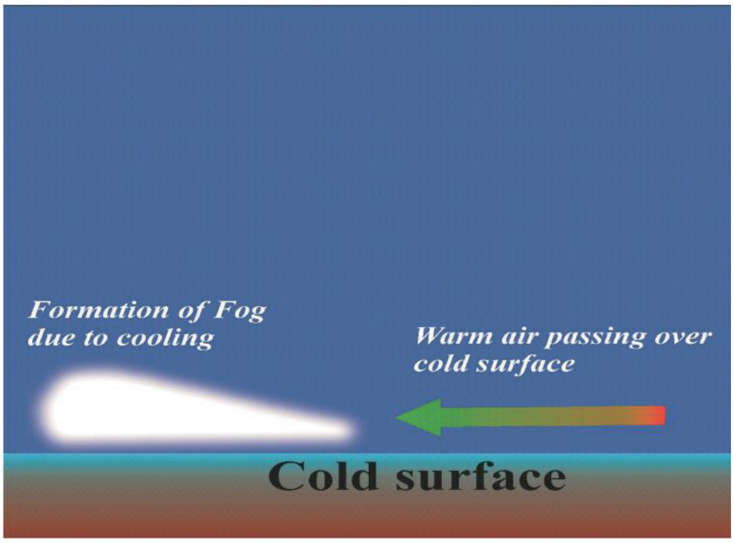

Fig. 8.6: Advection Fog.

d) Sea Fog

Sea fog is a type of advection fog which forms at sea when warm air, associated with a warm current, drifts over a cold current and condensation takes place. Sometimes such fog is drawn inland by low pressure. It occurs often on the Pacific coast of North America.

e) Upslope Fog

Upslope fog forms when light winds push moist air up a hillside or mountainside to a level where air becomes saturated and condensation begins. This type of fog usually forms at a good distance from the peak of the hill or mountain and covers a large area. During the winter months it frequently occurs in the Rocky Mountains, when cold air behind a cold front drifts westwards and encounters the eastward facing slopes.

f) Ice Fog and Freezing Fog

This type of fog forms when air temperature is well below the freezing point and is composed entirely of tiny ice crystals that are suspended in the air. Ice fog can only be witnessed in cold Polar Regions where air temperature is -7°C or even below.

8.6.2 Clouds and their Types

Clouds are another form of condensation and you all are familiar with them. Clouds can be classified into different types depending on their colour, texture, shape or height at which they form. According to colour, clouds can be pristine white to different shades of grey. They can be composed of water droplets, ice crystals or both depending on whether they form close to the earth surface or high above. Clouds are sometimes thin enough to allow the sun or moon to shine through them producing optical effects which make it possible to distinguish between ice crystal and water droplets present in clouds. A halo which is a bright ring or circle of light around the sun or the moon is indicative of a cloud having ice crystals. On the other hand, a corona which is composed of small concentric rings around sun or moon is indicative of a cloud composed of water droplets.

Based on shape, clouds are classified as cirriform (feathery, wispy in appearance), stratoform (arranged in layers) or cumuliform (heaped in appearance).

In order to make a comprehensive classification of clouds the World Meteorological Organisation (WMO) has recognized ten basic types or genera of clouds based on their height from the earth surface. All these ten types contain the terms cirrus, stratus or cumulus.

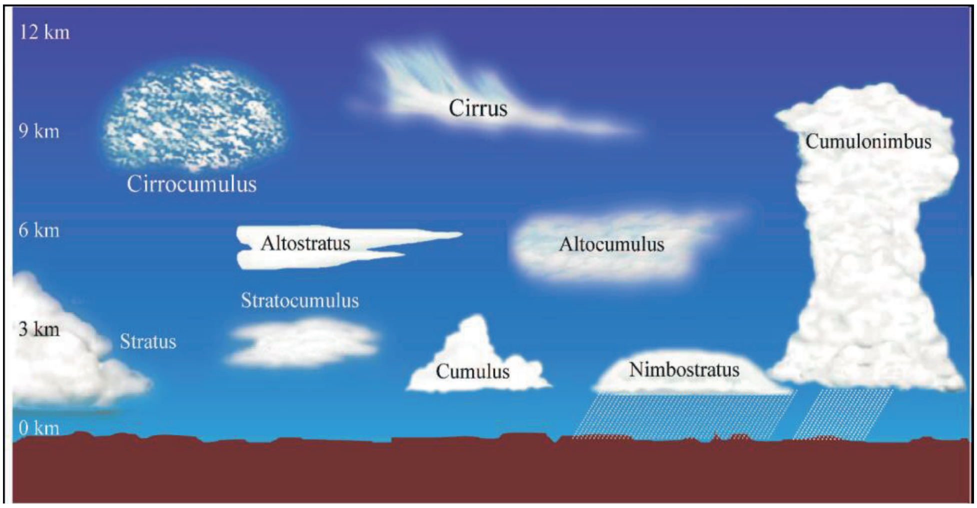

Fig. 8.7: Cloud Types.

So these ten types of clouds are combined in four groups based on their heights above the ground. They are:

- High clouds
- Middle clouds
- Low clouds
- Clouds with vertical development

Refer to Fig. 8.7 while studying different types of clouds.

A. High Clouds

These clouds have bases between 5-14 km. There are three types of high altitude clouds discussed below.

(i) Cirrus (Ci)

These are thin feather-like clouds with a fibrous structure. They have a delicate and silky appearance. They foretell fair weather if arranged irregularly. If systematically arranged in bands, then there would be stormy weather ahead.

(ii) Cirrostratus (Cs)

This is a thin, whitish sheet of cloud covering the whole sky, giving it a milky appearance. This type of cloud commonly produces a halo around the sun and the moon.

(iii) Cirrocumulus (Cc)

These are small white flakes or small globular masses usually without shadows. They are sometimes arranged in groups, lines and ripples resulting from undulations of the cloud sheet. Such an arrangement is called a 'mackerel sky'.

B. Middle Clouds

These are clouds with bases between 2 to 7 km. There are two types of middle altitude clouds.

(i) Altostratus (As)

These are uniform sheets of clouds greyish-blue in colour and usually have a fibrous structure. This type of cloud often merges with cirrostratus. Through it the sun and moon shine faintly. A corona is sometimes present. Widespread and continuous precipitation is common from such clouds.

(ii) Altocumulus (Ac)

They are flattened globular masses of clouds arranged in lines or waves. They are different from cirrocumulus as they have larger globules capable of producing shadows.

C. Low clouds

These clouds have bases typically below 2 km. Under this category there are three types of clouds.

(i) Stratocumulus (Sc)

These clouds have large globular masses. They are soft roll clouds which are usually arranged in a regular pattern.

(ii) Stratus (St)

This is a low uniform cloud layer resembling fog, but not resting on the ground. This type of cloud produces a corona.

(iii) Nimbostratus (Ns)

These resemble a dense shapeless mass of ragged layers of low clouds. Continuous precipitation falls from these types of clouds.

There are also various theories about the formation of precipitation. We would study about them at higher levels.

D. Clouds with Great Vertical Extent

These clouds have bases below 2 km but may rise all the way up to the troposphere. Under this category we have two types of clouds.

(i) Cumulus (Cu)

These are thick dense clouds with vertical development. The upper surface dome is shaped with cauliflower-like structure and the base is nearly horizontal. They are fair weather type of clouds but towering cumulus may develop into cumulonimbus.

(ii) Cumulonimbus (Cb)

These are heavy masses of clouds with great vertical development. The summits are like mountains or towers. It has a characteristic anvil-shaped top. Often these clouds are accompanied by heavy showers, squalls, thunderstorms and hail.

Now let us get acquainted with different forms and types of precipitation

8.7 PRECIPITATION

Precipitation is defined as water in some form, falling from clouds and settling on the earth's surface. It occurs when the condensed moisture droplets or crystals become too heavy to be suspended in the atmosphere. So they fall towards earth as precipitation. As mentioned earlier, it is one of the three main processes of hydrological cycle, the other two being evaporation and condensation which you have already read. Rain, snow, hail, sleet, and freezing rain are all different forms of precipitation. Let us get acquainted with them.

8.7.1 Forms of Precipitation

The different forms of precipitation received by earth depends on the variation of temperature above the surface.

a) Rain: Rain is precipitation in liquid form. In temperate latitudes, rain may begin as snow but if the air temperature near the surface is above freezing, the snow will melt into rain and fall in liquid form.

b) Snow: Snow is precipitation in solid form. If the air temperature is below freezing, then precipitation would be in the form of snow. Ice crystals form (typically) a hexagonal shape. Size and shape of the crystal depend on the moisture content and temperature of the air.

c) Sleet: This occurs when snow falls through a warm layer of air and melts and again passes through a cooler layer of air due to which water refreezes and falls as solid form known as sleet. These are small pellets of ice with diameters about 5mm or less.

d) Freezing Rain: This occurs when snow melts upon passing through a warm layer of air and then freezes on the surface whose temperature is at or below freezing.

e) Hail: Hail falls as large pellets or balls of ice having diameters about 5-50mm. Hailstones form due to up and down movement of moisture laden air inside a cumulonimbus cloud. Cloud droplets freeze when they reach temperatures below freezing and then melt and then refreeze once more and the process goes on as air moves up and down through the storm. This creates concentric rings of ice inside the hailstone.

f) Drizzle: Drizzle are extremely minute droplets of water having a diameter of about 0.5 mm or even less which fall continuously from the low stratus clouds. However, the amount of water that has fallen is significantly low in this case.

8.7.2 Types of Precipitation

There are three distinct ways that precipitation may occur. These include orographic, convective and cyclonic type of precipitation. Convective precipitation is generally more intense, and of a shorter duration, than cyclonic or orographic precipitation. Let us discuss them all.

a) Orographic Precipitation

This occurs when moist air is blown over by the prevailing winds and is forced to rise up a mountain or plateau barriers obstructing it. As the rising air cools it condenses to form clouds and leads to precipitation. This type of rainfall is common in the Western Ghats and in the northeastern parts of our country. Refer to Fig. 8.8 for this type of rainfall. Most of the rain falls on the windward slope, while the other side of the slope, that is, the leeward slope is dry.

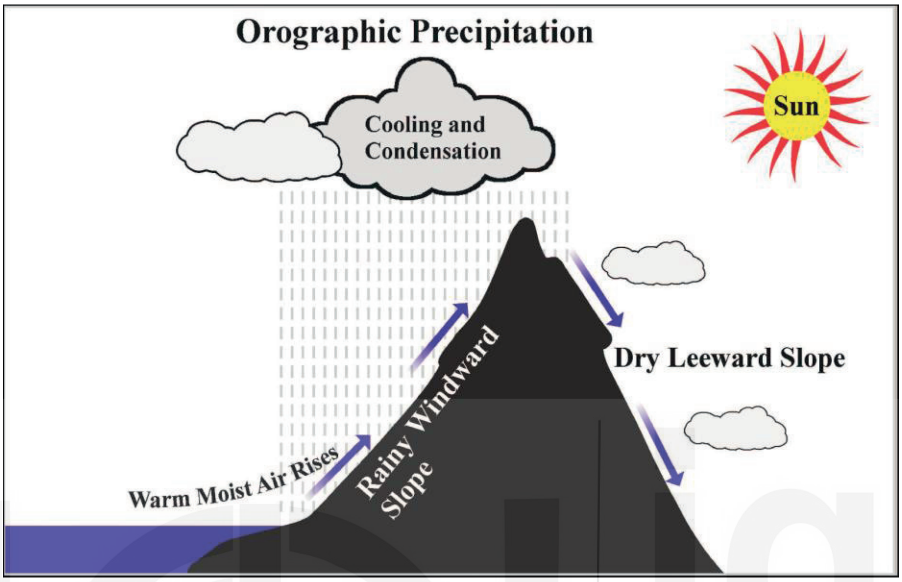

Fig. 8.8: Orographic Precipitation.

b) Convective Precipitation

Convective precipitation occurs usually in equatorial regions which receives huge amount of insolation and has high humidity levels. Due to intense heating of the ground, the air in contact with the ground gets heated, expands and rises. This ascending air cools due to dry adiabatic lapse rate and at a point it becomes saturated. Cumulonimbus clouds form and results into heavy downpours accompanied by thunderstorms, especially in the afternoon. Please refer to Fig. 8.9 to understand better. Convective precipitation also occurs in tropical, subtropical and temperate regions during summer. However, in temperate regions the rainfall is for a longer duration and is not that heavy.

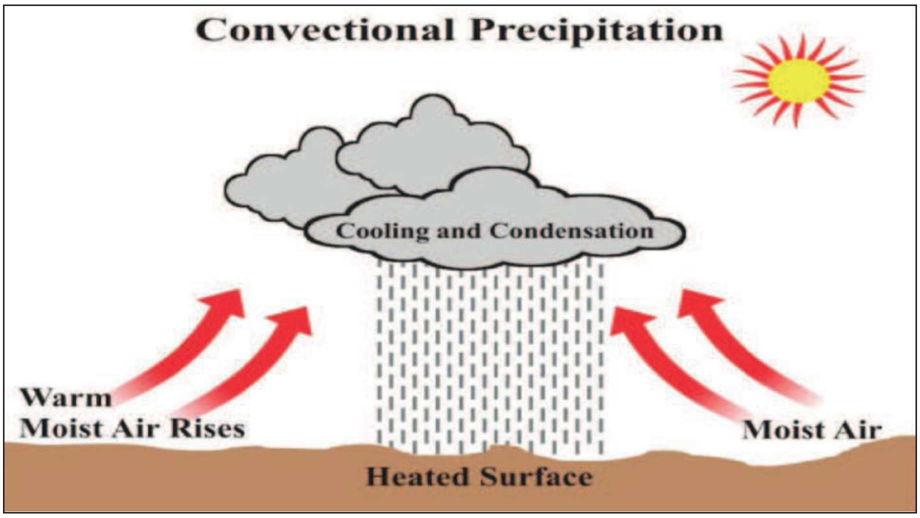

Fig. 8.9: Convectional Precipitation.

c) Cyclonic Precipitation

Cyclonic precipitation is typically associated with frontal regions in the mid-latitudes. This happens when warm air is pushed up above a wedge of cooler air. It is a common occurrence when warm tropical air is undercut by cooler polar air. As rising warm air cools, clouds form and precipitation falls over a wide area. In India, the north-western region gets this kind of precipitation during winter, which is also known as 'western disturbance'. Refer to Fig. 8.10 to understand better.

We would discuss cyclones and anti- cyclones in detail at higher levels. However, a brief introduction has been given to you in the previous unit.

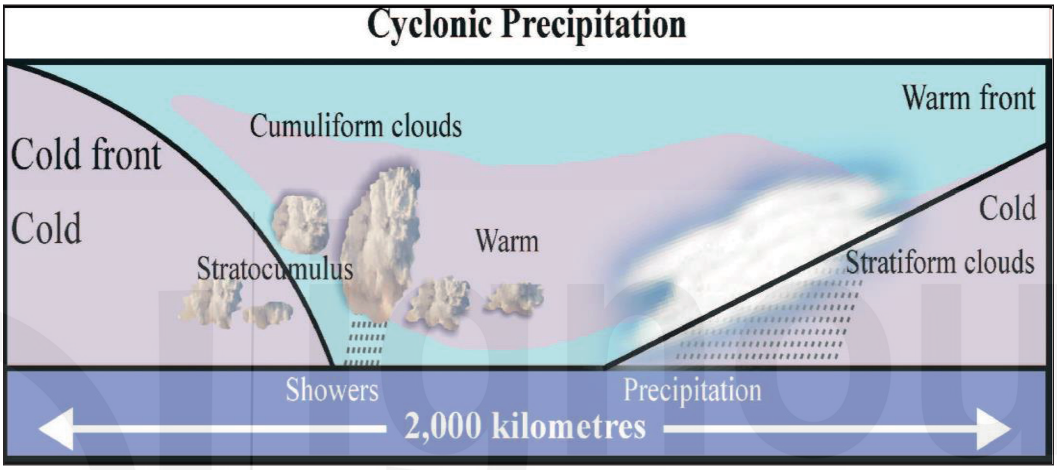

Fig. 8.10: Cyclonic Precipitation.

SAQ 3

a) How does Convective Precipitation occur?

b) What is the difference between halo and corona?

8.8 SUMMARY

In this unit you have studied so far:

- The presence of water in the atmosphere is a major determinant of weather. Its presence in all the three forms in the earth-atmosphere system drives the weather engine. There is constant consumption and release of energy as water changes its form from solid to liquid, to gas and vice versa.
- Water is present in the form of water vapour, which ranges between zero percent, in the driest air, to only about three to four percent in moist air.
- The content of water vapour in the atmosphere can be expressed in several ways, among which specific humidity, relative humidity are the variables of interest to the climatologist.
- The hydrologic cycle defines how water in its three forms moves around in the earth-atmosphere system. Evaporation occurs from evaporating surfaces like oceans, rivers, lakes, ponds as well as soil and vegetation

and changes water into gaseous form called water vapour. By the process of condensation, water vapour in the atmosphere changes to water droplets around hygroscopic nuclei. The water droplets aggregate to form fog, clouds and other condensation forms.

- The clouds precipitate water droplets as well as snow or ice when the air is unable to 'hold' them any more as they may have grown in size and have become too heavy. The air that rises is labelled as unstable or stable depending on the way it goes up when it is forced to rise. The rising air will cool and condense to form clouds which would ultimately lead to precipitation.
- To sum up, water or moisture in the atmosphere is the reason for all weather phenomena affecting the inhabitants of the earth's surface.

8.9 TERMINAL QUESTIONS

1. What do you understand by stability or instability of atmosphere?
2. Write a brief note on different types clouds.
3. Describe different types of fogs and explain why is fog considered as a natural hazard, while clouds are not, considering the mode of formation for both being same?
4. What are the different types of precipitation? Explain with suitable figures.

8.10 ANSWERS

Self-Assessment Questions (SAQ)

1. Evaporation is the process by which liquid is transformed into gaseous or vapour form. When the liquid is heated, it absorbs heat and gets energy required to escape from the surface of the liquid and become gas. Heat absorbed in the process of evaporation is called the latent heat of vapourisation.
2. a) 8g b) R.H.= (x/32)* 100; x = 8g
3. a) Convective precipitation occurs usually in equatorial regions due to intense heating of the ground. The air in contact with the ground also gets heated, expands and rises. This ascending air cools due to dry adiabatic lapse rate and at a point it becomes saturated. Cumulonimbus clouds form and heavy downpours accompanied by thunderstorms occur especially in the afternoon.

   b) A halo is a bright ring or circle of light around the sun or moon and is an optical phenomenon produced by ice crystals. Thus it is indicative of the presence of clouds composed of ice crystals. A corona, on the other hand consists of small concentric rings around sun or moon produced by diffraction of light from the celestial body by individual small water droplets. Thus it is indicative of the presence of clouds composed of water droplets.

Terminal Questions

1. Explain the concept of stable and unstable air giving examples as given in Sec. 8.5 of this unit.
2. First define clouds and then classify the clouds as per altitude. Then describe different types of clouds under each category as in 8.6.2 of this unit.
3. First define fog and describe different types of fog. Then explain why it is hazardous. Refer to section 8.6.1 of this unit.
4. First define precipitation and then go to describe their types with figures. Refer to section 8.7.2 of this unit.

8.11 REFERENCES AND SUGGESTED FURTHER READING

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UNIT 9

MONSOON

Structure

9.1 INTRODUCTION

In the previous unit, you have learnt about general atmospheric circulation and got the knowledge about planetary and seasonal winds. The upper atmospheric circulation jet streams and tri-cellular meridional circulation of winds help to understand the process of monsoon. In this unit you will learn about the origin of Indian Monsoon and factors governing the monsoon.

We all know that Monsoon is a climatologically complex phenomenon. The word "Monsoon" is derived from the Arabic word ***'mausim'*** which means season. This word was firstly used by Arabian sailors for seasonal change of blowing winds in Arabian Sea. During the winter season winds blown from north-east to south-west and in summer from south-west to north-east direction (reversal of wind direction is 180°) which you will study in sec. 9.2. There are many factors affecting the monsoon which you will study in sec.9.3. The El Nino and La Nina phenomenon will discuss in sec.9.4 and 9.5. Then we describe the Walker circulation and Southern Oscillation in sec.9.6 and 9.7 respectively. Finally, the concept of El Nino - Madoki and Indian Ocean Dipole which affects the monsoon will discuss in sec. 9.8 and 9.9 respectively.

In the next unit, you will study about Air Masses, its classification and global distribution.

Kailash Nath Singh

Expected learning Outcomes

After studying this unit, you should be able to:

- outline the different processes involved in origin of monsoon;
- explain the action of El Nino and La Nina phenomenon which affects the Indian monsoon;
- describe the Walker circulation and ENSO;
- analyse the changing conditions of El Nino Madoki phenomenon in south Pacific Ocean and
- discuss the Indian Ocean Dipole system and how to affects the Indian Monsoon.

9.2 ORIGIN OF MONSOON WITH SPECIAL REFERENCE TO INDIA

Monsoon is a complex process in which many factors have a combined contribution rather than the contribution of any one component. A number of concepts and theories put forth by climatologists to explain its origin. The ***Thermal concept*** is also named as ***'Classical Theory'*** propounded by *Edmund Halley* in 1686 to explain the origin of Indian Monsoon. He hypothesised that the primary cause of the annual cycle of the Indian monsoon is the deferential heating effect of the land and the sea. According to him monsoons are the extended land breeze and sea breeze on a large scale, produced by the deferential heating of the continents and the ocean basins. During the summer season in the northern hemisphere, when the sun is northward, the Indian part, especially the North-West India, starts heating up rapidly and develops strong low-pressure center near Peshawar (Pakistan) and lake Baikal (Siberia). Due to extreme heat till the month of June, low air pressure develops in North-west part of India, at the same time there is a development situation of high pressure in the Indian Ocean. As a result, the winds blow from high pressure from southern part of the Indian Ocean to low pressure area of Indian subcontinent. The winds coming from ocean towards the land is warm and moist. Due to the presence of land barriers such as Western Ghats and Himalayan ranges that come in the way of the moisture laden winds, they ascend and result into condensation and precipitation over the land. During the winter season the high-pressure areas develop near Peshawar (Pakistan) due to the low temperatures, while the Indian Ocean remains relatively warm having low pressure area. Consequently, the winds blow from high pressure areas of land towards the sea. As these winds are cold and dry, these are incapable to give precipitation during the winter season.

The ***dynamic concept*** about the origin of monsoon was propounded by *Flohn* in 1951. According to him monsoon is the result of seasonal migration of planetary winds and pressure belts. The Inter-Tropical Convergence Zone (ITCZ) is formed due the convergence of north-east and south-east trade winds near the equator. It shifts along with the sun's position during the summer season the sun's rays are vertical over Tropic of Cancer; the North Inter-Tropical Convergence (NITC) is extended up to 30°N latitude covering

South and South-East Asia. You may easily understand the shifting of ITCZ through Fig. 9.1. The equatorial westerlies become south west or summer monsoon winds and affect the Indian subcontinent. The NITC is responsible for development of tropical cyclones which yield heavy rainfall during wet monsoon months (July to September). Similarly, in winter season low pressure area is developed in the southern hemisphere the north-east monsoon is north-east trade winds which are reestablished over South and South-East Asia due to shifting of pressure and wind belts (ITCZ). Thus, the Indian subcontinent receives the lower rainfall or is generally dry during the winter season.

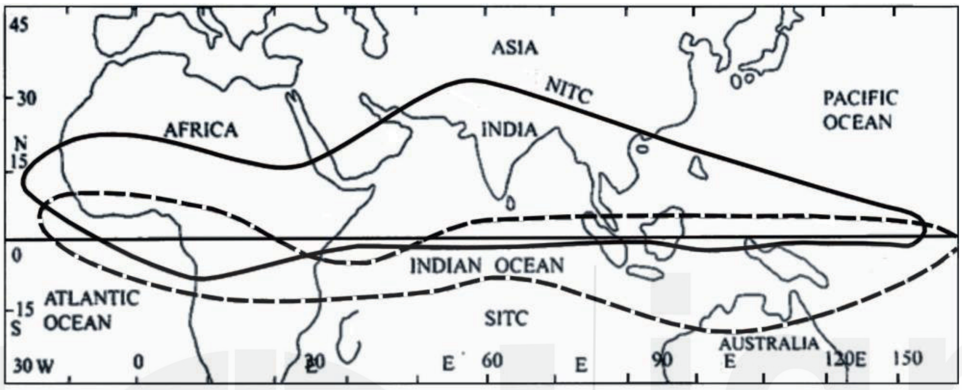

Fig. 9.1: Shifting of ITCZ during summer and Winter Season.

Members of the Indian and Russian expedition teams, i.e. scientists from *MONEX*, observed the phenomena of the monsoon in Indian Ocean and the Arabian Sea. On the basis of the data obtained, scientists arrived at the conclusion that the Tibetan Plateau plays a crucial role in initiating the monsoon circulation over the Indian subcontinent. In 1958 *Dr. P. Koteshwaram* had expressed his views that the summer time heating of Tibetan Plateau was the most important factor in the causation of the monsoon circulation. According to him Tibetan plateau, being 5000 meters high, receives more heat from the Sun; as a result, low pressure develops. Tendency of low air pressure is to pull the winds from the oceanic high pressure area. The Tibetan Plateau affects the monsoon into two ways, acting separately or in combination, that is, it acts as a physical barrier and well as a high-level heat source.

The word 'Monsoon' derived from an Arabic word 'Mausim', means the rhythm of season. With the apparent movement of sun, northwards or southwards, the air circulation changes twice in a year. The seasonal shift of direction of winds is called monsoon. Indian monsoon can be easily understood by dividing it into different seasons.

Summer Season: On March 21, the sun shines directly on the equator and due to the rays of the sun vertical on the Indian land, the amount of insolation intensifies. The jet stream is bifurcated by the Tibet plateau in winter and this southern jet stream continues to flow from west to east in the upper troposphere over the Gangetic plain till 15 May. The Sun crosses the equator and shines vertically in north hemisphere after the month of March. Due to the reception of excessive sunlight by the Indian land, the heat starts increasing. In the months of April and May, the air starts heating up in North and West

India which is located away from the sea. But due to the presence of jet streams above, the hot dry air is not able to rise up instead of the air moves from west to east on the surface. These surface hot dry blowing winds are called as ***'Loo'*** in North India. At the time when the heat wave prevails in North India, the ITC expands in South India and the northern branch of ITC extends near the Tropic of Cancer and the Southern branch near the equator till the month of May. In between of them, the slow westerly wind blows from west to east in the Arabian Sea and the wind rises slowly with the help of the west slopes of the hills of the Western Ghats and makes light rain in the form of a shower, it is called ***Mango shower*** in South India. Any time after 15th May, there is a sudden disappearance of jet streams from the south of Himalayas, because here the hot winds continuously uprise and pushes the jet streams upwards. As a result, the sudden withdrawal of jet streams from the south of the Himalayas creates a huge sucking point in the upper troposphere. To fill this void, the surface winds start uprising very fast and from the oceanic part i.e. the Bay of Bengal and the Arabian Sea and the hot humid winds move rapidly towards North India. Due to the position of West Bengal close to the ocean and the Himalayas, the hot humid winds coming from the Bay of Bengal rise up rapidly and condensation starts. Due to this short-term torrential rain here by the cumulonimbus clouds, the thunder of clouds and flashes of lightning cause loss of life. This event is called ***Kaal Baisakhi or burst of monsoon.***

Summer Monsoons- Due to abrupt withdrawal of jet streams in the last week of May, the westerly winds of the ITC zone over the Indian Ocean move rapidly towards North India. As a result, the southeast trade winds blowing south of the equator, which used to warm up south of the equator, cross the equator to fill the gap in the Arabian Sea and the Bay of Bengal, with the southwest monsoon winds. As it starts moving from southwest to northeast towards the Indian subcontinent between 60°-90° east longitude and reaches Kerala coast between June 1 and June 10. This is called the arrival of monsoon, after that these monsoon winds enter the Indian land in the form of two branches i.e. Arabian Sea branch and Bay of Bengal branch.

The winds running from the Arabian Sea reach the Western Ghats, raining in the western part of the Western Ghats like Gujarat, Maharashtra, Madhya Pradesh, and Rajasthan. The winds blow from Bay of Bengal branch, over the Meghalaya plateau, come out of the active route due to the inverted funnel shaped structure in between the Khasi and Jaintia hills, Mawsynram located there receives the highest rainfall in the world. In North-east India, Monsoon strikes and spreads over most of the area by the month of June, and traverses westwards in Ganga Plain parallel to the axis of the Himalayas. It reaches West Bengal and Bihar by the month of July. Consequently, it covers Jharkhand, Chhattisgarh, MP, UP, Haryana, Punjab by August and September. Normally, its withdrawal begins from northwestern part of the country by mid-September.

Retreating Monsoon- In the last phase, in the month of September (22 September), the sun starts shining again at the equator. After that the sun starts moving towards the southern hemisphere. ITC is completely removed from the Indian sub-continent. After that South India, is covered under the influence of the north-east trade winds. In October and November, the North

East trade winds bring rain over the "Coromandel Coast", which is called *"retreating monsoon".*

At this time, along with the trade winds, the monsoon winds returning to North India crosses the trade winds in the Arabian Sea and the Bay of Bengal, due to which the tropical cyclones originates in the Indian Ocean. These are called *"tropical cyclones".*

Winter Monsoon- As the sun starts moving towards the Tropic of Capricorn in the southern hemisphere, the air belts shift from 5^o to 10^o south. As a result, the western wind belt shifts to the south i.e. Rajasthan, Haryana, that is, the plains of the Ganges come under the influence of westerly wind flow. At the same time, south of the Himalayas, the southern branches of the jet streams form in the troposphere over the Gangetic plain. Westerlies winds which run over the Mediterranean Sea, enters in India after traveling a long-distance carrying humidity with it. Due to the formation of upper jet streams, westerlies are not able to rise up, but due to the formation of low air pressure over the Tibetan plateau, it rains through "condensation" while climbing up from the southern slopes of the Himalayas, which is called *"Western Disturbance"* in winter season. The rainfalls of winter season cover Rajasthan, Punjab, Haryana, Kashmir, Ladakh, Himachal Pradesh, Uttar Pradesh, Madhya Pradesh, Uttarakhand and Bihar. Patna is the eastern boundary of winter month rainfall. During winter season India receives only 2- 5% of the rain falls in the winter monsoon. Due to cooling of land surface and presence of jet streams in upper atmosphere, it moves in the form of westward wave, which is called "cold wave".

SAQ I

a. What is MONEX?

b. Define the Inter-tropical convergence Zone.

c. What is ‘Mango Shower’?

There are various factors affecting monsoon. These are thermal anomalies over land and water surface, shifting of wind belt and ITCZ which we have already studied so far. We need a detailed description of factors like Jet streams, El- Nino, Southern Oscillation, La-Nina, El- Nino Madoki and Indian Ocean Dipole, which we will do in the coming sections.

9.3 JET STREAMS AND INDIAN MONSOON

Jet streams are the most prominent upper atmospheric westerly winds flowing as irregular meandering bands of geostrophic winds travelling at the speed of 300 kmph (Kilometre per hour). It flows at a height of 7000-12000 meters between in the form of Polar Jet as well as Tropical Jet in northern hemisphere. The jet stream is extended up to upper atmosphere over the Gangetic plain during the winter season (October- February). In the winter season, jet streams are bifurcated into two branches due to the height of Himalayas. One is located at the south of Himalayas and other is positioned in the north of Tibetan plateau. Consequently, the winds tend to descend down over the north-western part of India resulting into the development of atmospheric stability and dry conditions. The westerlies moist wind blows from the Mediterranean Sea reaches to north-west part of India and is responsible for rain during the winter months. In the northern hemisphere during the summer season low pressure areas develop in the north-west parts of India due to intense heating of ground surface during the month April and May. But as long as the position of the upper air jet stream is present in upper atmosphere to south of Himalayas, the winds descend from the upper air high pressure obstructs the ascent of winds from the surface low pressure areas with the result that the weather remains warm and dry. These warm and dry winds blow in northern part of Indian subcontinent, these winds are called *Loo*. The jet stream restricts the monsoon winds over the Indian subcontinent till the 20th may. You may learn from the Fig.9.2 which depicts the position of winter and summer jet streams over the Indian sub-continent.

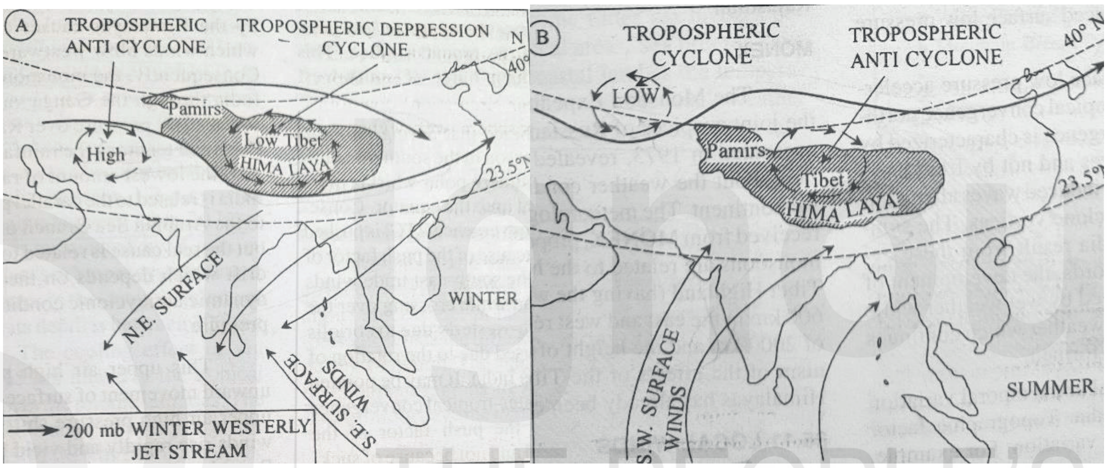

Fig. 9.2: The Position of Jet Streams in Winter and Summer Season.
(Source: Tiwari, R.C. Geography of India, p.109)

SAQ 2

Define Jet streams.

9.4 EL-NINO AND THE INDIAN MONSOON

The Indian monsoon is also influenced by El-Nino and southern oscillation. El-Nino, meaning (*the little boy)* is the name given to the occasional development of warm ocean surface waters along the coast of Ecuador and Peru. When this warming occurs the usual upwelling of cold, deep ocean water with rich nutrients is significantly reduced. El Nino means the Christ Child, and was used because the phenomenon often arrived around Christmas. A warm ocean current flows along the Peruvian coast, in place of the cold Peruvian current for every 2 to 7 years. The sudden increase of sea surface temperature is about 2°- 4°C. Hence, the phenomenon is referred as ENSO (El Nino and Southern Oscillation). El Nino has an impact on ocean temperatures, speed and strength of ocean currents, health of coastal fisheries, and on local weather which extend from Australia to South America. El Nino events occur irregularly with 2-7 years interval. El Nino was recognised by fishermen off the coast of Peru as the appearance of unusually warm water. It is called El Nino, meaning *“little boy”* in Spain. El Nino soon became to be described as irregular and intense climate changes rather than just the warming of coastal surface waters.

During an El Nino event, westward-blowing trade winds weaken along the Equator. These changes in atmospheric air pressure and wind speed cause eastward movement of warm surface water along the Equator, from the western Pacific to the coast of northern South America. These warm surface waters push the thermocline deeper. A thermocline is the transition layer between the warmer mixed water at the surface and the cooler deep water below. During an El Nino event, the depth of thermocline slopes downwards as far as 152 meters (500 feet).

This thick layer of warm water does not allow normal upwelling to occur. Without an upwelling of nutrient-rich cold water, the euphotic zone of the eastern Pacific can no longer support its normally productive coastal ecosystem. Fish populations die or migrate. El Nino has a devastating impact on Ecuadorian and Peruvian economies. Due to El Nino, rainfall increases drastically in Ecuador and northern Peru, contributing to coastal flooding and erosion. Rains and floods may destroy homes, schools, hospitals, and businesses. They also limit transportation and destroy crops.

As El Nino brings rain to South America, it brings droughts to Indonesia and Australia. These droughts threaten the region’s water supplies, as reservoirs become dry and rivers carry less water. Agriculture is threatened due to lack of water for irrigation. In Indian sub-continent, monsoon weakens due to El Nino condition in Pacific Ocean.

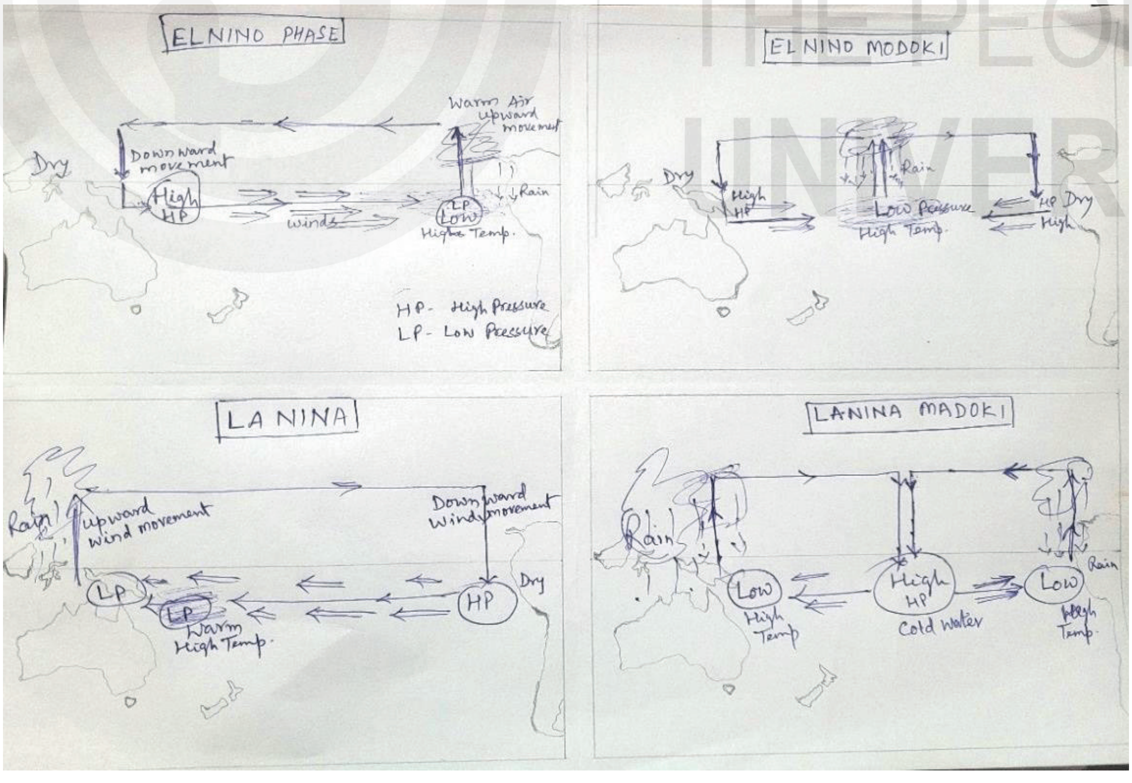

Fig. 9.3: Various Phases of El Nino, El Nino-Madoki and La-Nina. (Created by Author)

SAQ 3

What is El-Nino?

9.5 WALKER CIRCULATION

The walker circulation is caused by the pressure gradient force that results from a high-pressure system over the eastern Pacific Ocean, and a low-pressure system over Indonesia. The walker circulation of the tropical Indian, Pacific and Atlantic basins result in westerly surface winds in northern summer in the first basin and easterly winds in the second and third basins. As a result, the temperature structure of the three oceans displays dramatic asymmetries. The equatorial Pacific and Atlantic both have cool surface temperature in northern summer in the east, while cooler surface temperature prevails only in the western Indian Ocean. These changes in surface temperature reflect changes in the depth of the thermocline.

Normal Conditions

In a normal year, a surface low pressure develops in the region of northern Australia and Indonesia and a high-pressure system over the coast of Peru. As a result, the trade winds over the Pacific Ocean move strongly from east to west.

The easterly flow of the trade winds carry warm surface waters westward, bringing convective storms (thunderstorms) to Indonesia and coastal Australia. Along the coast of Peru, from bottom of the ocean cold water with rich nutrients upwells up to the surface to replace the warm water that is pushed to the west.

Normally the trade winds and strong equatorial currents flow towards the west. At the same time, an intense Peruvian current causes upwelling of cold water along the west coast of South America.

Walker Circulation (Occurs during Normal Years)

The Walker circulation (walker cell) is caused by the pressure gradient force that results from a high-pressure system over the eastern Pacific Ocean, and a low-pressure system over Indonesia. The Walker cell is indirectly related to upwelling off the coasts of Peru and Ecuador. This brings nutrient-rich cold water to the surface, with enormous fishing stocks. Fig. 9.4 reflects the position of thermocline. (Thermocline is a temperature gradient in a lake or other body of water, separating layers at different temperatures.)

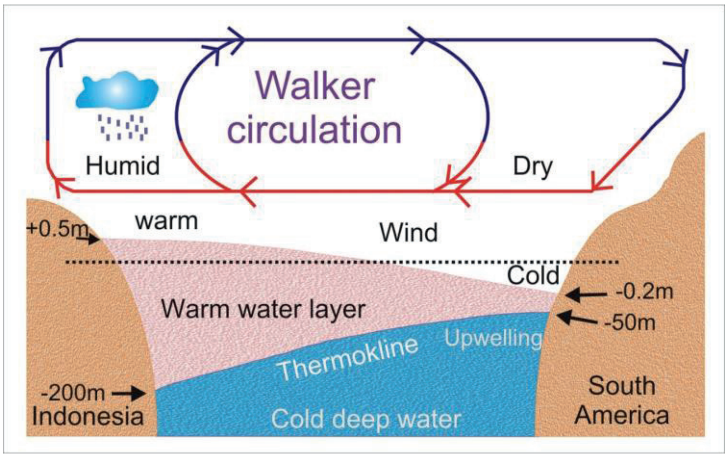

Fig. 9.4: Walker Circulation.

The Southern Oscillation is a change in air pressure over the tropical Pacific Ocean. When coastal waters become warmer in the eastern tropical Pacific Ocean (due to El Nino), the atmospheric pressure above the ocean decreases. Climatologists define these linked phenomena as El Nino-Southern Oscillation (ENSO).

9.6 EL NINO SOUTHERN OSCILLATION (ENSO)

The formation of an **El Nino** is linked with Pacific Ocean circulation pattern known as the **southern oscillation.** Southern Oscillation is a coherent inter-annual **fluctuation of atmospheric pressure** over the tropical Indo-Pacific region. It can be well explained through the Fig. 9.6. El Nino and Southern Oscillation (SO) coincide most of the times; hence their combination is called *ENSO.* SO exhibits a see-saw pattern of meteorological changes observed between the Eastern Pacific and Western Pacific. When the pressure was low over equatorial Eastern Pacific, it was high over the equatorial Western Pacific-ocean. The pattern of low and high pressures gives rise to vertical circulation along the equator with its rising limb over eastern pacific coast (Peruvian cost) and descending limb over Australian coast. This is the difference in pressure between *Tahiti* in French Polynesia (Central Pacific), representing the Central Pacific Ocean and *Port Darwin*, in northern Australia representing the Western Pacific Ocean. This is known as southern oscillation which is opposite condition of walker circulation. It shifts eastward from its normal position. During the El Nino years, monsoon rainfall is reduced in India. The periodicity of SO is not fixed and its period varies from two to five years.

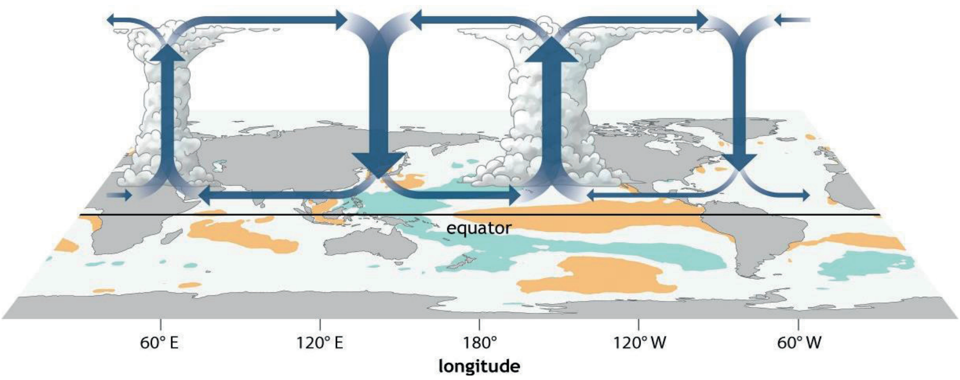

Fig. 9.5: El-Nino Condition.
(Source: NOAA Climate.gov drawing by Fiona Martin)

Effects of El Nino

The warmer waters had a devastating effect on marine life existing off the coast of Peru and Ecuador. Fish catches off the coast of South America were lower than in the normal years (due to absence of upwelling). Severe droughts occur in Australia, Indonesia, India and southern Africa and heavy rains in California, Ecuador, and Gulf of Mexico. El Nino and Indian monsoon are inversely related.

The most prominent droughts in India occurred since 1871 have been El Nino droughts, including the recent ones in 2002 and 2009. However, not all El Nino years led to a drought in India. For instance, 1997/98 was a strong El Nino year but there was no drought (Because of Indian Ocean Dipole (IOD)). On the other hand, a moderate El Nino in 2002 resulted in one of the worst droughts. El Nino directly impacts India's agrarian economy as it tends to lower the production of summer crops such as rice, sugarcane, cotton and oilseeds.

9.7 EL NINO MODOKI

El Nino Modoki is a coupled ocean-atmosphere phenomenon in the tropical Pacific. It is different from another coupled phenomenon in the tropical Pacific namely, El Nino. Conventional El Nino is characterised by strong anomalous warming in the eastern Equatorial Pacific. The El Nino Modoki phenomenon is characterised by the anomalously warm central equatorial Pacific, flanked by anomalously cool regions in both west and east as explained through the Fig. 9.7. Such zonal gradients result in anomalous two-cell Walker Circulation over the tropical Pacific, with a wet region in the central Pacific.

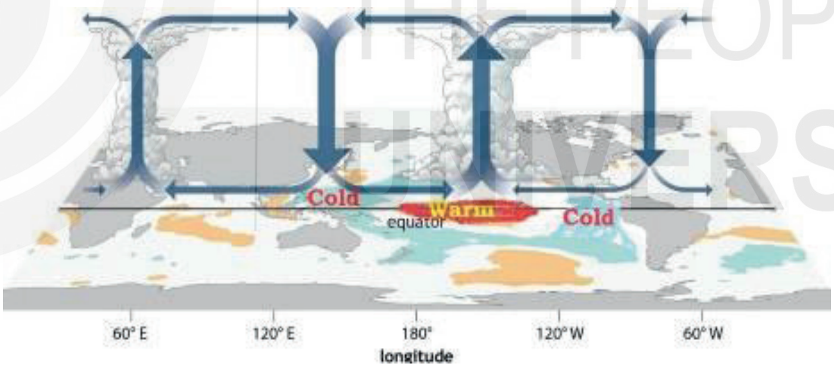

Fig. 9.6: El-Nino Madoki.
(Source: NOAA Climate.gov drawing by Fiona Martin)

9.8 LA NINA

After an El Nino event, weather conditions usually return back to normal. However, in some years the trade winds can become extremely strong and an abnormal accumulation of cold water can occur in the central and eastern Pacific. This event is called a *La Nina,* can be understood by the Fig 9.8.

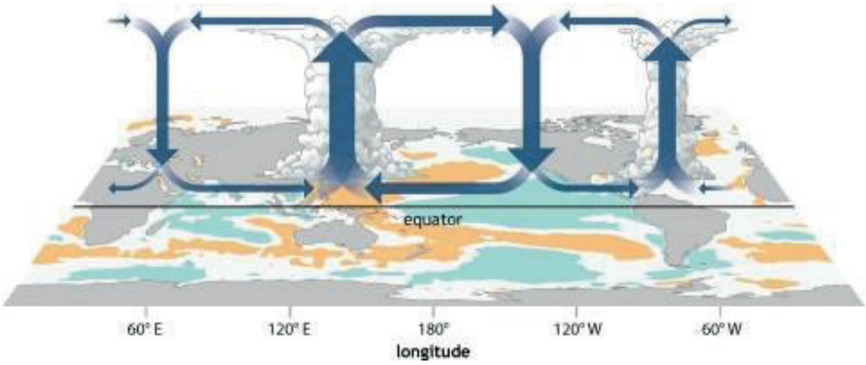

Fig. 9.7: La Nina. (Source: NOAA Climate.gov drawing by Fiona Martin)

Effects of La Nina

Some of the other weather effects of La Nina include:

- abnormal heavy monsoons in India and Southeast Asia,
- cool and wet winter weather in southeastern Africa, wet weather in eastern Australia,
- cold winter in western Canada and northwestern United States,
- winter drought in the southern United States.

9.9 INDIAN OCEAN DIPOLE

The Indian Ocean Dipole (IOD) is defined by the difference in sea surface temperatures between two areas (or poles, hence a dipole) – a western pole in the Arabian Sea (western Indian Ocean) and an eastern pole in the eastern Indian Ocean south of Indonesia. IOD develops in the equatorial region of Indian Ocean from April to May peaking in October. You can easily understand the position of positive and negative IOD with the map from Fig. 9.9.

- With a ***positive IOD*** winds over the Indian Ocean blow from east to west (from Bay of Bengal towards Arabian Sea). This results in warming of the Arabian Sea (western Indian Ocean near African Coast) cooling and dryness in the eastern Indian Ocean around Indonesia becoming colder and dry. Positive IOD (Arabian Sea warmer than Bay of Bengal) results in the frequency of more cyclones in Arabian Sea.

- In the negative dipole year (***negative IOD***), reverse conditions happen. Indonesia becomes much warmer and rainier. While African coast becomes colder and less rainy. Negative IOD results in stronger than usual cyclogenesis (formation of tropical cyclones) of Bay of Bengal. Cyclogenesis in Arabian Sea is suppressed.

It was demonstrated that a positive IOD index often nullifies the effect of ENSO, resulting in increase of monsoon rains in several ENSO years. Similar to ENSO, the atmospheric component of the IOD was later discovered and named as Equatorial Indian Ocean Oscillation [EQUINOO] [Oscillation of warm water and atmospheric pressure between Bay of Bengal and Arabian Sea].

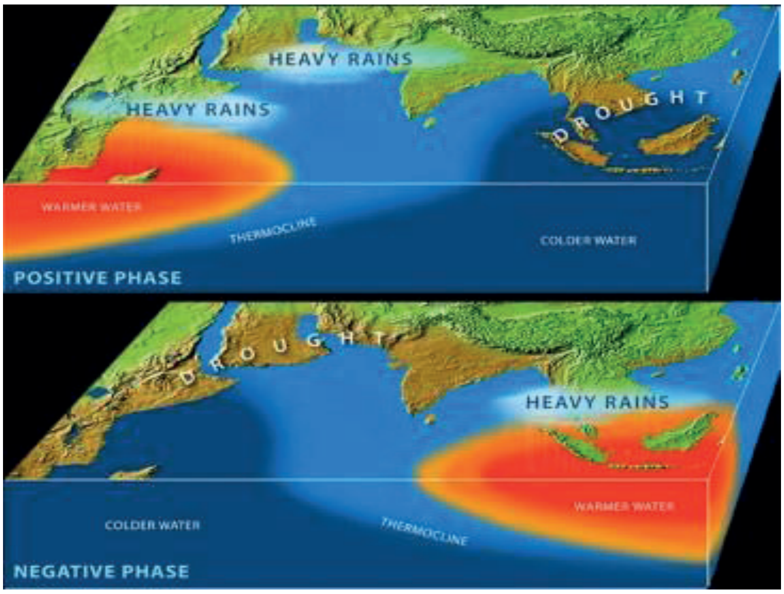

Fig. 9.8: Positive and Negative Indian Ocean Dipole.
(Source: http://www.whoi.edu as mentioned in https://discovery.ucl.ac.uk/id/eprint/10133324/9/Roy_Chapter11_Kriplani.pdf)

How Does Madden-Julian Oscillation (MJO) affect Indian Monsoon?

The Indian Ocean Dipole (IOD), El Nino and Madden-Julian Oscillation (MJO) are all oceanic and atmospheric phenomena, which affect weather on a large scale. IOD only confines to the Indian Ocean, but the other two affect weather on a global scale-up to the mid-latitudes. When it is over the Indian Ocean during the Monsoon season, it brings good rainfall over the Indian subcontinent.

On the other hand, when it witnesses a longer cycle and stays over the Pacific Ocean, MJO brings bad conditions for the Indian Monsoon.

9.10 SUMMARY

Let us now recapitulate what we have learnt in this unit.

The origin of Indian Monsoon is a complex phenomenon. There are so many factors are responsible for its origin. The heating factors such as and cooling of land surface, role of Tibetan plateau, seasonal shifting of ITCZ and Jet streams directly affects the origin of Indian Monsoon. Likewise, summer monsoon remains active due to normal condition of Walker movement and positive *IOD (Indian Ocean Dipole) condition.* But due to the change in wind circulation in the South Pacific Ocean due to the occurrence of El Nino, that is, due to the opposite condition of the Walker circulation, the monsoon weakens and drought conditions occur in the Indian subcontinent, it is called the *Southern Oscillation or El Nino.* When El Nino ends suddenly, South East Asia receives more rain than usual condition. This event is called as *"La Nina".*

9.11 TERMINAL QUESTIONS

1. Discuss the origin of Indian Monsoon with special reference to India.

2. Describe the concept of jet streams. How does it affect the Indian monsoon?
3. Give a detailed account on the impact of South Pacific oceanic circulation on Indian monsoon.
4. How does Indian Dipole system affect the monsoon of Indian subcontinent?

9.12 ANSWERS

Self-Assessment Questions (SAQ)

1. a) MONEX is the Monsoon Expedition which was organised as a joint venture between Soviet Union and India. Under this expedition, four Russian and two Indian ships, equipped with modern scientific instruments were presented into services in the Indian Ocean and the Arabian Sea to investigate the phenomenon of the Indian monsoons. The scientists of MONEX came to the conclusion that the Tibetan Plateau plays a crucial role in initiating the monsoonal circulation over the Indian subcontinent.

   b) Inter-tropical convergence zone is the region that circles the earth, near the equator, where the trade winds of the Northern and Southern Hemispheres converge and rise upward causing a vacuum area called Doldrums or the 'Zone of Calm' up to 5^0 north or south of equator.

   c) Mango Shower, describes the occurrence of pre-monsoon rainfall. They help in the early ripening of mangoes and are hence often referred as "Mango showers". This especially happens in Kerala, Karnataka and parts of Tamil Nadu in India. The mango showers occur as the result of thunderstorm development over the Bay of Bengal. They are also known as 'Kaal Baisakhi' in Bengal, as Bordoisila in Assam, and as 'Cherry Blossom' showers or 'Coffee Showers' in Karnataka.
2. The strong and rapidly moving circumpolar upper westerly air circulation in a narrow belt of a few hundred kilometers width in the upper limit of troposphere is called Jet Streams. These are also called circum-polar whirl because these move around the poles in both the hemisphere. The circulation of jet streams is from west to east in a narrow belt of a few hundred kilometers width at the height of 7.5-14 km in the upper troposphere.
3. El-Nino is considered as a significant weather phenomena or event which occurs off the west coast of South America, mainly off the Peru coast. It is called Christ Child. The cold-water mass near Peruvian coast becomes warm due to strong El-Nino event resulting into heavy rainfall in the first half of the year.

Terminal Questions

1. Describe the origin of Monsoon with special reference to India which is described in detail in sec.9.2 of this unit.
2. Discuss the detail concept of Jet Streams with pictorial presentation and its effect on Indian monsoon which is given in sec. 9.3 of this unit.

3. Explain the effect of South Pacific Oceanic circulation on Indian Monsoon in detail as given in sec. 9.4, 9.5 and 9.6 of this unit.
4. Explain the Indian Dipole System affecting the monsoon in Indian ocean monsoon as given in sec. 9.9 of this unit.

9.14 REFERENCES AND FURTHER SUGGESTED READING

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UNIT 10

AIR MASSES

Structure

10.1 INTRODUCTION

In the previous unit, you have learnt about origin of monsoon and its related phenomena. You may recall unit 7 where we learnt about the general atmospheric circulation and global circulation of winds. These winds are responsible for homogeneous conditions of temperature and humidity over a specific area for the formation of air masses. In this unit, you will learn about air masses, its meaning and definitions in section 10.2. Sources regions of air masses are discussed in section 10.3. We have discussed the characteristics of air masses in section 10.4. The Classification of Air Masses will be discussed on the basis of Geographical situations and thermodynamic conditions in section.10.5. Lastly you may learn the global distribution of air masses in sec. 10.6.

In the next unit you will learn about the formation of Front and cyclones.

Expected learning Outcomes

After studying this unit, you should able to:

- outline the concept of air masses;
- explain the sources and characteristics of air masses;
- describe the classification of air masses; and
- elaborate the regional distribution pattern of air masses.

10.2 MEANING AND DEFINITION

Meaning and Definition: In previous chapter you have learnt about the circulation of wind. You may recall that the large and extensive body of air is

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having homogeneity of temperature and humidity in horizontal and vertical condition.

An Air mass may be defined as a large body of air whose physical properties such as temperature and humidity and lapse rate are uniform horizontally for hundreds of kilometers.

According to *A.N. Strahler* and *A.H. Strahler* "a body of air in which the upward gradients of temperature and moisture are fairly uniform over a large area is known as an *Air mass.* An air mass may be so extensive that it may cover a large portion of a continent and it may be so thick in vertical dimension.

Critchfield defined air mass as an extensive portion of the atmosphere having characteristics of temperature and moisture which are relatively homogenous horizontally.

According to *T. Petterson* "An air mass is a huge body of air whose physical properties, notably temperature and humidity are more or less uniform horizontally".

Trewartha and Horn defined air mass as an extensive portion of the atmosphere in which temperature, humidity, and hydrostatic stability are relatively uniform in the horizontal direction.

The vertical distribution of temperature in an air mass, and moisture content of the air are two basic properties of an air mass which control the weather conditions of the area affected by that air mass. An air mass is designated as cold air mass when its temperature is lower than the underlying surface while an air mass is termed as warm air mass when its temperature is higher than the underlying surface.

SAQ I

a. What are the basic properties of air mass?

b. Explain the concept of Air mass?

10.3 SOURCE REGIONS OF AIR MASSES

The extensive areas over which air masses formed are known as source regions. The homogenous earth's surface either land or oceanic surface with temperature and moisture conditions uniform is the essential condition for the origin of air masses.

The source regions are classified on the basis of nature of surface continental or Maritime (oceanic) and on further on the basis of latitudinal location such as Equatorial, Tropical, Polar and Arctic. You can learn about classification of Air Masses through flow chart in Fig. 10.3.

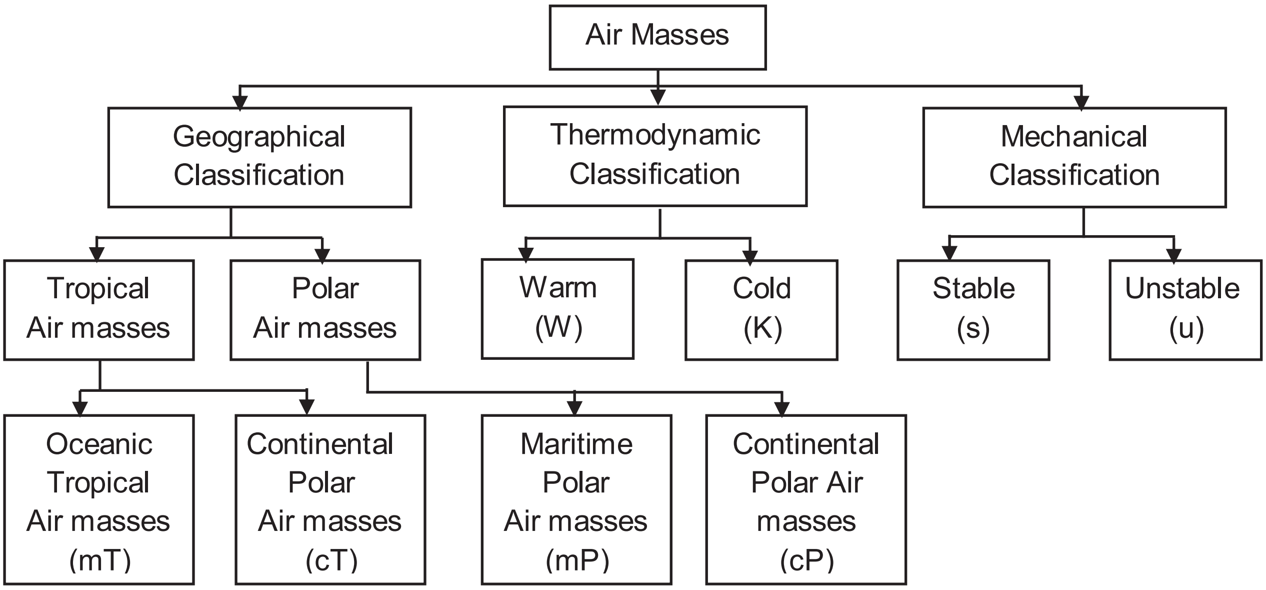

Fig. 10.1: Classification of Air Masses.

There are four major source regions of air masses:

1) ***Maritime Polar (mP) -*** At about 60°N and 60°S latitudes there are source regions of the air masses in the oceans and are called as maritime polar sources. The northern part of Antarctic and Pacific Ocean are the best source regions of air masses. Air masses also originate from the Arctic Source near the North Pole.

2) ***Continental Polar (cP) -*** These are located in the continental areas of the Polar Regions which noted for intense cold during winter season. The best example is the Antarctic Source region around Antarctic continent near the South Pole.

3) ***Maritime Tropical (mT) -*** Such source regions are located in the oceans of the tropical areas.

4) ***Continental Tropical (cT) -*** These sources are located over the continents in the tropical zone. They are more prominent in Asia and North Africa.

5) ***Maritime Equatorial (mE) -*** Air masses originate throughout the year at the inter-tropical convergence zone (ITCZ) near the equator. Since most of the air masses originate in the ocean, they are called as Maritime Equatorial Source.

The source regions of different air masses are affected by the amount of insolation on the surface of the earth and radiation from the surface, which is called Thermodynamic Modification. On the basis of temperature, these are further divided in to warm and cold air masses. The movement of air masses affects the temperature of land and water surface. The upward or downward movements of warm and cold air masses are called unstable (u) and stable (s). This process is called as mechanical or dynamic modifications.

10.4 CHARACTERISTICS OF AIR MASSES

The characteristics of air masses determined on the basis of its temperature, specific humidity, stability and instability and the nature of source regions. The characteristics of the air masses can be categorised on the basis of locational aspect of their source regions and nature of surface. You may learn the position of major air masses according its source region on map with fig.10.4. The characteristic features of these major air masses are discussed below: -

A. Polar Continental Air Masses

Polar continental air masses originate from northern central Canada (North America) and Siberia (Russia) regions and are thermodynamically and mechanically modified. These air masses have different physical characteristics during summer and winter seasons due to the position of the sun. These are generally cold and dry but when these move over warmer surface they are heated from below and become unstable and moist to some extent resulting into the formation of low stratocumulus clouds. The source areas, due to their location in high latitudes, are frozen during winter season. The air masses of these regions are cold, dry and stable. Intense cold waves are generated in those areas where these extremely cold air masses move. When these air masses move over the oceanic surfaces, they are warmed and regain moisture from the oceanic surface and give some precipitation through cumulus or low stratocumulus clouds.

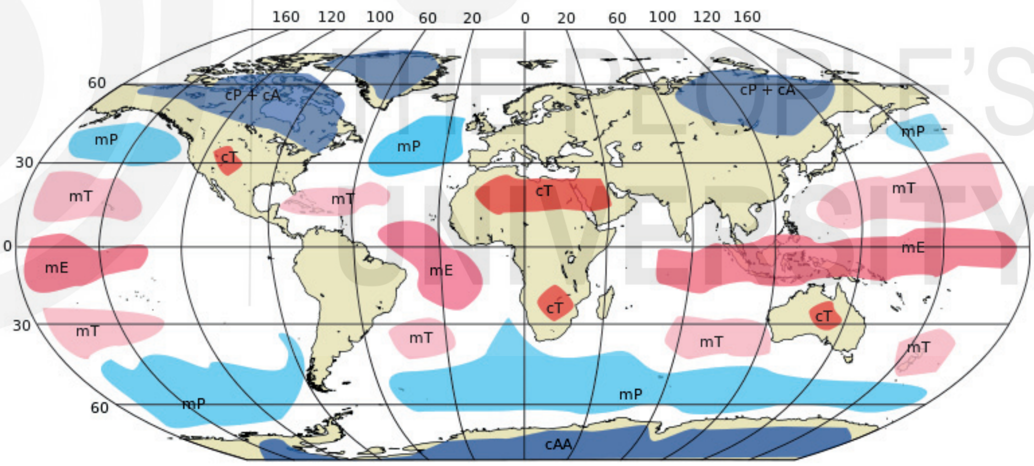

Fig. 10.2: Major Air Masses and their Source Regions
(Source: https://en.m.wikipedia.org/wiki/File:Air_masses.svg, CC: Public Domain, Credit: NASA)

B. Polar Maritime Air Masses

These air masses originate in the same latitudinal source regions of continental polar air masses. When continental air masses move out from their source regions and travel over oceanic surfaces of high latitudes, their lower parts are heated from below by the relatively warm surfaces of open oceans and become maritime polar air masses of the air mass. Increase of temperature and lapse rate causes convective instability in the lower parts of the air masses. On the other hand, the upper part is dry and cool. The modified air masses are mechanically forced to ascend and become unstable. The convective instability results in condensation and precipitation on the windward slopes of the mountains. The descending air masses on the leeward side of the mountains gets adiabatically warmed and become stable dry continental air masses.

C. Continental Tropical Air Masses

The source regions of continental tropical air masses are in the subtropical high-pressure areas of hot deserts located between 20°- 30° latitudes in both the hemispheres which are characterised by vertical descent and horizontal divergence of winds. These air masses are characterised by very high temperature (above 40°C), least moisture content, steep lapse rate, atmospheric stability, and dry weather. These air masses rarely move out from there source regions, but whenever they move out to ocean surfaces, they are modified into maritime tropical air masses.

D. Maritime Tropical Air Masses

The source regions of Maritime Tropical Air Masses are over warm ocean surfaces of tropical regions confined between 30°N and 30°S latitudes. These are warm, moist and unstable air masses and more extensive in areal extent. They are associated with convective instability, cumulous clouds which give abundant rainfall when the air mass is associated with frontal activity or is forced to ascend by mountain barriers. It may be mentioned that the maritime tropical air masses are modified and become stable when they move towards the poles and travel over colder water (of oceans) or land surfaces. They become unstable when they move over warm land surfaces.

10.5 CLASSIFICATION OF AIR MASSES

Classification of air masses is based primarily upon their source regions and secondarily upon temperature and moisture properties. The two main categories are tropical and polar, because the great source regions are located at high and at low latitudes. The sub division of these groups is made according to whether the source regions are oceanic or continental. These air masses of source regions (oceanic and continental) are further divided on the basis of thermodynamic modification and its movement. The heating and cooling of the surfaces is dependent on the amount of insolation received, radiation from surface, nature of surface and movement of air masses. These oceanic (polar/tropical) and continental (polar/tropical) air masses are further divided into warm air mass (w) and cold air mass (c). The mechanical or dynamic modification of an air mass involves vertical upward movements termed as unstable (u) air mass. While downward or subsidence of air mass called stable (s) air mass.

10.5.1 Geographical Classifications

Trewartha has classified air masses on the basis of geographical locations into two categories: (1) Polar air mass (P) and (2) Tropical air mass (T). Further these two divided on the basis of their source regions (1) maritime (m) and (2) continental (c). These air masses are divided into four categories:

(1) Continental polar air mass (cP)

(2) Maritime polar air mass (mP)
(3) Continental tropical air mass (cT)
(4) Maritime tropical air mass (mT)

10.5.2 Thermodynamic Classifications

These air masses are further divided on the basis of thermodynamic modifications into (1) Cold (k) and (2) warm (w) air masses. Eight such air masses are listed below:

(1) Continental Polar cold air mass (cPk)
(2) Continental Polar warm air mass (cPw)
(3) Maritime Polar cold air mass (mPk)
(4) Maritime Polar warm air mass (wPw)
(5) Continental Tropical cold air mass(cTk)
(6) Continental Tropical warm air mass (cTw)
(7) Maritime Tropical cold air mass (mTk)
(8) Maritime Tropical warm air mass (mTw)

10.5.3 Composite Classification

On the basis of mechanical or dynamic modifications of air masses, each air mass further divided into (1) stable(s) air mass and (2) unstable (u) air mass. The above 8 categorisation of air masses are further divided on the basis of stable and unstable air masses into 16 categories. These 16 types are as follows:

1. Continental polar cold stable air mass (cPks)
2. Continental polar cold unstable air mass (cPku)
3. Continental polar warm stable air mass (cPws)
4. Continental polar warm unstable air mass (cPwu)
5. Maritime polar cold stable air mass (mPks)
6. Maritime polar cold unstable air mass (mPku)
7. Maritime polar warm stable air mass (mPws)
8. Maritime polar warm unstable air mass (mPwu)
9. Continental tropical cold stable air mass (cTks)
10. Continental tropical cold unstable air mass (cTku)
11. Continental tropical warm stable air mass (cTws)
12. Continental tropical warm unstable air mass (cTwu)
13. Maritime tropical cold stable air mass (mTks)
14. Maritime tropical cold unstable air mass (mTku)
15. Maritime tropical warm stable air mass (mTws)
16. Maritime tropical warm unstable air mass (mTwu)

SAQ II

a. How are air masses classified on the basis of thermodynamic modifications?

b. What is the composite classification of air masses?

10.6 DISTRIBUTION OF AIR MASSES

10.6.1 Air Masses of North America

A. Winter Air Masses of North America

1. Continental Polar Air Masses (cP): This is cold, dry and stable, and originates over the snow-covered central Canada to the north of 50°-60° N latitude, and Alaska while continental arctic air masses originate over arctic basin and Greenland ice cap. These air masses move out of their source regions and enter the USA between and Rocky Mountains and the Great Lakes. This air mass moves in southerly and south-easterly directions and brings extreme cold conditions. The air masses are forced to move upward along the Appalachians, becomes unstable, clouds are formed and the western slopes of the Appalachian mountains receive heavy snowfall.

2. Maritime Polar Pacific Air Masses (mP): These originate in the northern parts of the North Pacific, mainly near Aleutian Islands where winter low pressure is formed. This region is surrounded by cP air mass from all sides except in the south. The water surface is warmer than the air lying over it. Consequently, when the cold maritime polar air mass comes over this area it is warmed from below and thus becomes unstable and moves to the west coast of North America. When mP air mass reaches the Great Plains of the USA after crossing over the coastal ranges and the Rocky Mountains, it undergoes the process of thermodynamic modification and transformed into cold, stable and dry continental polar air mass. As a result, sky becomes clear and air circulation becomes slow and the temperature returns to normal.

3. Maritime Polar North Atlantic Air Mass (mP): These air masses originates over the North Atlantic Ocean mainly in the region between Greenland, Newfoundland and Labrador where winter temperature ranges between -15°C and 4.4°C while during summer season it becomes 10 °C to 15.5°C. This air mass is dry and stable in its upper layers while it is moist and unstable in the lower parts. This air mass brings in bad weather which is locally known as 'north-easter', characterised by strong north-east cold winds. Extreme low temperatures well below freezing point, high moisture content in the air and precipitation mainly in solid forms such as snowfall, sleet and hailstorms.

4. Tropical Maritime Atlantic Air Masses (mT): These air masses originate over Gulf of Mexico, Caribbean Sea and subtropical western portion of the North Atlantic Ocean. They are hot, moist and unstable and are capable of unleashing heavy showers. These air masses affect eastern part of the Rocky Mountains (USA). Temperature ranges between 21°C and 26°C and remains almost uniform in the source regions with the result tropical maritime Atlantic air mass becomes warm and moist air mass. These modified air masses are known as maritime tropical stable warm air masses. These stable air masses incapable for precipitation but whenever it comes in contact with cP air mass, the upper air instability increases and the air mass is modified to maritime tropical warm unstable air mass. As this air mass rises along the mountain barriers, it yields heavy showers and produces several thunderstorms.

5. Tropical Maritime Pacific Air Masses (mT): These originate over the subtropical portions of the East Pacific west of USA and Mexico mainly over the high-pressure areas located to the south west of California. The air mass becomes stable because of subsidence of air from above due to anticyclonic circulation. This maritime tropical stable air mass is dry, cold and stable near the Pacific coast of the USA. Whenever this air mass is associated with cyclonic circulation, it becomes unstable and brings rains. This air mass seldom crosses the Rockies.

B. Summertime Air Masses of North America

1. Polar Continental Air Mass (cP): This air mass originates over the snow-covered central Canada and Alaska. The temperature becomes relatively higher in summers than in winters, but adjoining oceanic areas have relatively low temperature. During summer season, it is initially cold and stable. This stability of the cold and stable arctic air mass disappears when this air mass moves southward over relative warm ground surface. The continental cold air mass becomes warm due to thermodynamic modification when it moves over the ocean. The southward movement of cP air mass brings chilly weather in the eastern and central USA due to which the effects of summer heat waves are eliminated and fine weather sets in. Whenever this air mass is associated with cyclonic circulation, it provides sporadic rainfall in the north-central and eastern parts of the USA.

2. Maritime Polar Atlantic Air Masses (mP): These air masses originate over the area located between Cape Cod and Newfoundland. These cold and stable air masses reach as far as south northern Florida where temperature is reduced by -9.4 to -3.8°C. Low temperature, clear sky and full visibility are the weather characteristics associated with these air masses. Thus, these air masses produce fine and pleasant weather in the region extending from Newfoundland to Cape Hatteras. There is no ground fog due to dry condition.

3. Maritime Tropical Atlantic Air Masses (mT): These air masses originate near Bermuda forming high pressure. They move northwestward and control the weather conditions of vast areas of the USA east of Rocky Mountains during summer months. Thermally induced low pressure over southern and central USA draws maritime tropical air masses far inland but the existence of polar front in the vicinity of the Great Lakes restricts their entry to Canada. By the arrival of these air masses in the central and eastern USA, the weather becomes oppressive and unpleasant. As these air masses enters the USA after crossing over the Gulf of Mexico, surface temperature increases, and they are modified into maritime tropical unstable air masses because the heating of overlying relatively cold air masses. Thus, thunderstorms and cyclones are produced, which yield heavy showers. As the air mass moves northward, it becomes dry in the upper Mississippi valley. When these air masses move westward and rise along the Rocky Mountains, they yield heavy downpour with heavy cloud burst. Similarly, when they cross over the Appalachians, they give heavy showers through thunderstorms. You can easily identify the Air Masses on map in Fig.10.6

4. Maritime Polar Pacific Air Masses (mP): These originate in the area near Aleutian Island in the north Pacific Ocean. The air mass becomes stable because of subsistence of air from above during summer season. Thus, this air mass becomes cold and stable. It may be pointed out that the continental surfaces are warmer than the water surface of the Pacific Ocean. After crossing over the Rocky Mountains mP air masses are modified and resemble continental polar air mass in physical characteristics.

5. Maritime Tropical Pacific Air Masses (mT): These air masses originate in the tropical North Pacific Ocean off the west coast of Central America. These air masses are marginalised because of the prevalence of maritime polar pacific air masses (as referred to above) along the west coast of North America in summers.

6. Continental Tropical Air Masses (cT): These air masess originates in the source regions comprising Mexico, western Texas (USA) and eastern New Mexico (USA). The daytime characteristics of these air masses are high temperature, significantly low humidity and scanty rainfall. These air masses move to Great Plains and cause extreme arid conditions. It produces drought conditions if it stays for a longer period over an area.

10.6.2 Air Masses of Asia

A. Winter Air Masses

1. Continental Polar Air Masses (cP): These air masses originate over Siberia and outer Mongolia having very cold ground surface, initially, the air masses are very cold and dry in their source regions. The lower portion upto a height of one kilometer is characterised by temperature inversion. The air masses that move eastward are mechanically modified. Mechanical turbulence is produced when these air masses cross over the mountain barriers. This leads to the disappearance of inversion layer resulting into increase of temperature and humidity in the lower layer. When high pressure lies over Manchuria and Japan Sea, cP enters China through sea after moving over Japan Sea and Yellow sea and thus picks up abundant moisture. These air masses are relatively warmer and more humid than the cP air masses coming from land. The cP air mass move through sea and land converge along the east coast of Asia and develop cyclones through frontogenesis and cause precipitation.

2. Maritime Polar Air Masses (mP): These air masses that originate from the Okhotsk sea influence only the coastal margins of Siberia, Manchuria and South Korea while the eastern coast of Asia and south of Korea are deprived of their influence because (a) the winter air circulation is off shore i.e., from west to east due to which the westward advance of maritime polar air masses is blocked, and (b) continental polar air mass while entering China through sea route attains the characteristics of maritime polar air mass. You can easily identify the Air Masses on map in Fig.10.6.

These air masses also invade Japan in early summer and form fronts when they converge with overlying mT and bring moist weather with overcast sky and light precipitation.

3. Maritime Tropical Air Masses (mT): These do not effectively influence the weather conditions of the eastern Asia during winters because of the dominance of the continental polar air masses. These air masses are experienced only upto southern China. They are warmer and more humid than all of the wintertime air masses. Unstable maritime tropical air masses are more effective in south-west Pacific Ocean and in eastern Indonesia.

B. Summer Air Masses

1. Continental Polar Air Masses (cP): The source area of polar air masses extends further northward in central Asia because of high temperatures during summer season due to northward migration of the sun. The air becomes relatively warm, but Cp air masses do not effectively influence the weather conditions of eastern and southern Asia because maritime tropical air masses become more dominant during summer season. The cP enters China only through sea from Japan Sea and Yellow sea. These air masses are colder than maritime tropical air masses. They are associated with clear weather, scanty precipitation, and negligible thunderstorm. They produce cyclonic conditions when they converge with maritime tropical air masses.

2. Maritime Tropical Air Masses (mT): The weather of south and south-east Asia is largely controlled by mT air masses which are known as *summer monsoon*. They are warm, more humid and unstable. They yield torrential rainfall when they are forced to ascend by mountain barriers. They move north and north-eastward and after entering the mainland they are heated from below because of warm ground surface and become unstable and convectional currents are produced. The south-west summer monsoons of Indian subcontinent are typical representatives of maritime tropical summer air masses. These air masses produce cyclonic conditions when they converge with cP air masses during spring season in central China and during middle summer in Manchuria.

3. Maritime Polar Air Masses (mP): These air masses after originating over the Okhotsk sea and move westward and influence the weather conditions of the eastern Asia north of 40°N latitude. These air masses are more active during the summers than during winters. They are more effective in Manchuria and east Siberia. These air masses extend upto southern Japan in early summer, but later they are pushed northwards by mT air masses.

10.6.3 Air Masses of Europe

A. Winter Air Masses

1. Continental Polar Air Masses (cP): There are three source regions of continental air masses in Europe, namely 1) Fenno-Scandian Region, 2) Western Russia, and 3) Arctic Russia. All these source regions are located from 45°N latitude to the North Pole and are characterised by frozen ground surface. The continental polar air masses in winter are cold, less humid and stable in source regions. The arctic continental polar air mass is coldest of all the winter time continental polar air masses, but it is not very frequent but whenever it arrives in Europe it brings severe cold. The air masses from the first two source regions affect western and central Europe but the general westerly circulation of air restricts their further westward journey. The weather is generally characterised by clear skies and severe cold conditions.

2. Maritime Polar Air Masses (mP): The main source region of these lies in Europe in the North Atlantic Ocean, north of 60°latitude where in two sub-regions are very significant, namely (a) east of Greenland, and (b) north of Iceland. The air masses are characterised by more humid conditions and if associated with temperate cyclones, they are uplifted and produce heavy precipitation over plains and very heavy precipitation over highlands. Generally the mP air masses originated in North Atlantic Ocean (Greenland) reach Western Europe, they maintain the cold characteristics and less modified as stable air masses. The air masses originated over the frozen surface of Arctic Ocean during winter time reach the Western Europe and they are modified over Atlantic Ocean and attain the general characteristics of common mP air masses. Due to the absence of mountain barrier parallel to the west coast mP air masses influence the western and central Europe.

3. Maritime Tropical Air Masses (mT): The source region of maritime tropical air masses which invade the south-western part of Europe is the eastern part of subtropical high-pressure area over Atlantic Ocean. The source region is characterised by subsidence of air and divergence of air. During winter, maritime tropical air masses are relatively warmer and more humid than winter continental polar air masses because they are subjected to modification by the physical properties of the Atlantic Ocean and reach south-west coast of Europe. The warm-sector air masses in cyclonic storm, mT air gives an extensive rain and snow to western and central Europe.

4. Continental Tropical Air Masses (cT): These are warm, dry and stable in west North African Sahara Desert and dry areas of S.W. Asia mainly Arabian desert. After passing over the Mediterranean Sea they pick up moisture and give precipitation when they join the warm sector of western disturbances. It mainly influences the weather of Italy and eastern Mediterranean Sea.

B. Summer Air Masses

1. Continental Polar Air Masses (cP): These are cooler than continental tropical air mass bur is warmer than maritime polar air mass of western and central Europe. The lapse rate is not steep in these three air masses, that is why the summers are characterised by more or less uniform weather conditions in western and central Europe but since the Eastern Europe has interior location, the temperature contrast is more pronounced.

2. Maritime Polar Air Masses (mP): There is vast variation in different branches of maritime polar air masses which depend on the place of origin of mP air masses. Northern part of primary source covers shorter distance over the North Atlantic Ocean and reaches the Western Europe without being greatly modified, and hence become moderately unstable which may yield heavy precipitation when uplifted by frontal activity.

3. Continental Tropical Air Masses (cT): These air masses of Europe originate from two sources which are very hot and dry. (1) Sahara Desert of North Africa, (2) the South-Eastern Europe and Asia Minor, wherein the former is the principal source region becomes moist when it moves northward over

Mediterranean Sea. The second branch of cT originates over south-eastern Europe and Asia Minor but is less frequent. It is more or less stable air mass because it is associated with anticyclone conditions.

4. Maritime Tropical Air Masses (tm): Its source region is around Azores high pressure area in the Atlantic Ocean. It becomes stable because source region is characterised by the subsidence of the air from above and hence anticyclone conditions emerge and it passes over cool ocean surface. You can easily identify these air masses on map in Fig.10.6.

10.7 SUMMARY

Let us now recapitulate what we have learnt in this unit.

An air mass is a large volume of air in the atmosphere that is mostly uniform in temperature and moisture. It can extend up to thousands of kilometers across the land as well as oceanic surface of the earth. The places of origin of the air masse are called the *source regions*. Due to low wind speed, the air mass remains stationary for long time over the source region, which enables the air masses to gain properties of the source region whether it is hot or cold. When wind moves the air masses from the source region to a new region, these change the weather conditions of the new region. Meteorologists identified air masses and categorised into four types such as Arctic, Tropic, Polar and Equatorial on the basis of their source of origin. Air masses are again classified on the basis of weather over land or over oceanic surface these are continental air masses and maritime air masses

Air masses are classified on weather maps using three or four letters. A lower-case letter describes the amount of moisture in the air mass: m-maritime (moist), c-continental (dry). The upper-case letter describes the temperature of air mass; E- Equatorial, T-Tropical, P-Polar, A -Arctic or Antarctic. Again, air masses described in small letters; k-cold air mass and w-warm air mass. These air masses are distributed over the earth surface and it changes its position from season to season.

10.8 TERMINAL QUESTIONS

1. Explain the concept of formation, source region and characteristics of air masses.

2. Define the air mass and give a detailed classification of it.

3. Write notes on winter and summer air masses of North America.

4. Give a detailed account of air masses of Asia.

10.9 ANSWERS

Self-Assessment Questions (SAQs)

1. a) The vertical distribution of temperature in an air mass, and moisture content of the air are two basic properties of an air mass which control the weather condition of the area affected by the air mass. The physical properties of an air mass are determined on the basis of the characteristic feature of the surface through which it travels. An air mass also affects and modifies temperature and moisture conditions of the areas visited by it and in turn it is also modified by the local conditions of the visited areas.

   b) An air mass may be defined as a large body of air whose physical properties, especially temperature, moisture content, and lapse rate, are more or less uniform horizontally for hundreds of kilometers". It may be so extensive that it may occupy a large portion of a continent and it may be so thick in vertical dimension and extended into the troposphere. The air mass is designated as cold air mass when its temperature is lower than underlying surface while an air mass is termed warm air mass when its temperature is higher than the underlying surface.

2. a) Air masses are thermodynamically classified into two main categories: cold air masses (k) and warm air masses (w). These categories are further divided into eight types based on their source regions and thermal properties: Continental Polar cold (cPk), Continental Polar warm (cPw), Maritime Polar cold (mPk), Maritime Polar warm (mPw), Continental Tropical cold (cTk), Continental Tropical warm (cTw), Maritime Tropical cold (mTk), and Maritime Tropical warm (mTw).

   b) The composite classification of air masses considers both thermodynamic and mechanical (dynamic) modifications, dividing air masses into stable (s) and unstable (u) types. This results in 16 categories: for instance, Continental Polar cold stable (cPks), Continental Polar cold unstable (cPku), Maritime Polar warm stable (mPws), and Maritime Tropical warm unstable (mTwu). Each air mass type, whether polar or tropical, is further classified as stable or unstable based on atmospheric conditions.

Terminal Questions

1. Start your answer with definition of air masses then about the formation of air masses, there source region and their characteristics. Refer to sec. 10.2, 10.3 and 10.4 of this unit.
2. Discuss the detailed classification of air masses with pictorial presentation which is given in sec. 10.4 of this unit.
3. Write short notes on summer and winter air masses of North America as given in sec. 10.6.1 of this unit.
4. Write a detailed account on air masses of Asia as given in sec. 10.6.2 of this unit.

10.10 REFERENCE AND FURTHER READING

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UNIT 11

FRONT AND CYCLONES

Structure

11.1 INTRODUCTION

In previous unit i.e.unit-10, you have learnt about air mass and their distribution in detail. Here, you are going to learn one of the special features of climatology associated with air mass i.e. Front and Cyclones. You all are acquainted with the term cyclone; but have you ever tried to understand its origin or formation? Cyclones are of one type or they are of different types? This and many more questions are generating in your mind. Therefore, in this chapter or unit you are going to acquaint with front and cyclone. These are the two basic and unique aspects of climatology but its weather system has tremendous impact over cultural landscape. So, as a student of climatology it is compulsory to know about front and cyclones. In detail you are going to learn about front, their origin, and related weather phenomenon. Sec. 11.2 will acquaint you with fronts, their genesis and their end. Sec. 11.3 and 11.4 will elaborate on types of fronts and frontal regions respectively. You will learn about cyclones, their types, formation etc in the subsequent sections from Sec. 11.5 to Sec. 11.8.

In the next block you will study about climatic classification.

Expected Learning Outcomes

After studying this unit, you would be able to

- correlate the relationship between air mass and front;

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- describe about front, its types, and its features;
- deal and explain about the front related weather system;
- discuss about the applied aspect of front;
- differentiate between front and cyclones; and
- distinguish between tropical and temperate cyclones and their weather phenomenon.

11.2 INTRODUCTION TO FRONT

In the last unit you have read that –A large mass of air present over an extensive geographical region with uniform temperature and humidity (horizontally) and with equal normal lapse rate (vertically) is termed as an air mass. Once formed, air mass becomes unstable (at their place of origin) and moves ahead from the region. During the movement several types of changes occurs within air mass which depends on several geographical factors. During the movement, when two air masses of two physical properties comes in front of each other, transitional zone forms between them which is known as front. Fronts are the unique features of temperate region or mid-latitudes regions especially between 30^0 to 65^0 North and South latitudes. They are not common in equatorial, tropical and in Polar Regions.

11.2.1 Defining Front, Frontogenesis and Frontolysis

Fronts play an important role in understanding the climate and weather phenomenon of a region or place. It is because, front gives birth to different phases related to weather phenomena which are called cyclones and anticyclones. Therefore, sometimes fronts are termed as **Cradle of cyclones and anti- cyclones**. Norwegian scientists **Bjerknes and Slosberg** have introduced the concept of front and frontal surface in meteorology during World War I (They have considered the clash between two unlike air masses to be analogous to a confrontation between opposing armies along a battlefront).Actually, **Front is a three dimensional (3D) transition zone formed between two converging air masses with different physical properties.** The layer or surface which divides the two fronts is called **"Frontal Surface"**.

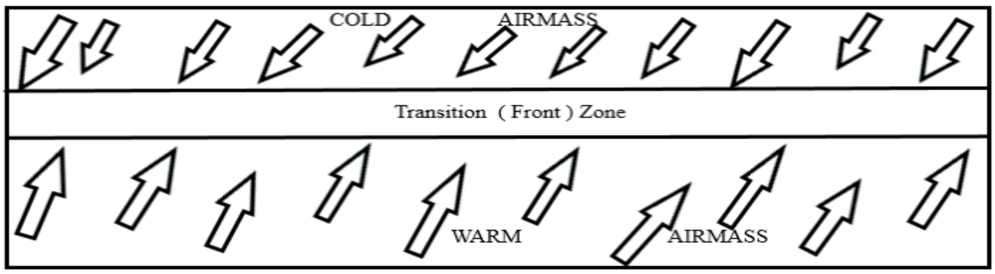


Fig. 11.1: Initial Stage of Front Formation.

In other words, when two air masses of two different physical properties like- temperature, humidity, wind speed, lapse rate and density encounter with each other through movement, they tries to intermingle. Due to difference in their physical properties (one of the two air mass is cold, dense, dry with high air pressure whereas , the other one is warm, lighter, moist with low air pressure), they do not merge with each other hundred percent and create a special transition zone between themselves. This special transitional zone is known as '**Front**' in climatology. This front is not like a **boundary** but like an invisible wall which has length, breadth and height. The front is neither parallel nor vertical to the earth surface rather it slopes on a certain angle. The slope or angle of front is based on the axial motion of the earth which increases towards pole. Thus front is a three dimensional sloping boundary.

11.2.2 Characteristics of Fronts

Front is a three dimensional sloping boundary area characterised by the atmospheric turbulences due to its location between two different air masses. The physical difference of two air masses is called **thermal potential**. Here, in transition zone; **thermal energy converted into kinetic energy**. During this process, warm air mass tries to lift up, so air current started. As warm air lifted up, cold air mass tends to move to fill the vacuum. Thus, horizontal movement of wind initiates. The uprising warm wind expands and starts cooling with **adiabatic lapse rate**. A flourishing cloud is formed and it rains heavily. Sometimes there is frost and snow fall. All these reasons cause instability in the atmosphere. Front is formed in temperate zone between 30^0 - 65^0 North and South. In temperate zone, its extension is 1500-2000 miles, thickness is of some mile and height is up to 1000 feet. The speed of wind is 32- 48 km per hour in temperate zones.

SAQ I

a. What is front?

b. Who introduced the concept of front?

c. What is thermal potential?

d. What is adiabatic lapse rate?

11.2.3 Frontogenesis and Frontolysis

The invasion and pushing of two air masses with each other changes the shape of the front and it begins to appear like a wave. Temperate cyclone started with the development of front; because cold air mass enters into warm air mass region. This mechanism tends to start circular movement. According to Climatologist, the genesis of circular movement of air/ wind in frontal zone is known as **'Frontogenesis'**. The process of frontogenesis takes place in an anticlockwise direction in northern hemisphere and clockwise direction in southern hemisphere. The clockwise and anti-clockwise direction of winds depends on the Coriolis force and its effect formed due to the rotational movement of the earth. The circular movement of mid latitude cyclone are known as Temperate cyclone and Extra tropical Cyclones.

During the invasion and pushing of two air masses, one becomes dominant. It means, one air mass wins the frontal competition and dominates over the other. Therefore, the 3D weakens and loses its significance. The end or dying stage (dissipation) with circular movement is called **'Frontolysis'**. Frontolysis is the stage when the condition of inversion of temperature generates. Simply, **Frontogenesis** is the war between two air masses and **Frontolysis** is the phenomenon when one air mass wins against the other. In other words you can understand it as- Convergence of two different air masses is frontogenesis while overriding of one of the air mass by another is Frontolysis. **Bergeron has introduced the term frontogenesis and its development.** According to Trewartha, the area where two air masses of two distinct natures converge is the areas of frontogenesis. Patterson has said- The line intersecting the frontal surface and earth surface is called front and the mechanism which forms front is called frontogenesis. The best development of front is in the North Atlantic region.

11.2.4 Favourable Conditions for Frontogenesis

Fronts are developed over some defined regions. It means that some favourable conditions are necessary for the formation or genesis of fronts. They are –

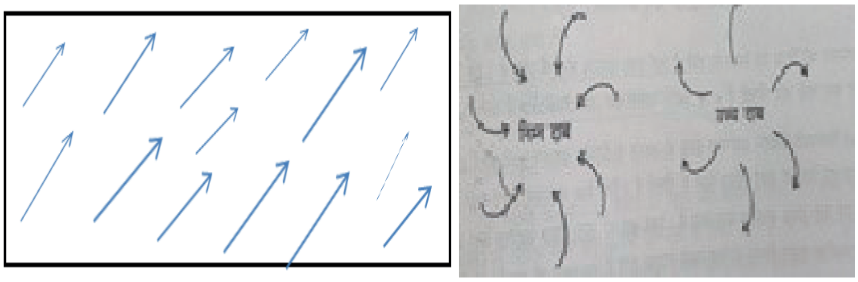
a. Presence of two air masses with different temperatures and densities.
b. Convergence of air masses.

Presence of two air masses with contrasting temperatures is necessary for the formation of front. In mid latitude region when warm and cold air masses try to collide, cold air mass pushes the warm air mass and formation of front occurs. Just opposite of this at equator, two trade winds comes from opposite direction but due to same temperature they are unable to form front. At 60^0 -65^0 north latitude front forms due to the meeting of Polar cold air mass and sub-tropical warm air mass.

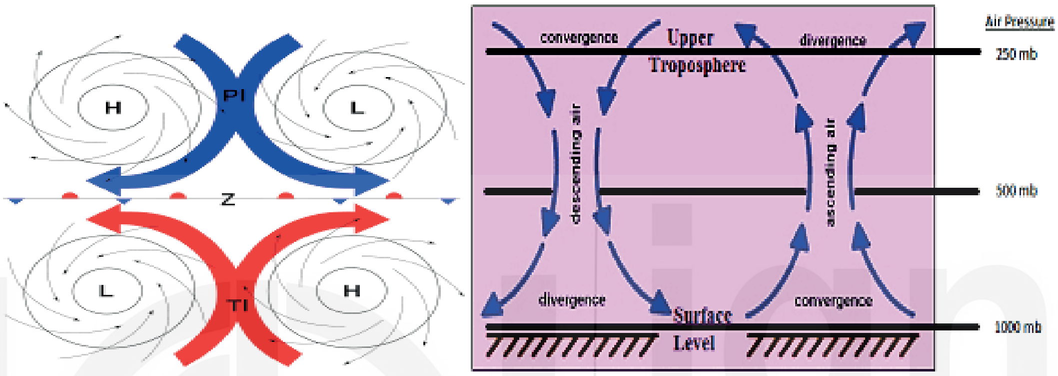
Convergence of two different nature air masses is essential for the formation of front. Patterson has mentioned four types of wind movement system in which last situation provides favourable conditions for the genesis of front. As a student of climatology, you know that temperature and pressure differences are responsible for the wind movement in different forms described below:

- **Translatory circulation:** In this type of movement wind blow in one single direction. Isotherms are parallel and situated very far from each other. Therefore, front formation is not possible.
- **Rotatory circulation:** In this situation wind blow in a circulatory pattern. In fig. 11.2.b you can see the circulatory pattern of two types of rotation of wind - a. Cyclonic b. Anti-cyclonic.
- **Convergent and Divergent Circulation:** Convergence occurred where low air pressure situation prevails. Hence, wind tends to move upward. This is not a suitable condition for the formation of front as two air masses are there with one centre whereas two air masses are necessary along one line. Divergence occurs where high air pressure prevails in the centre. In this condition, wind tends to settle down and spread in the surrounding region. This condition is favourable for Frontolysis. Fig. 11.2.c clearly explains the convergent and divergent condition of wind.
- **Deformatory Circulation**: In this type of air circulation (Fig. 11.2.d), two air masses with two different temperature spread in horizontal direction along a line during colliding with each other. The line through which air spread outwards is called out blow axis line whereas the second axis is known as

inner blow axis line. The inner flow axis line is most suitable for the formation of front. Such condition is found around a **'Col'**. Col is the meeting point of outer and inner flow of wind.



a) Translatory Circulation **b) Rotatory Circulation**



c) Convergent and Divergent Winds **d) Deformatory Circulation**

Fig.11.2: Different types of Wind Circulation identified by Patterson

11.2.5 Nature of Front

Fronts are stable or unstable. There are no atmospheric disturbances associated with stable front. On the other hand, when front is unstable, cloud formation and rain occurs. The amount of rainfall depends on the temperature gradient and on humidity. In this regard, such fronts are more active over coastal region where maritime air masses meet with continental air mass. Fronts are also active over mountainous region. Here, temperature gradients are active between mountainous peak and valley floor.

SAQ 2

a) What is frontogenesis and frontolysis?

b) Explain the favorable conditions of frontogenesis.

c) What are the different forms of wind movement?

11.3 TYPES OF FRONTS

According to thermodynamic properties, fronts are of four types.

11.3.1 Stationary Front

This is the first and last stage of a front. Two air masses of two contrast temperatures and humidities come near to each other; then they move parallel in opposite direction. Since, there is no displacement of air, no air current generates, no cloud formation and precipitation occurred. Such type of front is called **Stationary** front.

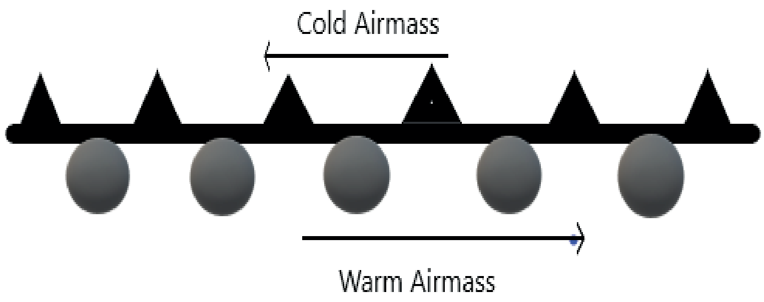
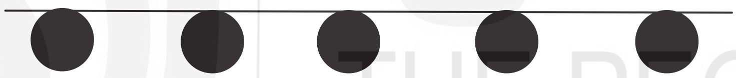


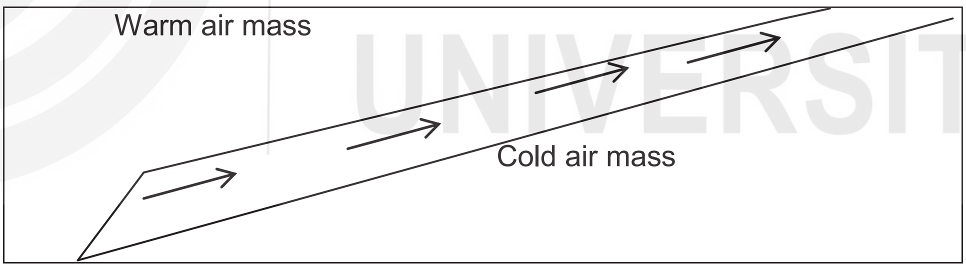
Fig. 11.3: Section of Stationary Front.

11.3.2 Warm front

In this case, warm air mass moves forward and actively and over rides cold air mass. Here, the frontal slope is found up to 1:80 to 1:200 or 1:100 to 1:400.Slowly rising warm air cools adiabatically. The weather becomes unstable leads to stratus cloud formation and ultimately precipitation occurs. Gentle to moderate precipitation continues for a long time i.e. for many hours. It rains on intervals for long hours on an extensive area. At the warm front cirrus, cirro-stratus, stratus clouds are formed from top to bottom simultaneously.



Section of warm front



Situation of Warm front
Fig. 11.4: Warm Front.

When warm front ends, the eye of cyclone comes in the centre; called warm section. With this the weather condition suddenly changes. Air pressure becomes low. Precipitation stops and sky becomes clear.

11.3.3 Cold Front

Front is the leading edge of cooler air mass at the ground level which replaces a warmer air mass. The slope becomes 1:25 to 1:100. In cold front condition, warm air uprising very speedily. Therefore, condensation also becomes very rapid and clouds form especially cumulonimbus clouds are seen followed by heavy rain. After rainfall visibility improves and temperature goes down.

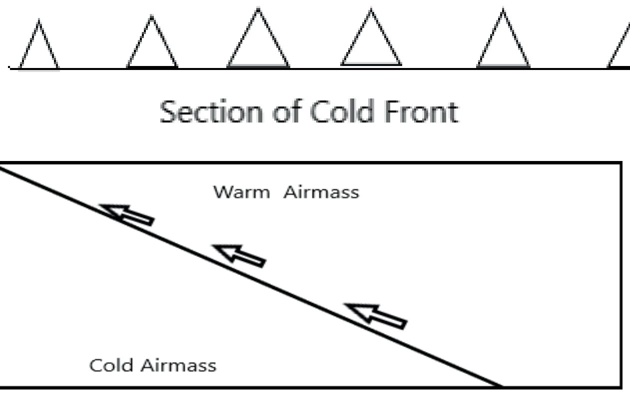


Fig. 11.5: Weather condition in Cold Front.

Cold front is also of two types:

a. In such type there is cold air invasion in lower surface. But its speed is very slow. Hence, cirrus clouds are formed at height without yielding any precipitation. Inversion of temperature is the common feature of such type of cold front.

b. Here, there is down streaming air is behind the front. But the air situated ahead is uprising very quickly which forms cyclonic condition. Heavy rain with fast moving air is the characteristic feature. Air pressure changes very rapidly.

11.3.4 Occluded Front

When cold air mass and warm air mass intermingle with each other and there is completely disconnection of warm air from the surface; then this condition is called **Occluded front.** In this situation warm air completely over ride above the cold air and inversion of temperature can be seen .Occlusion of front are happen by two types depending upon the relative temperature of the air mass.

Warm Front Occlusion: When cool air that is less stable, overrides more stable colder air, the warmer air between them is forced to move upwards leading to the formation of warm front occlusion. Formation of occluded front takes place when warm air mass between two cold air masses is pushed upwards. As a result temperature decreases and warm air mass is occluded (cut off) and pushed upwards. Such type of condition prevails over western part of India during winter season. Here, cold continental air meets with warm oceanic air.

Cold Front Occlusion: In cold front occlusion, the very stable cold air underrides the less stable cooler air. As a convergence, the warm air which was initially between them is forced upwards.

When moving cold air mass enters into the cold air mass areas situated beyond warm front, then it is called warm front occlusion. Warm front lifted up and creates warm front occlusion. Such condition is can be seen in the eastern part of the continents. Here, occlusion process is very slow, so bad weather condition prevails for long time. Sky becomes clear at the end of the front.

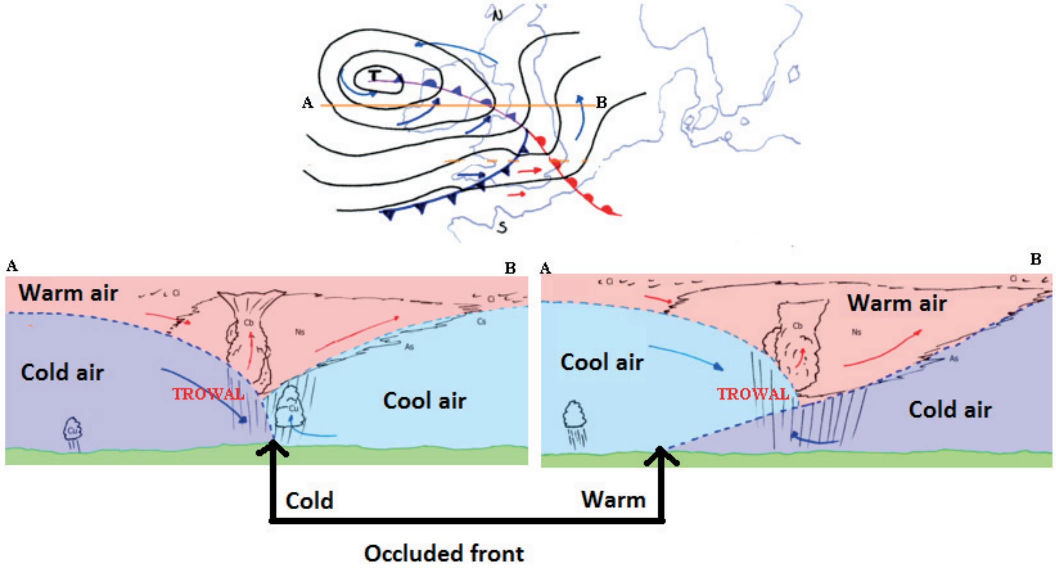


Fig. 11.6: Occluded Front.
(Source: https://upload.wikimedia.org/wikipedia/commons/d/d2/Front_occlus_trowal_en.png, Author: Pierre_cb, CC: Public Domain)

Thus, a front originates and with the passage of time, warm air overrides the cold air. After the completion of such mechanism frontal surface does not touch the earth surface. Inversion of temperature occurs as cold air lies beneath the warm air. Then, stability in atmosphere comes after front related activities are ceased. All such process is called frontolysis. Thus, you can say that frontogenesis and frontolysis is a cyclic process.

11.4 FRONTAL REGIONS

There are two prominent regions on the earth where air convergence process occurs. Such regions created favourable conditions for the formation of front.

A. Equatorial Low Pressure Zone/Belt

Here, north-eastern and south-eastern trade winds meet to form front. These trade winds form clouds and heavy rains occur.

B. Sub-Tropical Low Pressure Zone/ Belt

In the hemisphere, Polar cold air and tropical warm and light air meets at 30^0 to 45^0 latitudes to form Polar front. During winter season it is more active over north Atlantic and north Pacific Oceans.

Other than this, front is also form near Arctic region where Polar Continental and Polar Oceanic air meets but there is no prominent differences in their temperature, hence low intense front is formed. Such type of fronts can be seen in the north of North America and Eurasia.

SAQ 3

a. Mention the different types of front.

b. What is stationary front?

c. Differentiate between warm front and cold front.

d. What is meant by occlusion of front?

e. What are the different types of occlusion?

11.5 CYCLONE

In this unit so far, you have learnt that when two contrasting air masses (warm and cold) converges, it creates front. In this process cold air remains under the upper warm air. Therefore, the upper warm air gradually becomes cooler from the lower level. As condensation starts, cloud forms and rainfall occurs. Tropical, temperate and monsoon region are known for cyclonic rainfall. Some coastal regions are also known for cyclone and cyclonic rainfall. Sometimes cyclone becomes disastrous. A cyclone is a rotating low-pressure weather system and is usually formed over warm oceans such as the Atlantic, Pacific and Indian Ocean, etc. These tropical cyclones get their energy from the intense thunderstorms forming around the eye of the storm.

Due to differences in air pressure, the moving air becomes unstable. This instability creates circular flow of wind and after sometimes it intensifies and forms; cyclone or anti-cyclone. When you are seeing it, it seems that the whole wind of the area is moving fast around an axis or drift like a whirlpool. This whirlpool is of two types-

- Central low pressure area is surrounded by high pressure (Cyclone).
- Central high pressure is surrounded by low pressure wind (Anti-cyclone).

A. Cyclone

Cyclones are revolving tropical storms caused by winds blowing around a central area of low atmospheric pressure. In northern hemisphere, the wind in move anti-clockwise and clockwise in southern hemisphere towards the low pressure centre. The wind tries to reach at the centre but due to high temperature and low pressure they lifted up before reaching there. The central part of the system experiences clear skies without clouds, which is known as the **Eye of Cyclone**.

In Pacific Ocean, low pressure belt has narrow part formed by Asia and North America. Due to lack of an extensive area small front develops here with negligible effect.

B. Anti Cyclone

If there is central high pressure zone surrounded by low pressure areas then wind tries to move outwards from the central high pressure area. This condition is known as **anti-cyclone**. The winds in northern hemisphere move in clockwise direction while in southern hemisphere anticlockwise.

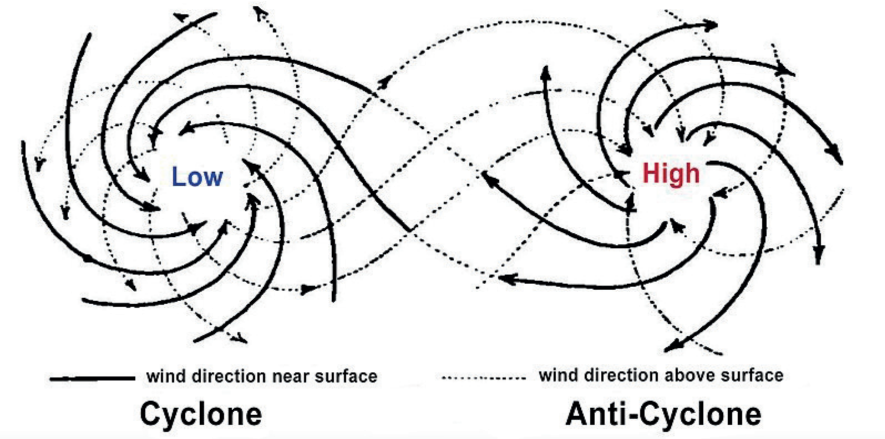


Fig. 11.7: Cyclone and Anticyclone in Northern Hemisphere.

11.6 TYPES OF CYCLONES

According to genesis, cyclones are of two types- **temperate** cyclones and **tropical** cyclones. Both of these cyclones have different mechanism of their genesis and are also found at different places. The genesis of temperate cyclone is best explained by Polar front theory which you are going to learn ahead in this chapter.

11.6.1 Temperate Cyclone

Temperate cyclone originates due to convergence of polar cold air and sub-tropical westerly warm air in sub polar low pressure belt i.e. 60^0 to 65^0 latitudes. Here, two air masses from two different directions come and try to meet with each other. The air masses are of two different properties so they can't intermingle readily. They mix with each other very slowly. As a result, front develops in between them. Front is linear in nature and sometimes it is thousands of kilometers long, 5-75 km wide and 1.5 to 3 km thick. Thus, front is a transition zone where mixed properties of two air masses are found.

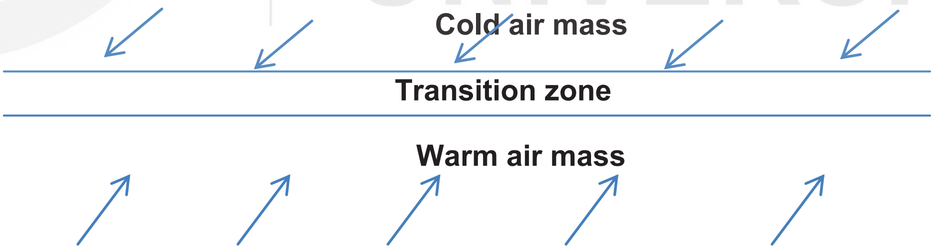


Fig. 11.8: Temperate Cyclones.

Temperate cyclone starts with the development of front. Cold air tries to enter into the warm air area which causes origin of cyclic pattern of movement. The entire mechanism of the genesis of cyclic flow is called frontogenesis. And the end or dying process is called frontolysis. Frontolysis is the stage when front dissipates or temperate cyclone dissipates and air masses/ again above in two opposite directions. After re-mixing, develops the transition zone and initiates the second cyclone. Thus, temperate cyclone is a cyclic process. Temperate cyclones mostly develop over north Atlantic region. Think over it. Why it is not common in Pacific Ocean? Generally, the radius of temperate cyclone is 250 to 1000 km whereas it is 750 km for tropical cyclone.

11.6.2 Tropical Cyclones

Tropical cyclones originate between $5^0 – 30^0$ N & S. Generally, they occur at the end of summer season. Their size is comparatively smaller than temperate cyclones. They have different names at different places. They are called as Hurricanes in Caribbean Sea, Typhoons in China Sea, Tropical cyclones in Indian Ocean, Taifu in Japan, Wily Willies in Northern Australia and Baguio in Philippines.

Convection activity is the main reason behind the genesis of such tropical cyclones. According to meteorologists, when temperature rises at sea; the concerning wind uprises and become light and creates atmospheric disturbances. Thermal influence play dominant role in the formation of tropical cyclones. After sometimes, this wind reaches to landmass where it meets with more intense warm air. At the coastal region both the warm air (one is comparatively cold and other one is warm) meets and creates a whirlpool like situation and becomes disastrous with their speed and rainfall. In India, every year Cyclones originates before monsoon, during monsoon and after monsoon.

11.6.3 Comparison Between Tropical Cyclone and Temperate Cyclone

Now, you will understand the difference between tropical and temperate cyclones. How they differ from each other and in what manners? Come and understand it point wise.

1. Tropical cyclones are low latitude features while temperate cyclones are of high latitudes.
2. The period of tropical cyclone is of shorter duration while it is longer in temperate cyclone.
3. Tropical cyclone has ‘eye’ in its central part known as Eye of cyclone whereas in temperate cyclone front develops instead of eye.
4. Cumulo-nimbus clouds are formed followed by heavy rains in tropical cyclone while in temperate cyclone several levels of cloud are formed and bad weather prolongs for long time.
5. Most of the time tropical cyclone becomes disastrous whereas temperate cyclones are not so disastrous. In tropical cyclone, air is hot so very fast moving but in temperate cyclones both the air mass are comparatively less warm due to their location in high altitudes; their movement is comparatively slow so they are less disastrous.

Table 11.1: Comparison between Tropical and Temperate Cyclones

Tropical	Temperate
1) Move from east to west	1) Move from west to east
2) Smaller extent	2) Larger extent
3) Velocities of winds are very high	3) Velocity of winds are comparatively lower
4) They form of oceans where temperatures of more than 26-27^{0}C	4) They form both on land and sea.
5) The life span is not more than 7 days	5) They can last for a duration of 15 to 20 days

11.7 FORMATION OF TEMPERATE CYCLONE

Different theories have been put forward, but **Polar front theory** is most accepted theory regarding origin of temperate cyclones. The Polar front theory has been postulated by a Swedish meteorologist /scientist Bjerkins, Jacob and Fitzarald. There are six stages in the life cycle of temperature cyclones. Each stage has different weather characteristics.

A. First Phase

This phase is also known as initial stage of temperate cyclone. Formation of transition zone is the prominent feature of this phase which marks the meeting of two different air masses coming from two different directions or latitudes. Stationary front develops in between warm and cold air masses. It remains stable on very extensive areas. Cold air mass comes from Polar Regions whereas warm air mass comes from sub-tropical regions. You can find temperature, pressure; visibility and humidity etc. are in transition phase.

B. Second Phase

In second phase, cold air mass tries to enter into warm air mass areas. It means, front has been pressurise to move towards low latitude. Stability of front now disturbed which creates two parts of the front- Cold front and Warm front wave can be seen at their meeting point. It means that cold front moves towards low latitudes or to the south it seems like bend towards south or low latitude. But warm front remains in their position. In other words- cold air mass now spread over comparatively more extensive areas and compression starts in warm air mass area.

Drastic changes occur in the areas of cold front and warm front. These changes are referred to the weather conditions of temperate cyclone. In cold front region, warm air rises rapidly due to which the cloud formation of takes place after condensation followed by heavy rain. But in the warm front region, warm air gradually rises and forms layered clouds. Therefore, bad weather with drizzle occurs for longer time.

C. Third Phase

In this phase, cold front again moves towards low latitudes and cold air covers more extensive areas. Hence, a clear cut characteristics cyclic movement can be seen. The area of warm air again compressed to a smaller area and develops a warm sector. The push factor creates a cyclone instead of a central low pressure area.

D. Fourth Phase

Warm sector converted into a linear sector and cold air covers all the areas. So cold air front again moves towards high latitudes. The features of cold air mass itself changes very much. Temperature and humidity increases as it moves towards south and it decreases as it moves northwards.

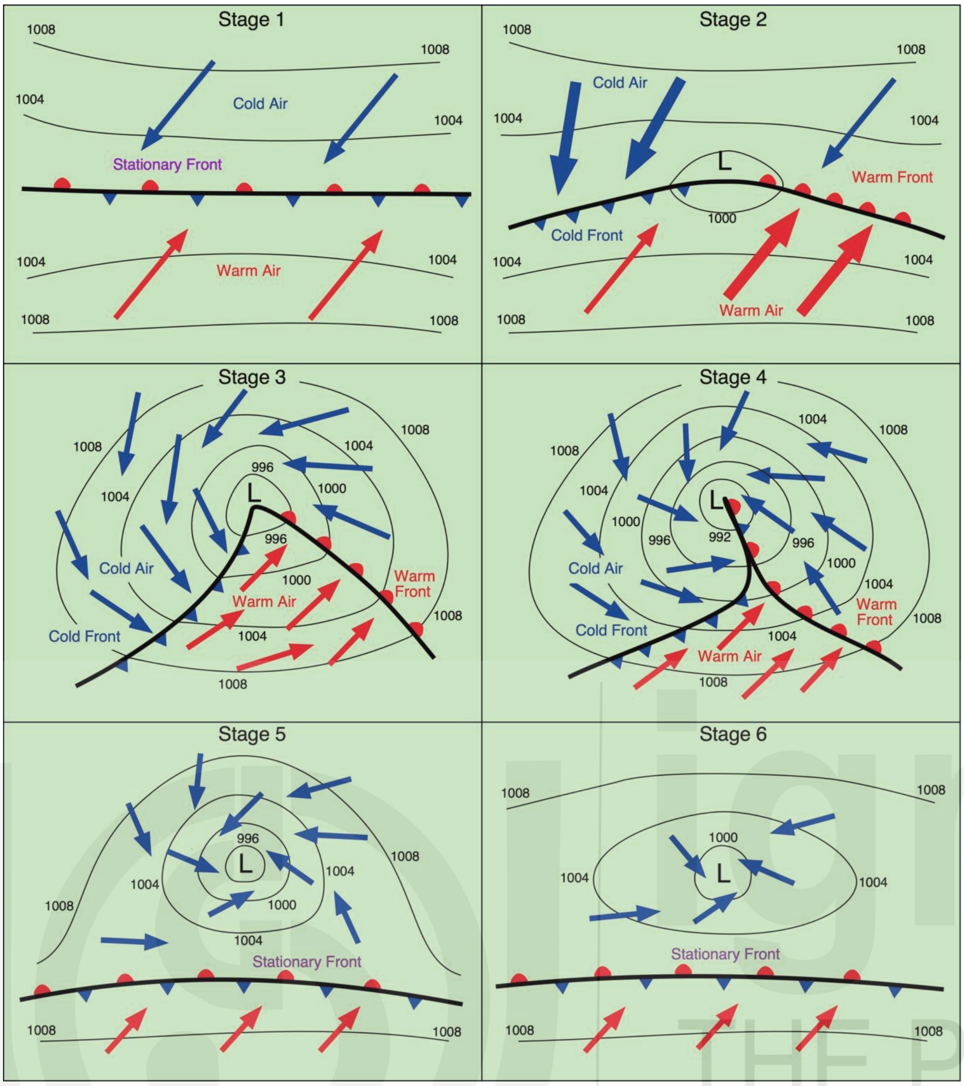


Fig. 11.9: Simplified Stages in the Life Cycle of a Mid-latitude Cyclone (Northern Hemisphere).

(Source: https://pressbooks.bccampus.ca/physgeoglabmanual1/chapter/lab4/ Image Copyright: Michael Pidwirny. Creative Commons Attribution 4.0 International License)

E. Fifth Phase

In this phase, warm and cold fronts meet with each other and creates occluded front. Thus, warm air completely **disappears.** This occlusion is of two types you have already studied above. Fifth phase is the phase of dying wind in which there is no capacity of circular movement as warm sector already been comes to an end.

F. Sixth Phase

Due to absence of front, planetary effect starts on the direction of wind. Wind becomes easterly and westerly and the first phase of temperate cyclone starts again. Thus, there is an end of a temperate cyclone and there will be initiation of second or another temperate cyclone.

11.8 DEPRESSION

Indian Meteorological Department, New Delhi monitors any cyclone that develops within the North Indian Ocean between 45^0 East to 100^0 East. The official classification used in the North Indian Ocean is as a low pressure is known as depression having wind speeds of 31-49 km/h. After that the tropical cyclone scale is used like this-

1. Depression=31-50 km/h (1924-1988)
2. Deep Depression=51-62 km/h
3. Cyclonic Storm= 63-88 km/h
4. Severe Cyclonic Storm= 89-117 km/h (introduced in 1988)
5. Very Severe Cyclonic Storm= 118-165 km/h (introduced in 1999)
6. Extremely Severe Cyclonic Storm= 166-220 km/h (introduced in 2015)
7. Super Cyclonic Storm= 221 and above km/h

Intensity Scale of Tropical Cyclone in South-west Indian Ocean is -

1. Lowest- Tropical Disturbance=<50km/h
2. Tropical Depression=51-62km/h
3. Moderate Tropical Storm= 63-88km/h
4. Severe Tropical Storm= 89-117km/h
5. Tropical Cyclone= 118-165km/h
6. Intense Tropical Cyclone= 166-212km/h
7. Very Intense Tropical Cyclone= >212km/h

11.8.1 Some Severe Cyclonic Hits in India

It is estimated that, around 10,000 people are killed on average each year as a result of tropical storms at world level. On an average, 2 to 3 tropical cyclones make landfall in India each year, with about one being a severe tropical cyclone or greater. The strongest tropical cyclone India has ever recorded is the 1999 Odisha cyclone. Whereas, the Bhola cyclone is one of the deadliest natural disasters ever recorded. The storm was formed over the Bay of Bengal in the month of November 1970 and made landfall on the coast of East Pakistan (Present Bangladesh) before continuing on to West Bengal. India has seen some severe cyclonic hit to its coastal states in recent past during 2020.

1. Cyclone Nisarga

Cyclone Nisarga is the second pre-monsoon cyclone that has emerged from the Arabian Sea and has expected to hit Goa, Maharashtra and Gujarat. Cyclone Nisarga has hit Alibag in Mumbai.

2. Cyclone Amphan

Cyclone Amphan was a powerful tropical cyclone which led to the destruction of lives and property in the states of Odisha and West Bengal. Cyclone Amphan was the first pre-monsoon super cyclone of this century and emerged from the Bay of Bengal.

3. Cyclone Kyarr

Cyclone Kyarr was the second strongest tropical cyclone since cyclone Gonu in 2007. Cyclone Kyarr developed in the Arabian Sea and moved towards the

Gulf of Aden from the Indian coast. It hit the Western India, Oman, UAE, Socotra and Somalia.

4. Cyclone Maha

Cyclone Maha was an extremely severe cyclonic storm which became very intense while moving parallel to the Indian coast. The cyclone weakened when it approached Gujarat. Cyclone Maha made landfall near Gujarat as a depression which weakened afterwards.

5. Cyclone Vayu

Cyclone Vayu emerged from the Arabian Sea and was a very severe cyclonic storm which caused moderate damage to lives and property in the State of Gujarat. Cyclone Vayu was the strongest cyclone that hit the State since the 1998 Gujarat Cyclone. Along with India, cyclone Vayu also affected Maldives, Pakistan and Oman.

6. Cyclone Hikka

Cyclone Hikka emerged from the Arabian Sea and turned intense and hit Oman. In 2019, 4 cyclones emerged from the Arabian Sea-- Kyarr, Maha, Vayu and Hikka.

7. Cyclone Fani

Cyclone Fani was the strongest tropical storm that hit Odisha since the 1998 Odisha Cyclone. Cyclone Fani emerged from the Indian Ocean and caused huge destruction of lives and property in Odisha, West Bengal, Andhra Pradesh and East India. Outside India, it hit Bangladesh, Bhutan and Sri Lanka.

8. BOB 03

A depression formed in the Bay of Bengal and Indian Meteorological Department named in BOB 03. The very next day after the identification, the BOB 03 hit the north Odisha-West Bengal coastline and caused huge destruction of the lives and property.

9. Cyclone Bulbul

Cyclone Bulbul was a very severe cyclonic storm that hit the West Bengal in India. It caused huge rainfall, floods, etc. causing destruction to lives and property. Outside India it hit Bangladesh.

11.8.2 Colour Code for Cyclones by IMD

Green: The color green denotes that everything is smooth and in order, or that "everything is well" with no bad weather.

Yellow: The yellow color code requests that the security personnel "be updated" to deal with adverse weather that could linger for days and could have an impact on everyday activities.

Orange: The color-coded alert meaning "be prepared" is orange. It may serve as a warning of severe damage to communication breakdowns that could result in power outages, traffic and rail jams, and other problems. The orange notice also serves as a warning to evacuate and to prepare the essentials for families.

SAQ 4

a) Why surrounding cold winds try to reach at central area in cyclonic condition?

b) Define cyclone.

c) What are the major types of cyclone?

d) What are the movement pattern of cyclone and anti-cyclone in northern and southern hemisphere?

11.9 EXTRA-TROPICAL AND TROPICAL CYCLONES

Extra-Tropical cyclones are sometimes called mid-latitude cyclones or wave cyclones as they are low-pressure systems which form outside the tropics and in the middle of the latitudes of 30^0 and 60^0. They are capable of producing mild showers, heavy gales, tornadoes, etc. Ex-Tropical cyclones or post-tropical cyclones are those which are formed when the characteristics of the cyclone are changed. The Bureau of Meteorology, Australia, calls post-tropical cyclone as an ex-tropical cyclone.

The Tropical Cyclone Warning Centre in Jakarta monitors cyclones between the longitudes of 90^0 East and 141^0 east from the Equator to 11^0 south and if cyclone develops in this region, it will be assigned a name by TCWC. However, the Australian Bureau of Meteorology monitors the cyclones between the longitudes of 90^0 East and 160^0 East below 10^0 South and if cyclone develops in this region, it will be named by BOM. As this cyclone originated in the region assigned to Indonesia, thus TCWC named this cyclone as 'Tropical Cyclone MANGGA'.

11.10 HOW CYCLONE TAKES ITS NAME

The general term cyclone i.e. tropical cyclone has different name in different parts of the world. In Japan, Philippines and South China Sea (in western North Pacific) it is called **Typhoon**. Cyclone of Mexican coasts, Caribbean Sea, Central and eastern North Pacific and its surroundings is known as **Hurricanes**. The cyclone develops over southern Indian Ocean, northern Australia and coast of Madagascar is known as **Willy-Willies**.

Fig. 11.10: Tropical Cyclone Darian in the Indian Ocean.
(Source: https://www.flickr.com/photos/sentinelhub/52591926583CC BY 4.0 Deed)

Cyclone is the name given to an area of low pressure surrounded by closed isobars which assume a more or less oval form. A typical hurricane produces the energy equivalent to 8,000 one megaton bombs. 90% of those who die from hurricanes die from drowning.

Since 1953, Atlantic tropical storms had been named from lists prepared by the National Hurricane Center. They are now maintained and updated through a strict procedure by an international committee of the World Meteorological Organisation. The six lists are used in rotation and re-cycled every six years, i.e., the 2016 list will be used again in 2022. The only time that there is a change in the list , if a storm is so deadly or costly that the future use of its name on a different storm would be inappropriate for reasons of sensitivity. If that occurs, then at an annual meeting by the WMO committee (called primarily to discuss many other issues) the offending name is stricken from the list and another name is selected to replace it. Several names have been retired since the lists were created. Here is more information the history of naming tropical cyclones and retired names.

If a storm forms in the off-season, it will take the next name in the list based on the current calendar date. For example, if a tropical cyclone formed on December 28th, it would take the name from the previous season's list of names. If a storm formed in February, it would be named from the subsequent season's list of names. In the event that more than twenty-one named tropical cyclones occur in the Atlantic basin in a season, additional storms will take names from the Greek alphabet.

11.11 SUMMARY

Let us now recapitulate what we have learnt in this unit.

During movement of air, several types of changes occur in air mass which depends on several geographical factors. Front and Cyclones are the two basic and unique weather events of climatology but its weather system has tremendous impact over cultural landscape. During movement, when two air masses of two contrast physical properties comes together as a result a transitional zone known as front forms in between them. Front play an important role in understanding the climate and weather phenomenon of a region or place. According to Climatologists, the genesis of circular movement of air/ wind in frontal zone is known as 'Frontogenesis'. The dying process (dissipation) of the circular movement is called **'Frontolysis'**. Frontolysis is the stage when the condition of inversion of temperature generated. Front are of different types. Due to differences in air pressure, the moving air condition becomes unstable. This instability creates circular flow of wind and after sometimes it intensifies and forms; cyclone or anti-cyclone. The strongest tropical cyclone India has ever recorded is the 1999 Odisha cyclone. Whereas, the **Bhola cyclone** is one of the deadliest natural disasters ever recorded.

11.12 TERMINAL QUESTIONS

1. What is front? Explain the different types of fronts in detail with suitable diagram.
2. Give a detailed description of the formation of front and also describe the weather associated with it.
3. Differentiate between frontogenesis and frontolysis. Discuss the weather conditions related with them.
4. Give detailed information about temperate cyclone.
5. Differentiate between temperate and tropical cyclones.

11.13 ANSWERS

Self-Assessment Questions (SAQ)

1. a) Front is a three dimensional transitional zone formed between two converging air masses which have contrasting physical properties.

   b) Norwegian scientists Bjerknes and Slosberg have introduced the concept of fronts and frontal surface in meteorology during World War I.

   c) The physical difference of two air masses is called thermal potential.

   d) Adiabatic lapse rate is the change in the atmospheric temperature with a change in altitude. It is further subdivided into dry and wet adiabatic lapse rate.

2. a) According to Climatologists, the genesis of circular movement of air/ wind in frontal zone is known as 'Frontogenesis'. The end or dying process (dissipation) of this circular movement is called 'Frontolysis'.

   b) Front is developed over some defined regions. It means that some favorable conditions are necessary for the formation or genesis of front. They are as follows:

   i. Presence of two air masses with contrasting characteristics like contrasting temperatures and densities.
   ii. Convergence of air masses.

   c) Temperature and pressure differences are responsible for different forms of wind movement. These are as follows:

   i. Translatory circulation
   ii. Rotatory circulation

iii. Convergent and divergent circulation
iv. Deformatory circulation

3. a) According to thermodynamic properties, fronts are of four types:

   i. Stationary front
   ii. Cold front
   iii. Warm front
   iv. Occluded front

   b) This is the first and last stage of a front. Two air masses of contrasting characteristics come together. Then they move parallel in opposite direction. There is no displacement of air. Therefore, no air current generates, no cloud formation takes place and neither precipitation occurs. Such type of front is called Stationary front.

   c) In case of warm front, warm air mass moves forward and actively ride over cold air mass or try to ride over cold air mass. Here, the slope is found up to 1:80 to 1:200 or 1:100 to 1:400. Slowly rising warm air cools adiabatically. The weather becomes unstable leads to stratus type of cloud formation and ultimately precipitation occurs.

   Whereas, cold front is the condition where cold air mass invades into warm air mass region and pushes the warm air upward. The slope of front varies from 1:25 to 1:100. In cold front condition, warm air rises up very speedily. Therefore, condensation also becomes very fast and clouds form especially cumulonimbus clouds are seen followed by heavy rain. After rainfall, visibility improves and temperature drops down.

   d) When cold air mass and warm air mass intermingle with each other, there is completely disconnection of warm air from the surface. Then this condition is called occluded front. In this situation warm air completely overrides above the cold air and inversion of temperature can be seen. Occlusion of front happens in two ways depending upon the relative temperature of the air mass, that is, Cold front and warm front occlusion.

   e) There are two types of occlusions: cold front occlusion and warm front occlusion

4. a) The cold wind tries to reach at the centre of cyclone, but due to high temperature and low pressure they lifted up before reaching there. Therefore, the central part is devoid of any disturbance or cloud, which is known as the Eye of Cyclone.

   b) Due to differences in air pressure, the moving air becomes unstable. This instability creates circular flow of wind and after sometimes it intensifies and forms cyclone or anti-cyclone. If there is centrally low pressure area surrounded by high pressure wind, the surrounding cold winds tries to reach at the central low pressure area. This condition is known as cyclone. In northern hemisphere the movement of wind is anti-clockwise and clockwise in southern hemisphere.

   c) Based on the genesis cyclones are of two types-temperate cyclone and tropical cyclone. Both of these cyclones have different mechanism of their genesis and are also found at different places.

d) In the northern hemisphere the movement of wind in cyclonic condition is anti-clockwise and clockwise in southern hemisphere. In northern hemisphere anti-cyclone moves clockwise direction while it takes anti-clockwise direction in southern hemisphere.

Terminal Questions

1. First give the definition and nature of front according to the lesson. After that, explain the mechanism of the formation of front with suitable diagrams.
2. Here you have to give a brief introduction to front. After that give a detailed explanation of formation of front and associated weather conditions with appropriate diagrams.
3. Differentiate between frontogenesis and frontolysis with whole mechanism.
4. As per unit you have to deal here the whole information of temperate cyclone and its associated weather phenomenon with diagram.
5. First you have to define cyclone. Then explain its type as tropical and temperate cyclone. At last differentiate between tropical and temperate cyclone according to the unit.

11.14 REFERENCES AND FURTHER READING

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GLOSSARY

Air Mass : Air mass is defined as a homogeneous body of air in which the upward gradients of temperature and moisture are uniform over extensive area covering thousands to millions of square kilometres.

Burst of Monsoon : Burst of monsoon is defined as sudden and powerful outbreak and surging of south-west monsoon in June in Indian sub-continent.

Cherry Blossoms : The rain during hot and dry summer season (mid-March to mid-June) in Karnataka is called cherry blossoms and mango rains in south India and some parts of north India.

Cold Air Mass : The air mass having less temperature than the temperature of underlying surface is called cold air mass.

El Nino : This is a name given to the periodic development of a warm ocean current along the coast of Peru as a temporary replacement of the cold Peruvian current. 'El Nino' is a Spanish word meaning 'the child', and refers to the baby Christ, as this current start flowing during Christmas. The presence of the El Nino leads to an increase in sea-surface temperatures and weakening of the trade winds in the region.

El Nino Modoki : El Nino Modoki is a coupled ocean-atmosphere phenomenon in the tropical Pacific. El Nino Modoki is associated with strong anomalous warming in the central tropical Pacific and cooling in the eastern and western tropical Pacific.

Indian Ocean Dipole : It is the difference in sea surface temperature between two areas (or poles, hence a dipole) – a western pole in the Arabian Sea (western Indian Ocean) and an eastern pole in the eastern Indian Ocean south of Indonesia.

Jet Stream : The strong and rapidly moving circumpolar upper air westerly air circulation in a narrow belt of a few hundred kilometres width in the upper limit of the troposphere's is called jet stream.

La Niña : In some years, the trade winds can become extremely strong and an abnormal accumulation of cold water can occur in the central and eastern Pacific. This event is called a La Niña.

Loo : It is a strong, dusty, gusty, hot and dry summer wind from the west which blows over the Indo-Gangetic Plain region of North India and Pakistan. It is especially strong in the months of May and June. Due to its very high temperatures, exposure to it often leads to fatal heat strokes.

Mango Shower : The summer rains are called mango showers in south

India.

Northeaster : The bad weather brought by winter maritime polar North Atlantic air mass in the north-eastern USA is locally called 'North-Easter' which is characterised by strong north-east cold winds, exceedingly low temperature well below freezing point, high moisture content in the air, snowfall, sleet and hailstorm.

Phytoplanktons : These are microscopic marine algae.

Retreating Monsoon : In the month of September the North-East trade winds bring rain on the "Coromandel Coast", which is called *"retreating monsoon".*

Source Region : The place of origin of the air masses is called as source region.

Southern Oscillation : Spatio-temporal changes in the high- and low-pressure system in the tropical eastern and western Pacific Oceans are called southern oscillation (SO).

Thermocline : The thermocline is a subsurface ocean horizon where temperature rapidly decreases with depth. This shallow thermocline in the eastern equatorial Pacific is a key component of the ocean-atmospheric connection that characterises the tropical Pacific and El Nino-Southern Oscillation.

Thermodynamic Modification : Thermodynamic modification of an air mass involves its heating and cooling from below while passing through different surfaces away from the source region.

Tropical Cyclone : It is a rapidly rotating storm system characterised by a low-pressure centre, a closed low-level atmospheric circulation, strong winds, and a spiral arrangement of thunderstorms that produce heavy rain and squalls.

Walker Circulation : A typical east-west convective cell of circulation of tropical winds is called Walker circulation named after G.T. Walker in the year 1922.

Warm Air Mass : A warm air mass is that the temperature is greater than the surface temperature of the region over which it moves.

Western Disturbances : The cyclonic waves visiting north-west India and the Ganga plains during winter and early summer seasons are called western disturbances.