PREFACE

In a bid to standardize higher education in the country, the University Grants Commission (UGC) has introduced Choice Based Credit System (CBCS) based on five types of courses viz. *core, general elective, ability and skill enhancement* for graduate students of all programmes at Honours level. This brings in the semester pattern, which finds efficacy in sync with credit system, credit transfer, comprehensive continuous assessments and a graded pattern of evaluation. The objective is to offer learners ample flexibility to choose from a wide gamut of courses, as also to provide them lateral mobility between various educational institutions in the country where they can carry their acquired credits.

UGC Open and Distance Learning (ODL) Regulations, 2017 have mandated compliance with CBCS for U.G. programmes for all the HEIs in this mode. Welcoming this paradigm shift in higher education, Netaji Subhas Open University (NSOU) has resolved to adopt CBCS from the academic session 2021-22 at the Bachelors Degree Programme (BDP) level. The present syllabus, framed in the spirit of syllabi recommended by UGC, lays due stress on all aspects envisaged in the curricular framework of the apex body on higher education. It will be imparted to learners over the six semesters of the Programme.

Self Learning Materials (SLMs) are the mainstay of Student Support Services (SSS) of an Open University. From a logistic point of view, NSOU has embarked upon CBCS presently with SLMs in English/Bengali. Eventually, the English version SLMs will be translated into Bengali too, for the benefit of learners. As always, all of our teaching faculties contributed in this process. In addition to this we have also requisitioned the services of the best academics in each domain in preparation of the new SLMs. I am sure they will be of commendable academic support. We look forward to proactive feedback from all stakeholders who will participate in the teaching-learning based on these study materials. It has been a very challenging task well executed, and I congratulate all concerned in the preparation of these SLMs.

I wish the venture a grand success.

Professor (Dr.) Subha Sankar Sarkar
Vice-Chancellor

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NETAJI SUBHAS
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Module-1

Module-2

MODULE-1
ELEMENTS OF THE ATMOSPHERE

Module 1 : Elements of Atmosphere
Learning Objectives:

The objectives of the module are:

1. Climate has the immense influence on the earth's surface. Identify the interlinks of climate with lithosphere, hydrosphere, atmosphere and biosphere.
2. Trace the elements of atmosphere.
3. Explanation of the heat budget of the planet earth.
4. Identification of the factors controlling insolation.
5. Analyse of the horizontal and vertical distribution of temperature.
6. Analyse of the green house effects.
7. Identification of the importance of ozone.

Unit 1 ❐ Elements of the Atmosphere

Structure

1.1 Introduction

Weather is the physical state of the atmosphere at a given place and time. It refers to the physical condition of the atmosphere for a short period like one to seventy-two hours. Weather condition is therefore, regulated by the amount of solar radiation received at a particular place, and temperature, relative humidity, precipitation, evaporation, wind speed and wind direction. The state of atmosphere is never static but always it is changing to form equilibrium. Therefore, the climate is always in a dynamic equilibrium. Now a days, a variability in climatic components particularly the temperature and rainfall is observed. The rising trend in the maximum and minimum temperature and the erratic behaviour of precipitation are termed as significant features of climate change.

1.2 Objectives

i. To know the nature of the atmosphere.
ii. To know the composition of the atmosphere.
iii. To know the layers of the atmosphere.
iv. To know the structure of the atmosphere.

1.3 Nature, Composition of the Atmosphere

A blanket of gases, suspended solid and liquid particles that envelopes the earth's surface is called the atmosphere. The atmospherer is a mixture of many gases. In addition, it contains huge numbers of solid and liquid particles, they are collectively called aerosols. Some of the gases may be regarded as permanents atmospheric components that remain in fixed proportions to the total gas volume. Other components vary in quantity from place to place and from time to time.

The different components of the atmosphere have got their individual characteristics. These are–

Gases: Of all the gases oxygen happens to be the most important as it is so essential to all life forms. No life is possible without it. It is capable of combining with all other element to form different components. It is also essential for combustion. The proportions of the gases present in the atmosphere are given below–

Constituents	Percentage by volume
Nitrogen	78.08
Oxygen	20.94
Argon	0.93
Carbondioxide	0.03
Neon	0.0018
Helium	0.0005
Ozone	0.00006
Hydrogen	0.00005

Atmospheric Layers: Nature, composition and structure

Introduction–Atmosphere is described as 'a blanket of air' surrounding the earth. The density of atmosphere decrease with increase in altitude. About 97% of the air is concentrated in lower 29 km.

Characteristics–The atmosphere is different from the lithosphere and hydrosphere as air in colourless, odourless and can be felt only when it blow as wind.

Importance of terrestrial atmosphere–It provides oxygen and carbondioxide and maintain the requisite level of water and radiation in the earth system. It is gaseous covering of earth which maintain the temperature of earth that suits our planet. It also shields us from Sun's ultraviolet radiation and act as a protective wall against the *bombardment* of meteors of all size.

Composition of Atmosphere–The atmosphere can be described as blanket of air surrounding the earth. This enveloping mixture of gases contains huge numbers of solid and liquid particles collictively called *aerosols*, mostly Nitrogen, Oxygen, Argon, Carbondioxide and Water vapour made the bulk of atmosphere.

1. **Gases–**

(i) **Oxygen–**Of all the gases Oxygen is the most important. All living organism inhale Oxygen. No life is possible without it. Oxygen occurs throughout the year upto

120 km of the atmosphere. Below 60 km it exists as molecules of Oxygen (O_2) and above 60 km as dissociated atomic oxygen (O). It is only 20.94% by volume.

(ii) **Nitrogen–**It is another important gas which is about 78% present in atmosphere It serves mainly as diluent. It's main function in atmosphere is to regulate combustion by diluting Oxygen and indirectly helps in oxidation of different kind. Nitrogen is important for protein production.

(iii) **Carbondioxide–**The third important gas it is transparent to most of the solar radiaiton which are incoming but opaque to all outgoing terrestrial radiation. It is largely responsible for green house effect althrough about half of additional Carbondioxide is absorb by ocean or consume by planets.

The green plants in the process of photosynthasis extract Carbondioxide from the atmosphere and utilized it. It help in respiration of green plants.

(iv) **Argon–**It has least important of three major gases in terms of volume and its contribution. It enters the atmosphere as a result of radioactive breakdown of potassium within surface rocks. The name argon is derive from greek word *pyov*. meaning inactive. It is a noble gas.

(v) **Ozone (O_3)–**It is another important gas. It is a type of oxygen molecule form by three atoms. It is found in small quantity in upper atmosphere. It is found between word 10 to 50 km above the surface. It act as a filter and absorbs the ultraviolet rays radiating from the sun and prevent them from reaching earth surface.

(vi) **Other gases–**In our atmosphere we also found Neon, Helium, Hydrogen, Methane, Krypton and Xenon.

2. **Water vapour–**It is one of the most variable gases in the atmosphere, which decrease with altitude. In warm and wet tropics, it account for 4%, while in dry and cold area of desent and polar region may be less than 1%.

Water vapour also decrease from equater to pole. It absorbs part of insolation from the sun and preserues the earth radiated heat it thus act like a blanket allowing the earth neither to become too cold and too hot. Water vapour also contribute in stability and instability of air. Water vapour is a source of all cloud and precipitation. If there is high temperature in air, then larger the capacity to hold the moisture.

3. **Dust Particles–**Atmosphere as a sufficient capacity to keep small solid particles which may orginate from different sources and includes sea salts, fine soil, smoke-soat, ash, pollen, dust and particles of meteors.

- Dust particles are generally concentrated in the lower layers of the atmosphere as conventional air current may transport them to great heights. The higher concentration of dust particles is found in subtropical and temperate regions due to dry winds in camparison to equatorial and polar region.

- Dust and salt particles act as hygrosopic nuclei around which water vapour condenses to produce clouds.
- They absorb a part of incoming short wave solar energy.
- Dust particles by the process of scattering contribute a varied colours of red and orange at sunrise and sunset.
- The blue colour of the sky is also due to selective scattering by dust particles.
- The duration of dawn and toilight as well as their intensity are all controlled by the presence of these solid particles in air.

1.4 Layering of the Atmosphere

Introduction: Atmosphere consists of different layers with varying density and temperature. Density is highest near the surface of the earth and decrease with increse in altitude.

Structure of the a atmosphere can be analysed on the follwong bases:

(i) On the basis of *chemical composition*.

(ii) On the basis of *temperature*.

(A) On the basis of chemical composition, atmosphere can be divided into two zones, viz.

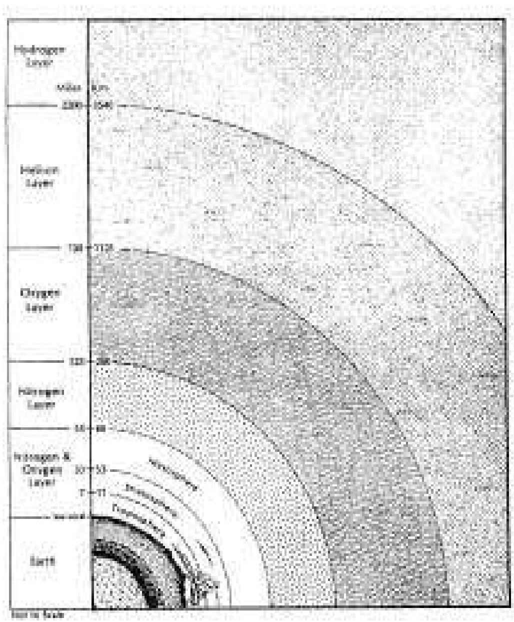

Fig. 1.1: Cross section of the atmosphere showing homosphere and heterosphere (affer Oliver & Hidore, 1984).

(i) Homosphere.

(ii) Heterosphere.

(i) **Homosphere–**It extends from the surface of Earth to 88 km. This region is the result of uniform mixing which is brough by turbulent mixing. Nitrogen, Oxygen, Argon and Carbon dioxide are constitute more or less hemogenous composition.

(ii) **Heterosphere–**Above 88 km the atmosphere is refered as heterosphere. In heterosphere, turbulent mixing has been reduced that the composition is no longer uniform. The molecules and atome above 88 km arrange them in two layers. In lowest level of heterosphere is made with heaviest molecule where as upper level is made up of lightest gases forming four distinct layers:

–Molecular Nitrogen Layer

–Atomic Oxygen Layer

–Helium Layer

–Atomic Hydrogen Layer

The upper reach of heterosphere is called exosphere.

(B) On the basis of temperature:

(i) **Troposphere–**Lowest part of atmosphere in which we live of most of the cloud form. It contains 75% of total gaseous mass.

The term troposphere was first suggested by **Teisserence de Bort**. Tropopshere has been derive from Greekword 'tropos' means 'mixing of'.

- It average height in 13 km. and extends roughly to a height of 8 km near poles and 18 km at the equator. Thikcness of troposphere is more in equator because heat is transported to a great height by strong concustion currents.
- This layer contain dust particles and water vapour.
- All changes in climate and weather take place in this layers.
- The temperature in this layer decreases at the rate of 1°C for every 165m of height.

Importance of Troposphere

(i) **Earth temperature–**The temperature decreases with 6.5^0C for 1 km. height until.

(ii) **Atmospheric phenomena–**All atmospheric phenomena such as rain, wind, clouds take place in this layer.

(iii) **The air movement–**The hot air current move up while cold air current move down.

(iv) **Gaseous–**It contain all the type of gases which are require by human to sustain life.

Layer of trophosphere

–Friction layer is about 1 km high from the surface of the earth. It controls wind speed and direction.

–Surface boundary layers extends upto few meters from the earth's surface.

–Laminar layer extends only few milimeter.

Tropopause–The separating zone between troposphere and stratosphere is tropopause. It is the upper limit of clouds and storm and temperature is constant here.

(ii) **Stratosphere–**It is found above tropopause. The lower stratosphere is isothermal in character because temperature does not change.

The height of the layer is 50 km. Stratosphere contains ozone layer, which absorbs ultra violet radiation and sheeld life on the earth. Pilot usually prefer flying aircraft through stratosphere because the lower part of stratosphere layer does not contain clouds or wather disturbance.

(iii) **Mesosphere–**It lies above stratosphere and below thermosphere which is extended upto 80 km. Temperature start decreasing with increase in altitude and reach upto-100°C. This layer contain limited quantities of helium and hydrogen gases. Mesosphere layer protect the planet earth from the celestial rocky masses that enters the atmospheric envelops, where they burn as a result of friction with the air molecules and forming luminous meteors. The upper limit of mesosphere is known as mesospause.

(iv) **Thermosphere** (Ionosphere)–It is located between 80 and 400 km. above mesopause. It contain electrically charged particles known as Ions. Radio waves transmitted from the earth are reflected back to the earth by this layer.

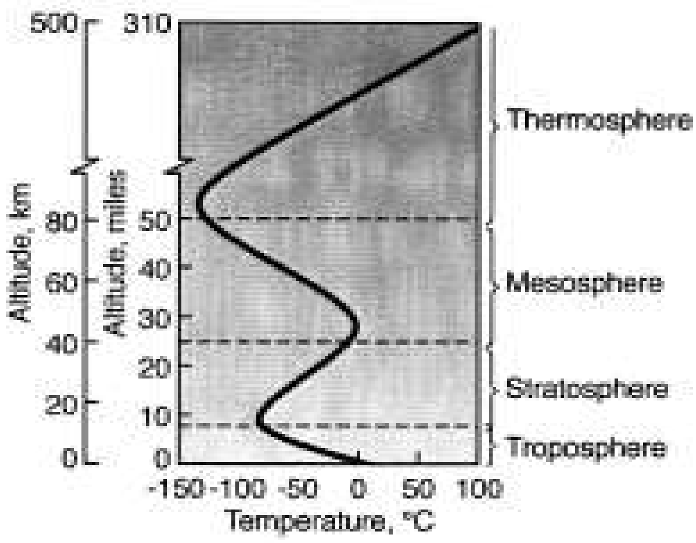

Fig. 1.2: Regions of the atmosphere.

Layers of Ionosphere

D-layer– It reflects low frequency radio waves but absorbs medium and high-frequency waves. It is found from 66 to 99 km. height.

E-layer– This layer is also called kennelly-heaviside layer. It reflect the medium and high frequency radio waves. It is produced by ultraviolet photons from sun interacting with nitrogen and nitrogen moleque.

Sporadict E-layer– This layer occurs under special circumstances. It is caused by meteors and by the same process that cause aurora light. It is at 110 km height and it affects very high frequency radio waves.

E_2 layers– This region is above E-layer. It produced by ultra violet photons acting upon oxygen molecules. Apper in day time and vanishes at the sunset.

Appleton Layers

F_1 Layer– It appears during the day but disappears at night. It is important in long-distance radio communications. It extends from 145 to 240 km.

F_2 Layer– This layer is characterized by diurnal and seasonal variation. It appears as directly related to sunspot activity. It extends from 240 to 465 km.

G-Layer– This layer is at 400 km. and above this layer existence came to be known as a result of the latest exploration carried into the upper part of the atmosphere.

(v) **Exosphere–**It is the outer most layer of the earth's atmosphere which lies between 400 and 1000 km. The density of atmosphere is very low. The atmosphere in this region is rarefied that it resemble nebula.

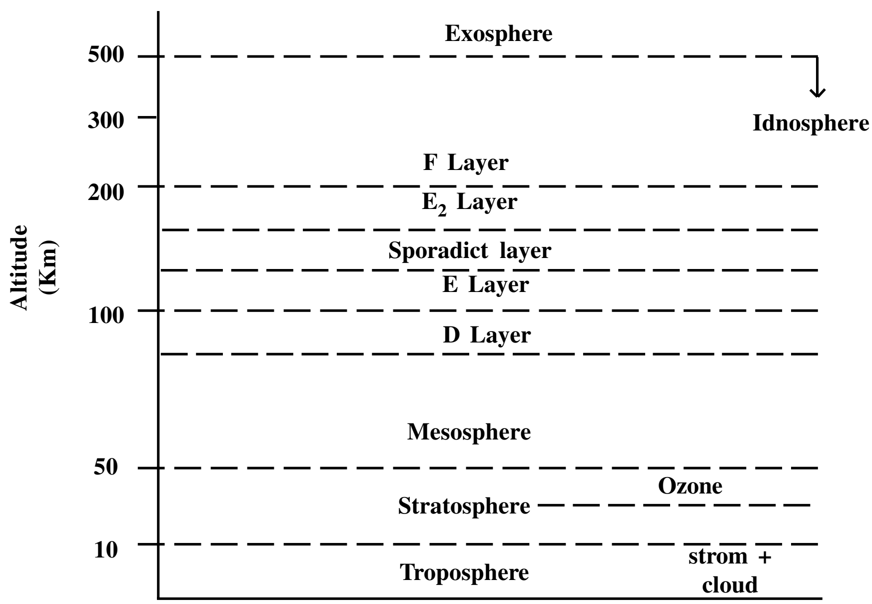

Fig. 1.3: Layers of Atmosphere

Nature of Atmosphere

1. Compared to radius of earth, atmosphere is a very thin layer of air. The radius is 6371 km. which in height of the atmosphere is very small.
2. About 99% of atmosphere lies below 29 km.
3. Height of atmosphere is 0.47% of the radius of earth.
4. Atmosphere is made up of several layers of air and it is influenced by solar radiation, temperature are precipitation.
5. It contain a protective zone called ozone layer.
6. It contain gaseous, water vapour and dust particles.
7. Difference between lower and upper atmosphere is tabulated blow–

Lower Atmosphere	Upper Atmosphere
Nitrogen and oxygen, together with tiny proportions of other gases	Slightly larger proportions of hydrgen, helium, ozone, ionized gases, increasing with height above surface
More water vapour	Little water vapour
More dust particles	Few dust particles
Large porportion of atmospheric gases	Extremely rarefied

1.5 Conclusion

The atmospherer is a mixture of many gases. Most of the gases is the permanents atmospheric components, having individual characteristics, that remain in fixed proportions. In addition, it contains huge numbers of solid and liquid particles, they are collectively called aerosols. Moreover, the atmosphere consists of different layers with varying density and temperature which is very important.

1.6 Summary

- Compared to radius of earth, atmosphere is a very thin layer of air. The radius is 6371 km. which in height of the atmosphere is very small.
- About 99% of atmosphere lies below 29 km.
- Height of atmosphere is 0.47% of the radius of earth.
- Atmosphere is made up of several layers and it is influenced by solar radiation, temperature etc.
- It contain a protective zone, called ozone layer.
- It contain gaseous, water vapour and dust particles.

1.7 Key words

Atmospheric composition, Water Vapour, Carbondioxide, Ozone, Troposphere, Stratosphere, Ionosphere, Tropopause, Stratopause, Mesopause

1.8 Model Questions

Short Answer type:

Write note note: 1. Troposphere, 2. Stratosphere, 3. Tropopause, 4. Ionosphere, 5. Ozonosphere

Long Answer type:

1. Give on account of nature and composition of atmosphere.
2. Describe the layers of atmosphere.

1.9 References

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Unit 2 ❐ Insolation: Controlling factors Heat Budget of the Planet Earth

Structure

2.1 Introduction

The source of energy is the Sun, which is made of hydrogen and helium. The core of the sun acts as huge nuclear reator and convert hydrogen into helium. In this process, huge quantities of energy are generated which is radiated in all direction in space through short waves. This is known as solar radiation. In this portion we came to know about such solar radiation, insolation and albedo. Energy transfer processes including radiation, conduction and connection, maintain a balanced through the heat budget at the earth's surface.

2.2 Objectives

i. To know the concept insolation.
ii. To know the factors controlling insolation.
iii. To know about albedo.
iv. To know the heat budget of the atmosphere.
v. To learn about heat balance of the earth.

2.3 Factors Controlling Insolation

Introduction–Sun is made of hydrogen and helium. The core of the sun acts as huge nuclear reator and convert hydrogen into helium. In this process, huge quantities of energy are generated which is radiated in all direction in space through short waves.

This is known as solar radiation. The incoming solar radiation through short waves is termed as insolation.

Factors affecting or controling Insolation–The amount of insolation received on the earth's surface is not uniform everywhere. It varies from place to place from time to time. The following factors which control insolation are:

1. **Angle of incidence of sun rays:** The earth is geoid shape therefore sun rays strike the surface at different angle. The vertical rays are spread over minimum

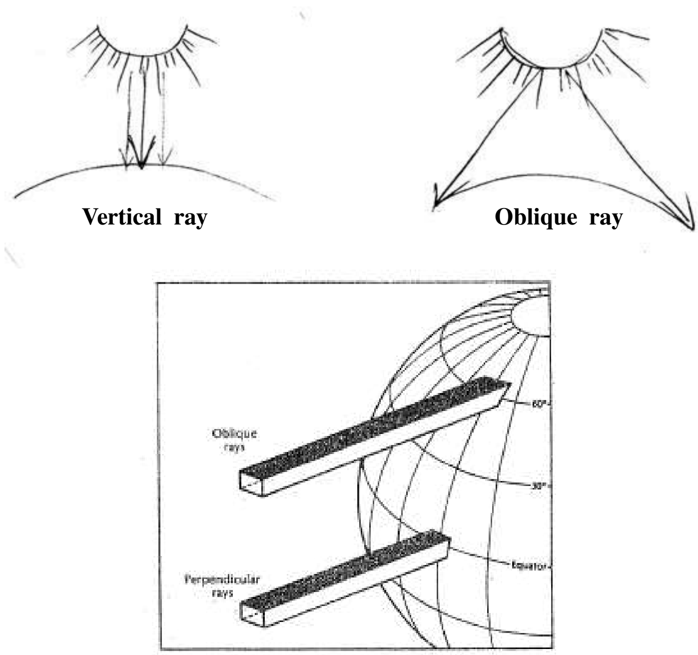

Fig. 2.1: Effect of altitude on Insolation.

   area of the earth's surface and they heat the minimum area but they received maximum solar energy. Oblique rays are spread over large area and therefore, the amount of solar energy receive per unit area decrease. Oblige rays have to pass through thicker portion of the atmosphere than vertical rays thus the oblique rays have to travel larger distance.

2. **Duration of Sunlight–**The duration of sunlight hours determines the length of the day. It varies from place to place and season to season. Greater the length of the day more the amount of insolation received.

   Days are longer in summer hence more insolation receive and days are shorter in winter, hence less insolation receive.

3. **Transparency of the atmosphere–**The amount of solar radiation reaching the earth's surface also depend upon the atmospheric condition. The amount of clould cover and its thickness, dust and water vapour determind the transparency of the atmosphere. Transparency of atmosphere affect the reflection, absorption and transmission of solar radiation. Transparency are closly related to latitude. In higher latitudes the sun's rays are more oblique so they have to pass through thicker layers of the atmosphere than lower latitudes.

4. **Rotation of the Earth** (Distance between the earth and sun)–Since the earth revolves arround the sun, the distance between earth and sun keeps on changing which depend on the insolation received by the earth. Each year on January 3, the earth comes closer to sun and this position is known as **perihelion** and on 4 July the earth is the farther from the sun, this position is called **aphelion**.

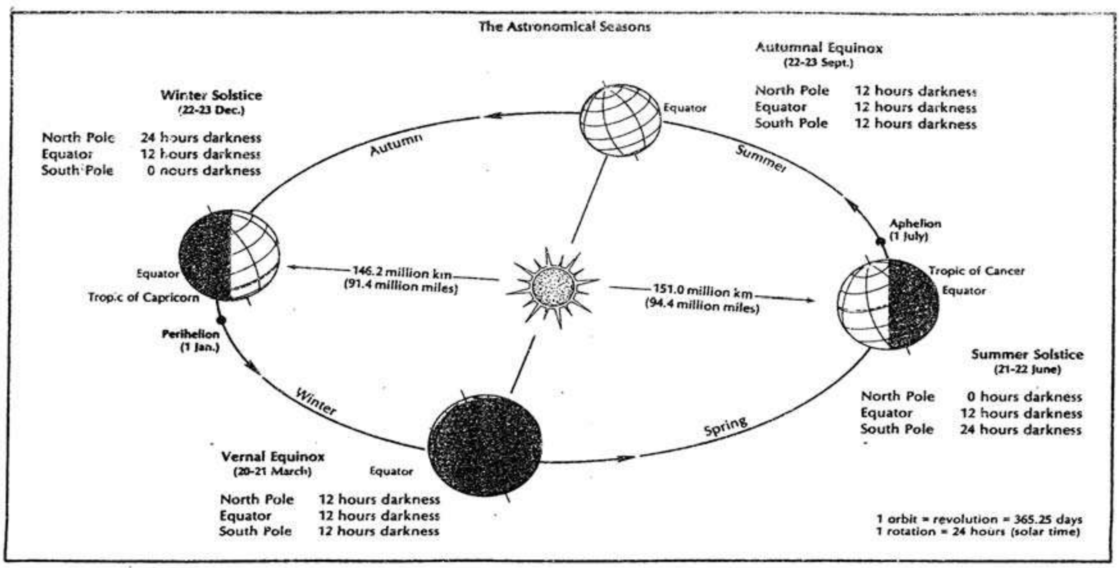

Fig. 2.2: The Earth–Sun relationship (after Oliver and Hidore)

5. **Solar Constant** (Sun Spot): Sun spot is defined as dark area within photosphere of the sun and surrounded by chromosphere. These dark areas are cool areas because they are characterized by 1500^{0}C less temperature than the chromospheres which surrounded them. They are cooler because of intense magnetic fielding. The energy radiated from the sun increases when the number of sunsports increases.

Albedo : The term 'albedo' derive the from latin word 'Whiteness'. Albedo is defined as the reflective quality of a surface. It is expressed as a percentage of reflected insolation to incaming insolation and 0% is total absorption while 100% is total reflected.

In terms of visible colour, darker colour have low albedo because they absorb more insolation and lighter colour have high albedo or rate of reflection in high.

The angle of sun also impacts albedo value, lower sun angles create greater reflection because the energy coming from a low sun angle is not stronger as compare to higher sun angle additionaly smooth surface have higher albedo while rough surface reduce it. The earth average albedo is arround 31%.

Albedo effect has a significant impact on our climate the lower the albedo, the more radiation from the sun that get absorbed by the planet and temperature will rise. If the albedo is higher and the earth is more reflective than more radiation is reflected to the space and the earth would be cool.

2.4 Heat Budget of the Planet Earth

Introduction–Heat budget is the perfect balance between incoming heat absorbed by earth and outgoing heat escaping it in the form of radiation. If the balance is disturbed then earth would get progressively warmer or cooler.

Atmospheric balance

- Let consider that the insolation received at the top of the atmosphere is 100%.
- While passing through the atmosphere some amount of energy is reflected, scattered and absorbed.
- Roughly 35 units are reflected back to space before reaching the earth surface so out of 100 – 35 = 65 left.
- About 27 units are reflected back from the top of clouds, 2 units from snow and ice cover and 6 unit get scatter and absorbed.
- The remaining 65 units, out of which 14 units absorbed with in the atmosphere.
- Only 51 units received by the earth surface and this 51 radiates back by long wave.
- About 17 units are directly radiated to space.
- Now 34 units are absorbed by atmosphere when the earth radiates back the heat out of 34, 6 units absorbed by atmosphere, 9 units through connection and 19 units through the latent heat.
- Now the 14 units which radiates back before and the 34 units radiates after reaching the earth surface is (14 + 34 = 48).
- Thus the total radiation returning from the earth and the atmosphere is 17 + 48 = 65 which is the total unit received by earth.

Latitudinal Heat Balance–It is a state of balance which exist between the latitodinal belts.

- The insolation on the surface of the earth varies because of its tilted axis or angle.
- Insolation decreases poleward from equator. At latitude below 40° or more, the solar radiation received more than lost. Beyond 40° latitudes, more heat is lost than received.
- In tropics, where the insolation is high throughout the year, more solar energy is received than heat loss.

In polar region on other hand, there is more heat loss than received. In this way tropics should have been getting progressively hotter and poles pregressively cooler. But this is not so because heat energy transfer within the atmosphere prevent such situation.

The imbalance in the atmosphere and ocean created due to insolation, winds and ocean currents which transfer heat from surplus regions (tropical) to deficit (pole) regions and help in maintaining overall balance on the surface of the earth.

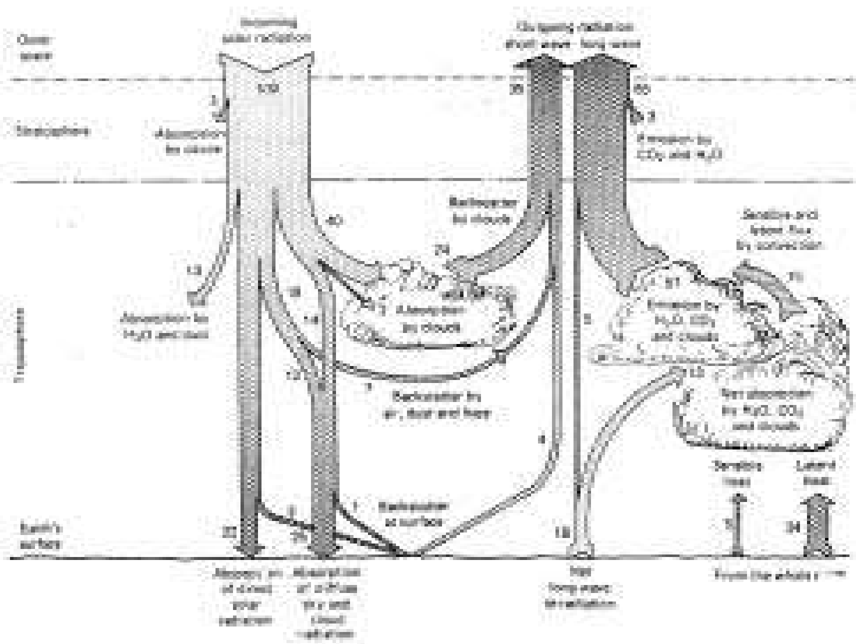

Fig. 2.3: The Earth's radiation balance (Gross, 1977).

Analysis of Heat Budget

The radiation budget of a place is seldom in balance. Actually there is an annual deficit at high latitudes and annual surplus at low latitudes, because of the two factors:

- Angle of incidence of sun's light.
- Surface Albedo

At any latitude, variation in slope, explosure, characters of surface cover (e.g. water, land or vegetation) produce regional difference in the radiation budget.

In the middle and low latitudes, a true radiation balance may exist briefly at the beginning and end of each daylight period, when deficits and surples replace one another.

Energy transfer processes including radiation, conduction and connection maintain a balanced heat budget at the earth's surface.

Analysis shows that for the earth atmosphere system as a whole, the incoming short wave radiation on an average exceeds the outgoing long wave radiation equatorwards of 35° latitudes while the long wave radiation exceeds the short wave radiation polewards of 35° in both hemisphere.

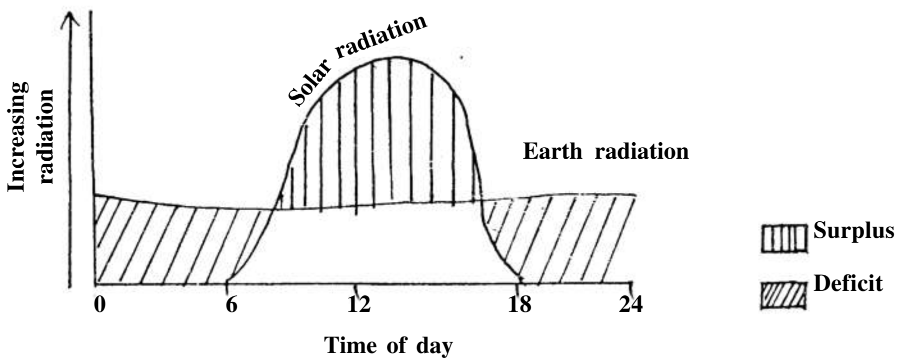

Fig. 2.4: Diurnal regimes of incoming and outgoing radiation at the earth's surface during a day near the time of an equinox.

Since all latitudes find to maintain the same means annual temperature from year to year, there must be a continual poleward transfer of energy from those latitudes equatorwards of 35° (where there is an excess of radiant energy) to those latitude poleward of 35° (deficit areas).

The transfer of this energy, which reaches a maximum at latitude 35° is the prime function of the general circulation of the atmosphere. Most of the energy treansfer (70°–90°) is done by atmosphere circulations, rest is tansfered by ocean currents.

Incident solar radiation averaged over the globe is:– solar constant × $\pi^2/4\pi R^2$ (where R = Radius of the earth and $4\pi R^2$ is the surface area)

This Figure is approx 342 wm^{-2} or 11 × 10^7 jm^{-2} y^{-1}

This may be regarded as 100 units.

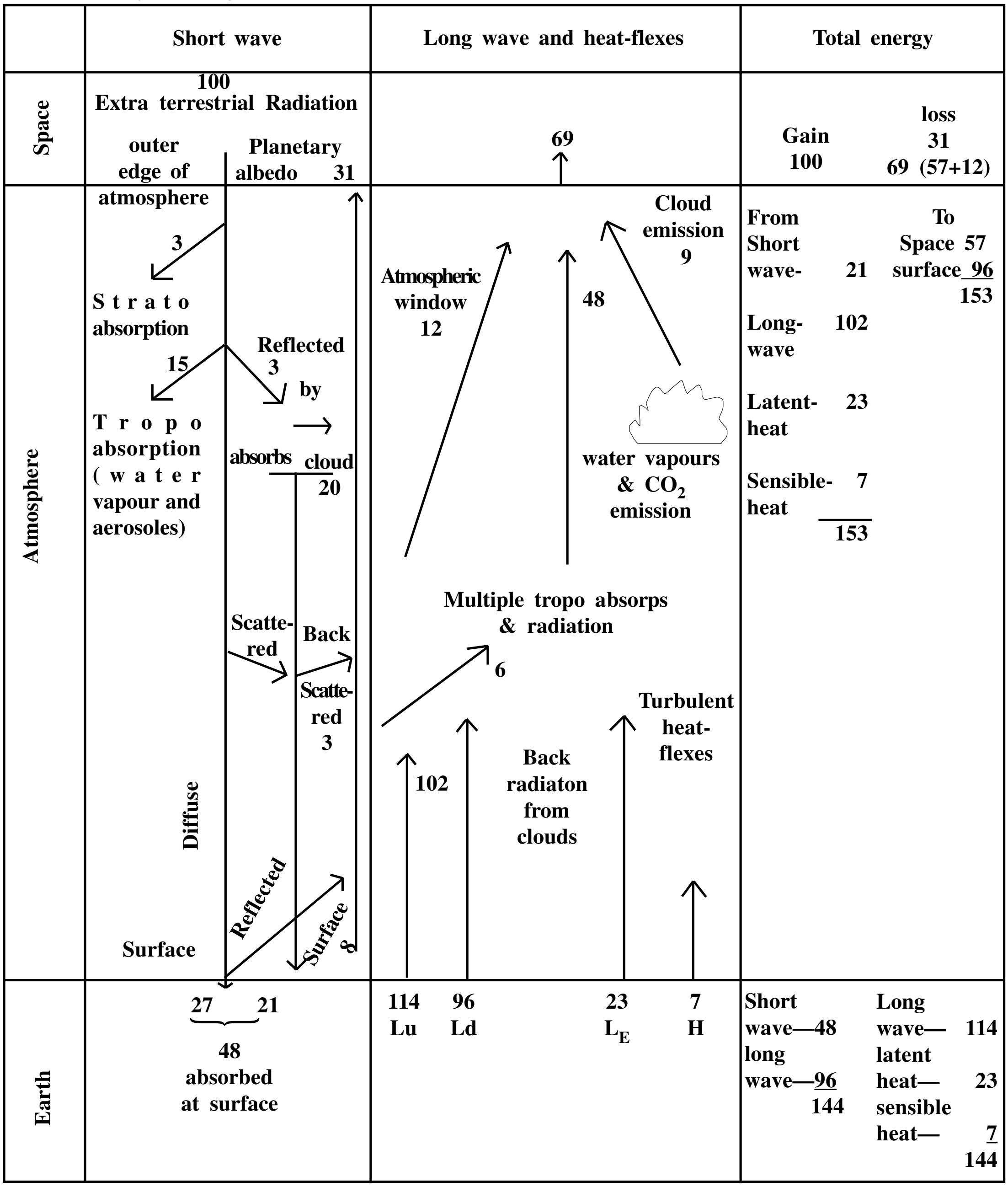

Fig. 2.5: Heat Budget

2.5 Conclusion

The solar radiation, insolation and albedo are operated in the earth's atmosphere which helps to maintain the heat balance of the earth. The incoming solar radiation to the earth surface is very much essestial to heat the earth. Moreover, the reflected energy, i.e. albedo is also very significant as different surface have diverse amount of albedo.

2.6 Summary

- The incoming solar radiation is the insolation.
- The amount of reflecting solar enrgy is albedo.
- The amount of insolation is 66%.
- The amount of insolation is 34%.
- Heat budget is the perfect balance between incoming heat absorbed by earth and outgoing heat escaping it in the form of radiation.

2.7 Key words

Insolation, albedo, heat budget, heat balance

2.8 Model Questions

Short Answer type:

1. What is Albedo?
2. What is Insolation?

Long Answer type:

1. Explain the factors or of Insolation.
2. Explain the heat budget of the earth.

2.9 References

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Unit 3 ❐ Temperature: Horizontal and Vertical distribution. Inversion of Temperature

Structure

3.1 Introduction

Temperature indicates the relative degree of heat of a substance. Heat is the energy which make them hot, while temperature measures the intensity of heat. There is a close relationship between heat and temperature as gain or loss of heat depend on higher and lower tempreature.

3.2 Objectives

i. To know the nature of temperature distribution pattern of the atmosphere.
ii. To know the horinzontal distribution of temperature in the atmosphere.
iii. To know the vertical distribution of temperature in the atmosphere.
iv. To know the inversion of temperature in the atmosphere.

3.3 Horizontal Distribution of Temperature

Introduction–Temperature indicates the relative degree of heat of a substance. Heat is the energy which make them hot, while temperature measures the intensity of heat. There is a close relationship between heat and temperature as gain or loss of heat depend on higher and lower tempreature.

Distribution of temperature can be analysed as:

(i) Horizontal distribution of tempreature

(ii) Vertical distribution of tempreature

(i) **Horizontal distribution of tempreature–**Distribution of temperature across the latitudes over the surface of earth is called horizental distribution. On map horizontal distribution is commonly shown by isotherms. Isotherms are the line connecting point with equal tempreature. Isotherms is made up of two word 'iso' and 'therms'. 'Iso' means equal and 'therms' means tempreature.

There are some parts of the earth where isotherms are closely spaced signifies temperature is changing rapidly in horizontal direction. Widely spaced isotherms signifies slight horizontal temperature difference. The rate of change of temperature is called the temperature gradient. Isotherms run parallel to latitude as same amount of insolation received by all the points located on same latitude.

Factors affecting the distribution of temperature:

1) **Latitude–**The sun ray strike differently in different part of earth surface at different angle. At equtor the rays hit the earth's surface at an angle of 90°, therefore, tempteature is higher rear equator and lower at the pole.

2) **Land and Sea–**The difference in heating of land and water affect the temperature of place, as land heat up more faster than sea similarly it also cools down faster than sea. Hence during day time temperature is relatively higher an land during day time and temperature is higher on sea at night time.

When sea is cooler than the land in summer, it lower the temperature of coastal place and during the winter sea is warmer than the land and keep costal place warm.

3) **Relief and Altitude–**Relief features such as mountains, plateaus and plains control the temperature by way of modifying its distribution. Mountain act as barriers against the movement of winds. The Himalayan ranges prevent cold winds of central Asia from entering India during winter.

4) **Ocean Currents–**There are two type of ocean currents, cold ocean currents and warm ocean currents. Cold ocean currents brings water from polar region to warm region and warm current bring warm water to cold or polar region. Therefore, warm current rise the tempreature in northern hemisphere and cold current decrease the tempreature.

5) **Prevalling wind–**Wind also affect temperature because they transport heat from one region to the other. The wind blow from land towards ocean drive

warm surface water away from the coast and uplight cold bottom water.

6) **Vegetation cover**–The land without vegetation cover absorb more heat as a result temperature rise, whereas land with vegetation cover absorb less heat as the vegetation receive more heat which don't allow radation to reach in soil.

7) **Other factors**–Other factors include nature of soil, slope, evaporation, condition etc. The horizontal distribution of temperature over the global can be studied easily from the maps of January and July month. Pattern of Horizontal distribution of Temperature:

(A) **Horizontal distribution of temperature in January:-**

– In January, the sun shines vertically overhead near tropic of capricorn. Hence, it is summer in southern hemisphere and winter in northern hemisphere.

– A high temperature is found over the landmasses mainly in 3 regions of southern hemisphere these regions are North-West Argentina, East and Central Africa and Central Australia. The isotherm of 30°C closes them.

– In Northern hemisphere, landmasses are cooler than the ocean. As the air is warmer over the oceans than over landmasses in the northern region, the isotherms bend toward the north when they cross the oceans and to the south (equator) over the continents.

– This can be clealry visible over the North Altantic Oceans. The presence of warm ocean and isotherms bend towards the pole. Over the land, the temperature decreases sharply and the isotherms bend towards the equator in Europe.

– In the southern hemisphere, the effect of the ocean is well pronounced due to few landmass.

– Here the isothems are more or less parallal to the latitudes and variation in temperature is more gradual than in northern hemisphere.

(B) Horizental Distribution of Temperature in July:-

– In July, the Sun shines vertically overhead near the tropic of cancer. Hence, high temperature are found in the entire northern hemisphere.

– The regions having high temperature including South Western USA, the Sahara, the Arabia, Iraq, Iran, Afghanistan, desert region of India and China.

– However, lowest temperature (0°C) is also noticed in the northern hemisphere during summer in the central part of Greenland.

– During summer, in the northern region, isotherms bend towards the equator while crosses occens and towards the poles while crossing landmasses isotherms are wide spaced over oceans while they are closely spaced over landmasses.

In July the deviation of isotherms is not that much pronouced as in January.

Cmparison between January and July isotherms: The maps reveals the following characteristics–

1 The latitudinal shifting of highest temperature as a result of migration of the vertical rays of the sun.

2. Highest value occur in low latitude equator to 40° and the lowest value in high latitude is due to decreasing insolation from equator to the pole.

3. In northern hemisphre, isotherms on land bend toward pole in winter and toward equator in summer. This is caused by difference of heating.

Horizontal Distribution of Temperature in January

Because of the preponderance of land in the northern hemisphere, the isotherms are more irregular and oosely spaced here. On the contrary, because of the larger percentage of water surface in the southern hemisphere, the earth's surface is more homogeneous there. This results in greater egularity in the east-west trends of isothermal lines in that hemisphere. The isothermal are relatively more symmetrical while passing from continents to oceans in the southern hemisphere. The northern hemisphere has a larger number of isothermal lines than the southern hemisphere.

On the continents of the northern hemisphere, the isotherms for the month of January bend sharply towards the equator. This clearly indicates that the cold polar winds lower down the temperature of even more southerly regions in this hemisphere because of the effect of continentality. The winter in the interior of the continents is more severe. On the other land, the isothermal lines on the oceans exhibit a poleward bend showing thereby that within the same latitudes, the oceans in the northern hemisphere are relatively warmer than the continents. This is quite natural, because of the surfaces cool more rapidly and to a greater degree than the water surface.

In January, the coldest place on earth is found in north-eastern Siberia. Another coldest region lies in the Greenland. In the middle latitude region, the western coastal regions of the continents are warmer than their counter parts on the eastern side. This primarily due to the fact that the prevailing westerlies carry warmer temperature from the oceans towards the coasts.

The isotherms in the vicinity of the north pole are conspicuous by their absense a fact which may be attributed to the pancity of climate data in the northern polar region. It may be pointed out that, due to the severity of winter and permafrost in the polar region, a large network of weather observing station is lacking there. Hence, the task of collecting weather data in this extremely cold region becomes very difficult.

The close spacing of the January isotherms over the continents in the northern hemisphere represents a steep temperature gradient. The temperature gradient on the eastern side of North America and Asia has been calculated as 1.5°C per latitude, while on the western side of these continents the temperature gradient is reduced to the value of 0.44° to 0.55°C only.

The mean January heat equtor is located to the south of equator. In this month, the belt of highest temperature on the earth's surface is located on the continents in the vicinity of latitude 35°C in the southern hemisphere.

In Janaury, the effect of warm ocean currents on the horizontal distribution of temperature is well-marked one the ocean in the northern hemisphere. The warm currents cause the isotherms to deflect more towards the pole. At this time of the year, there is larger contrast in temperatrure over the continents and oceans in the northern hemisphere. January being the month of summer in the southern hemisphere, the isotherms are rather straight in that hemisphere.

Horizontal Distribution of Temperature in July

The isotherms in the Northern Hemisphere (where it is summer) are most irregular and zigzag. On the contrary, in the southern hemispher (where it is winter) they are

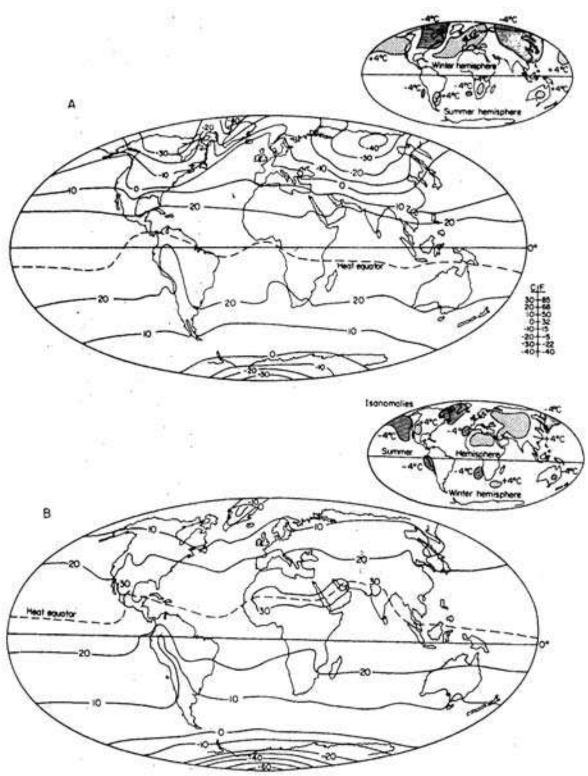

Fig. 3.1 The distribution of average surface air temperature

relatively more regular and straight, except at the edge or the continents where there is a slight bend towards the equator.

An elongated and extensive belt of high temperature about 32.2°C is seem exending from North Africa through south-west Asia to the North-western part of the Indian subcontinent. Another belt of high temperature is found in the south-western part of the United States of America.

In July, the low temperature belt of the cold season now disappears from the north-eastern part of Syberia. This region, because of the effect of continentatily becomes warmer than other region within the same latidues.

In the northern hemisphere, the continents are much warnner than the oceans which are relatively cooler. The maximum amount of temperature contrast is found between the North Pacific and the adjacent lands areas. During the Northern Hemisphere, in summer, there are lesser number of isotherms and they are widely spaced.

With the apparent movement of the sun towards the tropic of cancer, all the isotherms are displaced slightly towards the North, but there is little variation in their general tendency. In July the thermal equator is displaced to the North of the equator.

Another notewarthy feature of July isotherms is that over continents they towards the north pole and over oceans move towards the equator. Temperature gradient in the interior and the eastern margins of the continents becomes weak. There is no substantial change in temperature gradient along the western margins of the continents.

3.4 Vertical Distribution of Temperature

The temperature always decrease with the increase in altitude. This is called vertical distribution of temperature. Vertical temperature gradient are control by the lapse rate and adiabatic lapse rate.

Lapse rate–The obseved rate of vertical decrease in temperature is called vertical temperature gradient or lapse rate.

Lapse rate is not constant but varies with (1) height, (2) location or (3) season. The Lapse rate at a given place and time can be obtained only by actual observations.

- Lapse rate indicates the temperature conditions that are found in a stationary column of air.
- The upward decrease in temperature of the air continues only upto the base of the tropopause.

– In the lower layers of tropopause the lapse rate may be very high on clear, sunny days.

_ On occasions the rate of decrease of temperature may exceed the adiabatic rate. Where insolation is very intense, the lapse rate is super adiabatic upto 160 meters espacilly in dry summer.

– Laspe rate is zero when temperature is constant with elevation and negative when temperature increases with elevation/altitude.

– The conditions of atmosphere and the difference in elevation or local relief features also affected the vertical temperature gradient.

– If a valley in a mountaineous region filled with cold air in upper part of atmosphere the vertical lapse rate becomes low.

– If a surface is intensely heated during daytime the air lying close to it is also heated by the processes of heat transfer.

– The difference between the normal lapse rate in the atmosphere and the dry and wet adiabatic lapse rate determines the vertical stability of the atmosphere

(A) Vertical temperature profile of the Atmosphere

Temperature decreases with increase in altitude, like:-

Troposphere–It is about 13 kilometers thick on an average, it is thicker in summer than in winter. The troposphere, over low latitude regions is usually thicker than over high latitude regions. Troposphere is 18 kilometers thick over the equator and 8 kilometer in pole. The temperature in the troposphere decrease with height at average lapse rate of 6.5°C per kilometer. The air in tropospher is more unstable with strong connection. Almost all the water vapour in the atmosphere exist with in this layer.

Stratosphere–It extends from 13 to 50 kilometer. In lower part it has tropopause. up to 30–35 kilometer the temperature is almost constant. Above 35 kilometer the temperature actually increase with height at the average rate of 5°C per kilometers. Since almost no dust or water vapour from the land surface will reach the stratosphere the air flow in this layer is steady. The upper part of the stratosphere experiences an increase of temperature due to sun's ultra traviolet radiation which are absorbed by ozone layer.

Mesosphere–The region of mesosphere is about 50 to 80 kilometers in altitude. The temperature in this layer usually decreases as the height increases up to the top of mesosphere where the temperature can be low as -95°C or even low.

- The composition of gases in the atmosphere from the ground to the top of the mesosphere are almost identical except for water vapour or ozone, therefore, region upto the mesosphere is also called homosphere.

Thermosphere–This region is above mesosphere and the temperature in this layer decreases as the height increases. Where sun activity is low, this layer can extend to 400 km. During high sun activity, this layer can reach upto 500 kilometer in altitude. The air in the lower region of thermosphere is extremely thin; therefore the particles in the air can easily be ionized and hence it also called ionosphere and it is effecting in reflecting radio waves.

(B) Inversion of temperature

In lower part of the atmosphere upto a height of 881 kilometers from the surface, temperature normally decreases with increasing altitude. The normal lapse rate, as started earlier, is 6.5°C. But sometimes, under special circumtance temperature increase with altitude known as inversion of temperature.

Temperature inversion may occur at lower layer close to the land surface or it may develop at various atmospheric levels at different altitude from the earth's surface.

3.5 Inversion of Temperature

- Temperature inversion is a reversal of the normal behavior of temperature in the troposphere, in which a layer of cool air at the surface is overlain by a layer of warmer air. (Under normal conditions, temperature usually decreases with height).

Effects

- Inversions play an important role in determining cloud forms, precipitation, and visibility.
- An inversion acts as a cap on the upward movement of air from the layers below. As a result, convection produced by the heating of air from below is limited to levels below the inversion. Diffusion of dust, smoke, and other air pollutants is likewise limited.
- In regions where a pronounced low-level inversion is present, convective clouds cannot grow high enough to produce showers.
- Visibility may be greatly reduced below the inversion due to the accumulation of dust and smoke particles. Because air near the base of an inversion tends to be cool, fog is frequently present there.
- Inversions also affect diurnal variations in temperature. Dirnal variations tend to be very small.

Ideal Conditions For Temperature Inversion

1. Long nights, so that the outgoing radiation is greater than the incoming radiation.

2. Clear sky, which allow unobstructed escape of radiation.
3. Calm and stable air, so that there is no vertical mixing at lower levels.

Types of Temperature Inversion

(a) **Temperature Inversion in Inter mountain Valley (Air Drainage Inversion):**

- Sometimes, the temperature in the lower layers of air increases instead of decreasing with elevation. This happens commonly along a sloping surface.
- Here, the surface radiates heat back to space rapidly and cools down at a faster rate than the upper layers. As a result the lower cold layers get condensed and become heavy.
- The sloping surface underneth makes them move towards, the bottom where the cold layer settles down as a zone of low temperature while the upper layers are relatively warmer.
- This condition, opposite to normal vertical distribution of temperature, is known as Temperature Inversion.
- In other words, the vertical temperature gets inverted during temperature inversion.
- This kind of temperature inversion is very strong in the middle and higher latitudes. It can be strong in regions with high mountains or deep valleys also.

(b) **Ground Inversion (Surface Temperature Inversion)**

- A ground inversion develops when air is cooled by contact with a colder surface until it becomes cooler than the overlying atmosphere; this occur most

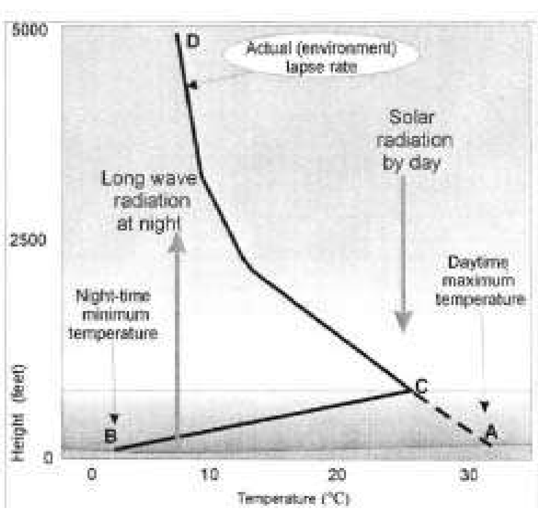

Fig. 3.2: Ground Inversion

often on clear nights, when the ground cools off rapidly by radiation. If the temperature of surface air drops below its dew point, fog may result.

- This kind of temperature inversion is very common in the higher latitudes.
- Suface temperature inversion in lower and middle latitudes occurs during cold nights and gets destroyed during daytime.

(c) **Subsidence Inversion (Upper Surface Temperature Inversion)**

- A subsidence inversion develops when a widespread layer of air descends.
- The layer is compressed and heated by the resulting increase in atmospheric pressure, and as a result the lapse rate of temperature is reduced.
- If the air mass sinks low enough, the air at higher altitudes becomes warmer than at lower altitudes, producing a temperature inversion.
- Subsidence inversions common over the northern continents in winter (are atmosphere) and over the subtropical oceans, these regions generally have subsiding air because they are located under large high-pressure centres.
- This temperature inversion is called upper suface temperature inversion because it takes place in the upper parts of the atmosphere.

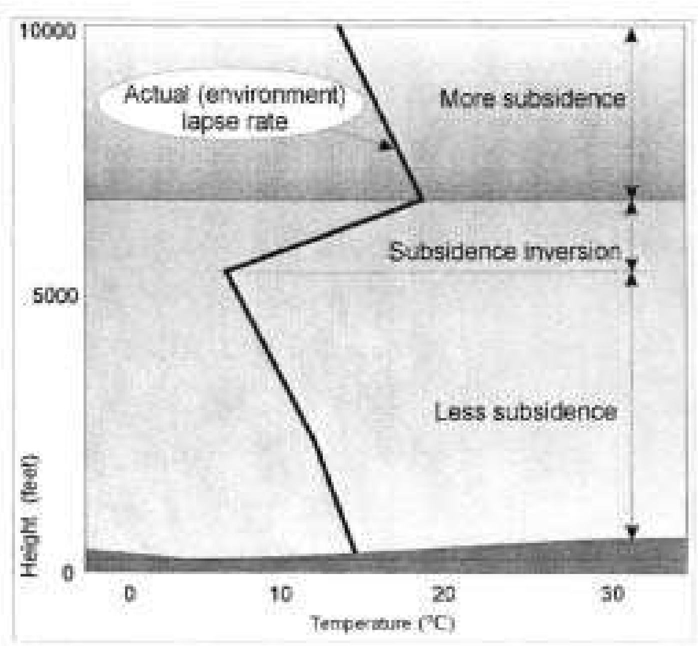

Fig. 3.3: Subsidence Inversion

(d) **Frontal Inversion (Advectional type of Temperature Inversion)**

- A frontal inversion occurs when a cold air mass undercuts a warm air mass

(Cold and Warm Fronts: we will study in detail later) and lifts it aloft. the front between the two qair masses then has warm air above and cold air below.

- This kind of inversion has considerable slope, whereas other inversions are nealry horizontal. In addition, humidity may be high, and clouds may be present immediately above it.
- This types of inversion is unstable and is destroyed as the weather changes.

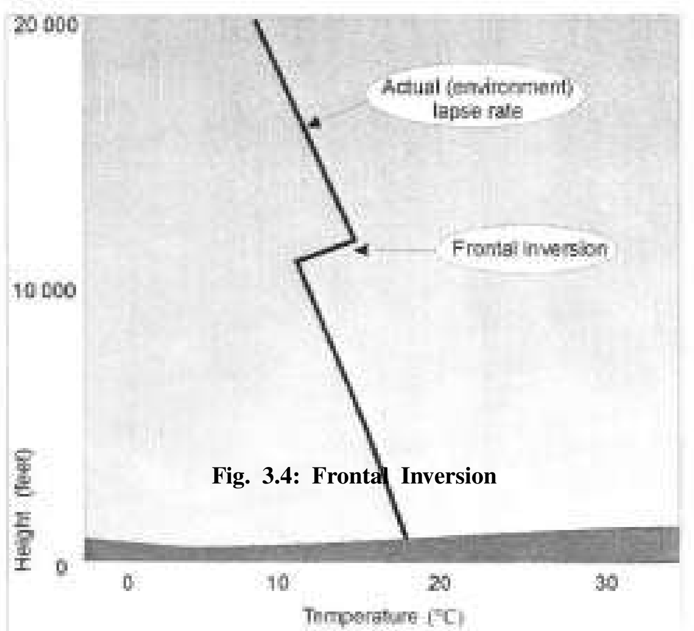

Fig. 3.4: Frontal Inversion

Economic Implications of Temperature Inversion–

- Sometimes, the temperature of the air at the valley bottom reaches below freezing point, whereas the air at higher altitude remains comparatively warm. As a result, the trees along the lower slopes are bitten by frost, whereas those at higher levels are free from it.
- Due to inversion of temperautre, air pollutants such as dust particles and smoke do not disperse in the valley bottoms. Because of these factors, houses and farms in intermontane valleys are usually situated along the upper slopes, avoiding the cold and foggy valley bottoms. For instance, coffee growers of Brazil and apple growers and hoteliers of mountain states of Himalayas in India avoid lower slopes.
- Fog lowers visibility affecting vegetation and human settlements.
- Less rainfall due to stable conditions.

Inversion of Temperature : Brief Note:–

As one moves from the equator towards the pole, steadily decreasing temperature are observed. In the same way there is a leady decrease of temperature with increasing elevation in the atmosphere. This is called vertical temperature gradient.

Vertical temperature gradient are controlled partly by energy transfer and partly by vertical motion in the air. However, various factors affecting interact in a complex manner. Energy treansfer involve the latent heat of condensation, cooling of air by the process of radiation and sensible heat transfer from ground. vertical motion is closely related to the pressure systems. High pressure systems produce descending air currents which leads to warming of extensive layers of air. This results in the decrease of vertical temperature gradient. On the other hand low pressure systems give rise to assending air currents which cool by expansion. This increases vertical temperature gradient moisture is an aditional factor which creates a lot of complication in the vertical distribution of temperature.

The fact that temperature in the lower layers of troposphere shows an upward decrease goes to prove that the direct source of atmospheric heat lies at the earth's surface.

It is noteworthy that heating of the lower layer of air is not caused because of nearness to the earth's surface alone, but there are other factors as well. The air close to the earth's surface is denser than the upper air and contains a larger quantity of water vapour, dust particles and water droplets. On the contrary, the air in the upper strata of the atmosphere is varified, dry and there are little dust particles. Therefore because of the lesser amount of water vapour and carbondioxide the upper air does not absorb as much as heat received from terrestrial radiation as is done by the lower air. Moreover the apper air being more transparent has a low temperature.

There is smaller vertical temperature gradient, if the layer of air near the surface, gets colder because it's contact with the chilled surface of the earth. On the contrary, if the surface is extreamly heated during daytime, the air wing close to it is also heated by the process heat transfer. Under these conditions the lapse rate becomes steeper. Thus, it is clear that sometimes the actual lapse rate is larger than the normal lapse rate and at times smaller than that.

Thus it may be noted that the temperature variation with altitude is many times greater than the latitude variation. Continents and oceans along with harizontal distribution of temperature also influence vertical distribution of temperature.

There are certain levels in the atmosphere where under certain conditions the normal condition of a decrease in temperature with increase in altitude is reversed and temperature increases with increase in altitude. Since in these conditions the cold air

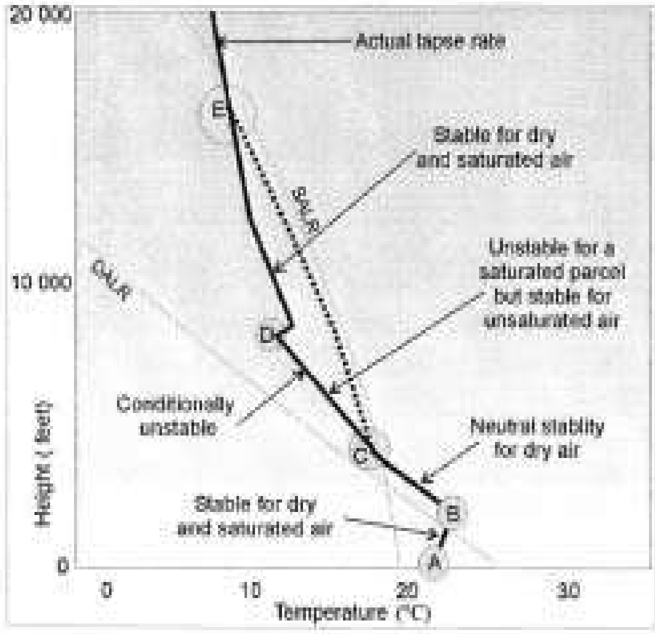

Fig. 3.5 Inversion of temperature

is overlaid by warmer air, the normal lapse rate is reversed. This phenomenon is known as **inversion of temperature.**

In the lower part of the atmosphere upto a height of 8–18 kilometer from the surface, temperature normally decrease with increasing altitude. The normal lapse rate is where with every 1 km. rise in altitude the temperature decreases at 6.5°C. But sometimes under special circumstances, it is reversed and the temperature instead of decreasing is found to increase with elevation.

According to the processes that cause then and the relative heights from the earth's surface at which they develop, the temperature inversion can be classified into the following types–

1) Ground or surface inversion:
   - a) Radiation inversion
   - b) Advection inversion
2) Upper air inversion:
   - a) Subsidence inversion
   - b) Turbulence and convection inversion
3) Frontal inversion

3.6 Conclusion

Temperature is an important weather elements and the distribution of it varies from space and time. It depend on a large number of factors, like latitude, land and sea, altitude, relief, ocean currents, prevailing winds, vegetation cover etc. Moreover, the worldwide, the horizontal distribution of temperation varies in January and July months. Apart from that the vertical distribution of temperation is also varies according to atmospheric layers and temperature inversion occurred in the atmosphere.

3.7 Summary

- An isotherm is a line that connects places that have the same air temperature.
- Distribution of temperature can be analysed by its horizontal and vertical pattern.
- The obseved rate of vertical decrease in temperature is called vertical temperature gradient or lapse rate.
- The temperature in the troposphere decrease with height at average lapse rate of 6.5°C per kilometer.
- Laspe rate is zero when temperature is constant with elevation and negative when temperature increases with elevation/altitude.
- Under special circumtance temperature increase with altitude known as inversion of temperature.

" There are surface, upper air and frontal types of temperature inversion occurred.

3.8 Key words

Horizontal and vertical distribution of temperature, lapse rate, inversion of temperature

3.9 Model Questions

Short Answer type:

1. What is Albedo?
2. What is Temperature inversion?
3. What is Lapse rate?

Long Answer type:

1. Explain the vertical distribution of temperature.
2. Describe the horizontal temperature distribution in Jannuary and July.

3. State the factors that controls horizontal temperature distribution.

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Unit 4 ❒ Greenhouse effect and importance of Ozone layer

Structure

4.1 Introduction

A beam of solar radiation (short wave) passes through the glass house, easily however the long wave radiation cannot pass through the glass and warms the glass house. The solar radiation when falls on the ground and any object, the surface is heated. The long wave radiations emitted by the surfaces are captured by carbon-di-oxide, water vapour, methane and oxides of nitrogen. This process warms atmospheric air thus increased the air temperature. The atmospheric gases which cause the temperature rise are known as Greenhouse gases. Global warming is a long term rise in the average temperature of the earth's climatic system. The global warming commonly refers to the observed and continually increased in average air and ocean temperatures since 1900 caused mainly by emissions of greenhouse gases in the modern industrial economy. The effects of global warming include sea level rise, regional changes in precipitation, more frequent extreme weather events such as- heat waves and expansion of deserts. Surface temperature increases are greatest in the Arctic, with the continuing retreat of glaciers, permafrost and sea ice. Overall higher temperatures bring more rain and snowfall in some areas but droughts and wild fire in some other areas. A majority of people consider global warming a serious threat to the existence of this planet.

4.2 Objectives

i. To know the gaseous component of the atmosphere.
ii. To know the effect of greenhouse gases.
iii. To know the causes of global warming due to greenhouse gases.
iv. To know the effect of global warming.

4.3 Greenhouse Effect

Worldwide changes in climate and sea levels caused by a warming of the atmosphere due to the realease of gases, principally carbon-di-oxide, which are transparent to shortwave radiation, but absorb radiation at certain long wavelengthes. Incoming short wave solar radiation (including visible light) and heat are absorbed at the ground surface by objects which then behave as black bodies, radiating heat (i.e., albedo radiation) back into space, certain, 'greenhouse gases', (e.g. carbon dioxide, water vapour and chlorofluro-carbons) absorb part of this radiation, then radiate it in all direction, some downwards and some to the side where it may encounter other molecules of these gases and continue the process. Thus the gases form a 'blanket' trapping outgoing heat, much as the glass or plastic does in a greenhouse, which lets through most of the incoming short wave solar energy but greatly retards the outgoing long wave earth radiation, thus surface temperature considerable higher than they otherwise would be. This is the so called 'greenhouse effect' of the earth's atmosphere.

Greenhouse-A greenhouse (also called a glasshouse, or, if with sufficient heating, a hothouse) is a structure with walls and roof made chiefly or transparent meterial, such as glass, in which plants requiring regulated climatic condition are grown. These structure range in size from small sheds to industrial-sized buildings. A miniature greenhouse is known as a cold frame, the interor of a greenhouse exposed to sunlight

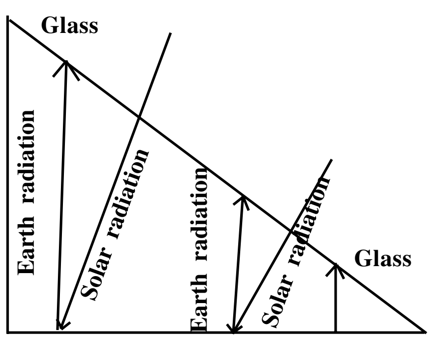

Figure 4.1: Greenhouse

becomes significantly warmer than the external ambient temperaure, protecting its contents in cold weather.

Uses–

1. Greenhouse allow for greater control over the growing environment of plants. Depending upone the technical specification of a greenhouse, key factors which may be controlled include temperature, levels of light and shade, irrigation, fertilizer application, and atmospheric humidity.
2. Greenhouses may be used to overcome shortcomings in the growing qualities of a piece of land, such as a short growing season or poor light levels, and they can thereby improve food production in marginal environments.
3. Greenhouses in hot, dry climates used specifically to provide shade are sometimes called "Shade houses".
4. As they may enable certain crops to be grown throughout the year, greenhouses are increasingly important in the food supply of high-latitude countries. One of the largest complexes in the world is in Ameria, Andalucia, Spain, where greenhouses cover almost 200 km^2 (49,000 acres).
5. Greenhouses are often used for growing flowers, vegetables, fruits, and transplants. Special greenhouse varieties of certain crops, such as tomatoes, are generally used for commercial production.
6. An "alpine house" is a specialized greenhouse used for growing alpine plants. The purpose of an alpine house it to mimic the conditions in which alpine plants grow; particularly to provide protection from wet conditions in winter. Alpine houses are often unheated, since the plants grown there are hardy, or require at most protection from hard frost in the winter. They are designed to have excellent ventilation.

Greenhouse effect Mechanism:

Greenhouse effect is the mechanism by which thermal radiation from earth's surface is reabsorbed by greenhouse gases and redirected in all directions. Some of the major greenhouse gases are water vapour, carbon dioxide, methane and ozone. Most of these gases are poor absorbers of solar radiation, therefore allowing much of the solar energy to pass through the earth's atmosphere thereby warming up the earth's surface. On the other hand, a proportion of the outgoing energy is absorbed by these gases, which is then redirected to earth's surface therefore further wrming up the atmosphere. This is what is called a greenhouse effect. For ages there has been a delicate balance between how much solar energy is redirected to earth and how much is reflected back to the space. With the increased burning of fossil fuels, the percentage of carbon dioxide in the atmosphere has significantly increased thereby adding to the greenhouse effect.

Disadvantages of Greenhouse effect :

- Since greenhouse gases helps to maintain the temperature, the primary effect of the increase in greenhouse gases would be on climate. This would mean warmer summers with natural disasters. Hurricanes have become common in recent years.
- Water level balance of the earth would be destroyed. Polar ice caps would melt leading to an increase in the ocean level. Floods will inundate low lying areas.
- Marine life and ecosystem would be destroyed. Oceans absord carbon dioxide thereby affecting the level of alkalinity. Many forms of marine life would be adversely affected if alkalinity increases. Polar ecosystems would be destroyed. In the Arctic, melting polar caps are threatening the habitats of polar bears and penguins.
- Global warming would also affect the weather pattern. Rainfall would become erratic in many parts of the world. This might eventually lead to desertification.
- The effect on human and economic life would also be tremendous. It is estimated that the rise in temperature would reduce global output by 2 to 3 percent. This cost would run into trilions of dollars. As agricultural production is affected, this might lead to frequent famines and famine related diseases.

Overall the impact of increased greenhouse effect on climate and human life would be disastrous. The world community therefore needs to wakeup now before it is too late.

Causes of the Greenhouse Effect :-

1. **Burning of Fossil Fules**: Fossil fules like coal, oil and natural gas have become an integral part of our life. They are used on large basis to produce electricity and for transpor ation. When they are burnt, the carbon stored inside them is released which combines with oxygen in the air to create carbon dioxide. With the increase in the population, the number of vehichles have also increased and this has resulted in increase in the pollution in the atmosphere. When these vehicles run, they release carbon dioxide, which is one the main gas responsible for increase in greenhouse effect.

   Apart from that, electricity-related emissions are high because we are still dependent on coal for electricity generation which releases large amount of CO_2 into the atmosphere and is still the primary source of fuel for generating electricity. Although, renewable sources are catching up, but it may take a while before we can reduce our dependance on coal for electricity generation.

2. **Deforestation:** Forests hold a major green area on the planet earth. Plants and trees intake carbon dioxide and release oxygen, through the process of

photosynthesis, which is required by humans and animals to suvive large scale development has resulted in cutting down of tress and forests which has forced people to look for alternate places for living. When the wood is burnt, the stored carbon in converted back into carbon dioxide.

3. **Increase in Population:** Over the last few decades, there have been huge increase in population. Now, this has resulted in increased demand for food, cloth and shelter. New manufacturing hubs have come up cities and towns that release some harmful gases into the atmosphere which increases the greenhouse effect. Also, more people means more usage of fossil fules which in turn has aggravated the problem.
4. **Farming:** Nitrous oxide is one the greenhouse gas that is used in fertilizer and contributes to greenhouse effect which in turn leads to global warming.
5. **Industrial Waste and Landfills:** Industries which are involved in cement production, fertilizers, coal mining activities, oil extraction produce harmful greenhouse gases. Also, landfills filled with garbage produce carbon dioxide and methane gas contributing significantly to greenhouse effect.

Greenhouse Gases

Water Vapour - It is the most abundantly found greenhouse gas constituting around 36–70% of all the gases contributing to greenhouse effect. Increase in temperature results in a relatively high presence of water vapour in the atmosphere.

Carbon Dioxide - Although this gas is present in a small amount naturally, urbanization, industrial revolution, and other human activities have largely contributed to the levels of carbon dioxide present in the atmosphere today. It roughly amounts to 9–26%.

Methane - Atmospheric methane is present as a result of both natural and anthropogenic sources. While manure of domestic livestock is one of the major natural contributors, landfills is the prime example of anthropogenic sources. Methane contributes 4–9% to the greenhouse effect.

Nitrous Oxide - This gas is produced by agricultural activities, landfills and burning of fossil fuels.

Chlorofluorocarbons (CFCs) CFCs have an entirely anthropogenic origin, primarily industries. Until recently, they were also used in refrigerators, aerosols, fire extinguishers and air conditioners.

As mentioned previously, greenhouse effect is a natural phenomenon. However, if the percentage of these gases increases to dangerously high levels, the repercussions are for everyone to see.

How to Prevent Greenhouse Effects :

Greenhouse Gases

According to the U.S. Environmental Protection Agency, or EPA, carbon dioxide makes up more than 80% of the greenhouse gas emissions in the country. Methane, nitrous oxide and fluorinate gases also have the ability to trap heat in the earth's atmosphere and create the greenhouse effect. Most of these gases enter the atmosphere when fossil fuels, like coal, oil and natural gas are burned. Paying close attention to energy use is an excellent way to help prevent the greenhouse effect.

Conserve Energy

Almost half of the greenhouse gas emissions in the U.S. are the result of electricity production and other industrial process that rely on the burning of fossil fuels, according to the EPA. To help prevent the greenhouse effect caused by these emissions, take steps to conserve energy. Turn off lights when you leave the room. Buy a programmable thermostat, and wear a sweater instead of turning up the heat, replace incandescent light bulbs with CFLs, and buy appliances with the EPA's energy star label.

Walk or Ride a Bike

According to the EPA, the transportation sector accounts for nearly 30% of greenhouse gas emissions, so if you have to drive to work, try car pooling with coworkers. Using public transportation, walking or riding a bike whenever possible will also help prevent the greenhouse effect. Buying locally made products reduces the distance that products need to be shipped to reach consumers, thereby reducing the greenhouse gas emissions caused by freight transportation. Hybrid cars also emit less greenhouse gases and consume less gasoline.

Plant a Tree

Trees and plants store carbon dioxide; during the process of photosynthesis, plants absorb carbon dioxide from the air, convert it to sugar for growth, and release oxygen back into the atmosphere. Planting a tree means another plant is absorbing carbon dioxide from the atmosphere and preventing the greenhouse effect. Deforestation releases stored carbon back into the atmosphere, so using wood and paper products sparingly will also help prevent the greenhouse effect by reducing the release of greenhouse gases.

A Global Issue

Everyone is affected by the greenhouse effect. Local changes are unlikely to prevent this global problem. United Nations climate scientists have set an upper limit for the amount of carbon dioxide that can be emitted before the greenhouse effect is irreversible. Unless all countries particlpate in plant to reduce carbon emissions and deforestation, this limit will be exceeded in a matter of decades. Individual, lifestyle changes are a good first step towards preventing the greenhouse effect, but this goal will not be achieved without large-scale changes in industrial practices.

Effects of increased greenhouse gas emissions :

The main effect of increased greenhouse gas emissions is global warming. Carbon dioxide, methane, nitrous oxide and fluorinated gases all help trap heat in the Earth's atmosphere as a part of the greenhouse effect. The Earth's natural greenhouse effect makes life as we know it possible. However, human activities, primarily the burning of fossil fuels and deforestation, have intensified the greenhouse effect, causing global warming.

Effects of increased greenhouse gas emissions

Increases in the different greenhouse gases have other effects apart from global warming including ocean acidification, smog pollution, ozone depletion as well as changes to plant growth and nutrition levels.

Global warming

Greenhouse gas levels have been increasing since the start of the Industrial Revolution, but over the last few decades growth has been particularly fast. Total greenhouse gas emissions have increased by about 80% since 1970, creating a radiative forcing of 2838 mW/m∧2 equivalent to an atmospheric concentration of 473 ppm CO_2.

With increasing levels of greenhouse gases being added daily, the greenhouse effect is now enhanced to the point where too much heat is being kept in the Earth's atmosphere. The heat trapped by carbon dioxide and other greenhouse gases has increased surface temperatures by 0.75°C (1.4°F) over the last 100 years.

Global warming is harming the environment in several ways including:

- Desertification
- Increased melting of snow and ice
- Sea level rise
- Stronger storms and extreme events

Ocean Acidification

Increases in carbon dioxide levels have made the world's oceans 30% more acidic since the Industrial Revolution. The ocean serves as a sink for this gas and absorbs about a quarter of human carbon dioxide emissions, which then goes on to react with seawater to form carbonic acid. So as the level of carbon dioxide in the atmosphere rises, the acidification of the oceans increases.

Changes to plant growth and nutrition levels

Since plants need carbon dioxide to grow, if there are higher amounts in the air, plant growth can increase. Experiments where carbon dioxide concentrations were raised by around 50% increased crop growth by around 15%. Higher levels of carbon dioxide makes carbon more available, but plants also need other nutrients like nitrogen, phosphorus etc. to grow and survive. Without increases in those nutrients as well, the nutritional quality of many plants will decrease. In different in different experiments with elevated carbon dioxide levels, protein concentrations in wheat, rice, barley, and potato tubers, decreased by 5–14%.

Smog and ozone pollution

Over the last century, global background ozone concentrations have become two times larger due mainly to increases in methane and nitrogen oxides caused by human emissions. At ground level, ozone is an airpollutant is a major component of smog which is dangerous for both humans and plants.

Long-term ozone exposure has also been shown to reduce life expectancy. 362000-700000 of annual premature cardiopulmonary deaths worldwide are attributable to ozone. Recent studies estimate that the global yields of key staple crops, like soybean, maize (corn), and wheat, are being reduced by 2–15% due to present-day ozone exposure.

Ozone layer depletion

Nitrous oxide damages the ozone layer and is now the most important ozone depleting substance and the largest cause of ozone layer depletion. This is because CFCs and many other gases that are harmful for the ozone layer were banned by the Montreal Protocol (MP) which has reduced their atmospheric concentration. Nitrous oxide is not restricted by the MP, so while the levels of other ozone depleting substances are declining, nitrous oxide levels are continuing to grow.

The Greenhouse Effect and Global Warming:-

How the Greenhouse Effect Works–

Carbon dioxide (CO_2) is an atmospheric constituent that plays several vital roles in the environment. It absorbs infrared radiation in the atmosphere. It plays a crucial role in the weathering of rocks. It is the raw material for photosynthesis and its carbon is incorporated into organic matter in the biosphere and may eventually be stored in the Earth as fossil fuels.

Most of the sun's energy that falls on the Earth's surface is in the visible light portion of the electromagnetic spectrum. This is in large part because the Earth's atmosphere is transparent to these wavelengths (we all know that with a functioning ozone layer, the higher frequencies like ultraviolet are mostly screened out). Part of the sunlight is reflected back into space, depending on the albedo or reflectivity of the surface. Part of the sunlight is absorbed by the Earth and held as thermal energy. This heat is then re-radiated in the form of longer wavelength infrared radiation. While the dominant gases of the atmosphere (nitrogen and oxygen) are transparent to infrared, the so-called greenhouse gasses, primarily water vapour (H_2O), CO_2, and methane (CH_4), absorb some of the infrared radiation. They collect this heat energy and hold it in the atmosphere, delaying its passage back out of the atmosphere. Due in part to the warming effects of the greenhouse gases, the global average temperature is about 15°T (59°F). Without the greenhouse gases the global average temperature would be much colder, about -18°C (0°F).

Greenhouse Gas Induced Global Warming

Since the industrial revolution got into full swing in the 19th century we have been burning ever increasing amounts of fossil fuels (coal, oil, gasoline, natural gas) in electric generating plants, manufacturing plants, trains, automobiles, airplanes, etc. Burning releases CO_2 into the atmosphere (much the same as respiration does). These fossil fuels may have formed tens or hundreds of millions of years ago from the buried and preserved remains of plant and animal matter whose carbon originated via photosynthesis.

Photosynthesis-Respiration-Combustion

photoshynthesis

$CO_2 + H_2O$ + sunlight-> $CH_2O + O_2$

respiration

$O_2 + CH_2O$ -> energy + $H_2O + CO_2$

combuston

O_2 + Hydrocarbons Energy -> + $H_2O + CO_2$

Photosynthesis and respiration in animal, fungi, bacteria, etc. exchange carbon between the CO_2 in the atmosphere and carbon compounds in organisms. But humans are now putting this natural carbon cycle out of balance. Because of the emission of CO_2 long-stored in fossil fuels the percentage of CO_2 in the atmosphere has increased from about 289 parts per million before the industrial revolution to over 360 parts per million and rising. Sometime during the 21st century the concentration of CO_2 will be twice what it was before the industrial revolution.

With higher CO_2 concentrations come expectations of a stronger greenhouse effect and therefore warmer global temperatures. This was originally proposed by a chemist named Arrhenius about a century ago. Global average temperatures have risen by a small, but measurable amount in the past 100 years, apparently in large part because of the higher level of atmospheric CO_2. Global average temperatures are expected to be on the order of 2–5°C (3.6-9°F) higher by the time Co_2 doubles the pre-industrial concentration. The temperature rise will be small in the tropics but much greater at high latitudes.

Consequences of Global Warming

Temperature measurements of the sea surface and deep ocean indicate that the oceans are warming. Rising ocean temperature causes rising sea level from thermal expansion of the water. Rising temperature also means melting glaciers and rising sea level through addition of meltwater to the oceans. Sea level rose about 1 foot during the last century, mostly from thermal expansion of the oceans. Sea level is expected to rise closer to 3 feet during the coming century. Rising sea level will cause increasing coastal erosion, flooding, and property damage during coastal storms on top of the potential for major loss of life from storms in low-lying coastal countries like Bangladesh and Island nations in the Indian and Pacific Oceans.

Warmer sea surface temperatures will result in more and stronger tropical storms (hurricanes and typhoons). Coastlines already ravaged by these storms will expect to see more strong storms than before, increasing the loss of life and damage to infrastructure.

It is much more difficult to predict how regional and local weather patterns will change but there will certainly be changes. While higher temperatures will produce more rainfall across the globe, the regional rainfall patterns will likely change. Some areas will get more, some areas will get less. The timing of wet and dry periods may change. But higher temperatures will also mean more evaporation. Higher temperatures may also mean stronger storms with damaging winds. All of these mean new risks and changing conditions for agriculture. Centuries old farming practices will have to change. Some areas may go from being marginal to becoming a breadbasket region, while other regions may go from major agricultural production to marginal.

Higher CO_2 allows plants to grow faster (more CO_2 enhances photosynthesis). That would sound good for agriculture. However, weed species tend to grow even better than crop plants under erihanced CO_2 conditions so improved crop growth may be nullified by weed competition.

Natural ecosystems will be hard pressed to keep up with the changing climate because the rate of change will be faster than typical long-term natural climate change.

Many species, especially plant species, will not be able to migrate to cooler areas fast enough to keep up with the warming of their habitats. And arctic species will have no place to go and may not be able to adapt to the new conditions.

Severe summer heat in areas not used to it can lead to deaths. Higher heat and expansion of tropical areas may lead to increased incidence of malaria.

What Can We Do About Global Warming :–

We can't realistically stop the rise of CO_2 in the near term, but we can slow it and therefore, reduce the consequences that will occur. More fuel-efficient cars, less frivolous driving, more use of mass transit, improved insulation to decrease the fuel burned to heat and cool our homes, more efficient appliances, use of fluorescent rather than incandescent light bulbs, and careful monitoring of home electricity usage (turn off the lights and TV when not using them) can reduce our energy needs. Conversion to alternatives like wind and solar power which don't burn fossil fuels and emit CO_2 into the atmosphere. Planting large areas with trees will consume CO_2 as the trees grow, until the forests mature. Stopping deforestation in the tropical forests around the world, especially in the Amazon and Indonesian rain forests, will keep that carbon in the forest rather than sending it back into the atmosphere as the trees are burned or decay and are not replaced by more. Other techniques have also been proposed such as the chemical removal of CO_2 from smokestacks and burial in deep underground reservoirs, though only certain areas can benefit from this, or disposal in the deep ocean where they will form a semi-stable compound under the cold temperatures and high pressures, though the CO_2 could too easily come bubbling back up. These latter solutions are not well studied and wouldn't be especially cheap.

Moreover, leaders, societies, communities, local planners, farmers, health organizations, need to recognize the changing climate and rising sea level as they make plans for the future. Our citizens need to be educated as to likely changes and how best to deal with the changing conditions.

Evidence of Global Warming:

1. Breaking up of Antartica ice sheet in 1995, 1998 and 1999.
2. Melting of Earth moutain glaciers, Eg. Mt Kenya and Alps in Eurpoe.
3. Rise of Sea level in 1961 to 2003 (the rate of increase is 1.8 mm per annum)
4. Thicking of Arctic ice and retreat.
5. During 1900–2005, precipitation has increase significantly in North and South America, North Europe and decrease in mediterranean region and some other parts of the world.

4.4 Importance of Ozone Layer or Ozonosphere

Ozone Layer/ Ozonosphere: There is a maxium concentration of ozone between 30 to 60 km. above the surface of the earth. Becasue of the concentration of ozone in this layer it is called ozonosphere. It's existance come to be known from the studies of meteors.

Importance:

(A) There is a general agreement among the scientists that this warm layer is deu mainly to selective absorption of ultravioeet radiation by ozone.

(B) In fact, the ozone layer acts as a filter for the ultraviolet rays of the sun.

(C) According to scientists, the presence of ozone layer in atmosphere is a boon to humanity as it protects us from sunburn by absorbing larger percentage of the ultraviolet radiation.

(D) The environmentalists are much concend that the emission of nitrogen oxide by large number of supersonic transport airplanes may lead to a deterioration of the ozone layer are also to a serious biological damage to people, animals and plants life.

(E) In this layer the temperature increases with height at the rate of 5°c/km. The maximum temperature recorded in the ozonosphere is some what higher than that at the earth's surface.

(F) It may be noted that because of the prepond erance of chemical processes, this sphere is sometimes called 'chemosphere'.

(G) The ozone layer plays a vital role on the earth's environment. Ozone is a form of oxygen which consists of three molecules. This ozone is formed in the ozonosphere just above the troposphere.

(H) Ozone is much more susceptible or weaker, it breaks and thus returns to it's oxygen form. It is found at 16–18 km at the polar latitude and upto 25 km at the equator.

(I) This ozone helps to keep the temperature of the earth's surface at a certain level as it absorbs the ultraviolet radiation from the sun.

(J) Hence the importance of this ozone layer autometically increases. This ozones are constantly being created and destroyed through natural chemical reaction.

(K) Oxides of nitrogen, hydrogen, bromide, chlorine etc are accelerating in the nature and destroying the ozone that are being created certain substance such as chloro-fluro-carbon (CFCs) and carbon tetra chloride (CCL) are harmful for ozone. This distruction of ozone layer is very harmful for mankind.

Ozone hole: 'British Antarctica Survey' found that there has been a 'ozone hole' created in the stratosphere. This ozone hole will have many considerable effects on the earth's environment. Such as–

i) The temperature of the earth's surface will increase steeply and as a result it will lead to more extinction of living being.

ii) Due to breakege, of ozone, the increasing temperature will lead to melting of glaciers.

iii) Due to melting of glaciers, floods will be created in large number of areas across the world.

iv) This uprising sea level which will result due to metting of glaciers will lead to submergence of the lands. Thus it is evident that breakage of ozones will land to extinction of life from the earth's surface.

This decomposition takes place under conditions of ultraviolet radiation into free chlorine atoms, which can react with ozone breaknig it down into ordinary oxygen and chlorine.

Cl	**+**	**O_3**	**→**	**ClO**	**+**	**_ O_2**
Cholorine		**Ozone**		**Chlorine monolide**		**Oxygen**

The simplified reactions are

O_3	**+**	**O**	**→**	**O_2**	**+**	**O_2**
O_3	**+**	**NO**	**→**	**NO_2**	**+**	**O_2 (nitrous oxide acting as catalyst)**
O	**+**	**NO_2**	**→**	**O_2**	**+**	**NO**
O_3	**+**	**Cl**	**→**	**O_2**	**+**	**ClO (with chlorine acting as catalyst)**
O	**+**	**ClO**	**→**	**O_2**	**+**	**Cl**

A single chlorine atom can destroy 100,000 ozone molecules before it drifts down into lower atmosphere and is washed away. The breaking of the ozone molecules has so much aggravated that finally it has created a hole, over Antractica, of the sise of African continent.

We know that in order to survive, mankind and other living beings has to depand on the ozone layer. So, human being has to be aware of the possible results due to the breakage of ozone and should take sufficient measures to stop this ozone depletion which will destroy life on earth. Hence we can understand how important this ozone layer is to mankind and other living organisms on the earth.

4.5 Fomation and Depletion: Ozone (O_3) Layer

Introduction–The Ozone layer or Ozone shield is a region of Earth's stratosphere that absorbs most of the sun's ultraviolet radiation. It contains high concentration of ozone (O_3) in relation to other part of atmosphere. This layer is mainly found in lower stratosphre. This layer was discovered in 1913 by french physicist Charles Fabry and Henri Buisson.

Role of Ozone Layer–

1. The absorption of ultra-violet radiation by ozone creates a source of heat. Thus it play a key role in temperature structure of earth's atmosphere.
2. The filtering action don't allow Sun's UV radiation to penetrate the atmosphere and reach earth surface.
3. If there is no ozone layer than sun UV radition cause harmful effect to crop, forest growth and human health.
4. It play an important role in preventing ice shifting.
5. It protect the environment and ecosystem of the earth.

Ozone hole–Excessive thinning of ozone layer when more than half of the ozone gas in a particular area is depleted and harmful ultraviolet rays can pass through it and reach earth surface, is called ozone hole.

Some parts of Antarctica upto 60% of the total ozone is depleted during Antarctic spring (September to November). O_3– Under the influence of ultraviolet rays of sun, oxygen (O_2) of the atmosphere decempose to Oxygen atoms (O) and one oxygen molecule combinees chemical with an oxygen atom to form ozone molecule of three oxygen atoms.

(i) one oxygen molecule (O_2) $\rightarrow$ two oxygen atom (O+O)

(ii) one oxygen molecule (O_2) + one oxygen atom (O) = one molecule of ozone (O_3)

Causes of Ozone Layer Depletion-

1. **Chlorofluoro Carbon (CFCs)**–This is are formed by chlorine, fluorine and carbonfare used in refrigerator, soluents and for manufacturer of spongy plastic. The most common are CFC 11, CFC 12, CFC 113, CFC 114 and CFC 115. The chemicals caused a reaction which made the ozone layer break down into Oxygen molecule and atom.
2. **Hydro Chero-Fluoro Carbon (HCFCs)—**This are used as substitutes for CFCs as many of their properties are similar and are less harmful to ozone. They realese fewer Clorin atom. But their use has been banned in developed countries since 1930.
3. **Halons–**They are compound formed by Br, F and C. Because of their ability to pur out fires, and are used in fire extinguishers. Their ability to harmful ozone layer is very high because they contain Br. Thus halon 1301 and halon 1211 have ozone deplation potentials of 13 and 14 respectively.

4. **Methyl Bromide (CH_3Br)** It is very effective pesticide that is used to fumigate soils and in many crop production. The Br damages the ozone layer.
5. **Carbon Tetra-Chloride (CCl_4)–**It is widely used as a raw material in many industires for manufacture CFCs and as solvent.
6. **Natural Cause of Depletion of Ozone Layer–**It is also affected by natural phenomena such as sun-spots and stratosphare wind but this cause not more than 1–2% depletion of ozene layer.

Effects of Ozone Layer Depletion:

1. **Effects of depletion of Ozone layer on human health–**

(i) **Skin Cancer**–The most common type of skin cancer called non-melanoma cause by exposures to UV-B radiation for several year.

(ii) **The immune system**–The exposure to ultraviolet light reduces the effectiveness of the immune system. The exposure to UV-B radiation reduce the of immune system to tolerate diseases.

(iii) It also cause sunburn, quick aging and catared problem.

2. **Effects on Aquatic ecosystem—**The loss of phytoplanktan, the basis of the marine food chain has been observed as the cause of the increase ultravioled radiation which can disrupted the marine food chain.
3. **Effects on terrestrial ecosystem–**

(i) **Animal–**UV-B radiation casue skin cancer which has been seen in goat, cow, cat, dog. Infection in cattle can be increase by increases of ultraviolet radiation.

(ii) **Plants**–UV-B radiation affect and damage the word plant growth and reduce resproduction capacity of plants.

4. **Impact on certain material**–Material like plastic, wood, fabrics, rubber are degraded too much by ultraviolet ray.
5. **Effect on bio-geo-chemical cycle–**It increase greenhouse gases in biosphere Eg. carbondioxide, carbon monoxide etc.

Solution of Ozone Layer Deplation—

1. **Pesticides–**Pesticides are great chemicals to rid your form of pests and weeds but may cause ozone layer depletion. Farmer should use alternative ecofriendly chemicals.
2. **Discourage driving of private vechicles–**To minimize ozone depletion we should limit the number of vehicles on the road. As this vehicles emit lot of green house gases and smog.

3. **Use of eco-friendly household cleaning products–**Usage of eco-freindly and natural clearing products to prevent ozone layer depletion. So we should use toxic free products.
4. **Prohibit the use of harmful nitrous oxide**–Government must take action to reduce the use of nitrous oxide to reduce ozone depletion.
5. **Regulation for rocket launches**–A lot of rocket launches happening in the world over without consideration about its damages to ozone layer. A study shows the harm caused by rocket lunches due to CFCs.

4.6 Ozone Hole Formation and its Effects

- **Introduction:** Ozone, is an inorganic molecule with the chemical formals O_3. It is a pale blue gass with a distinctively pungent smell. Ozone is formed from dioxygen by the action of ultraviolet light and also atmospheric electrical discharges and is present in very low concentrations throughout the Earth's atmosphere. Its concentration is highest in the ozone layer region of the atmosphere, which absorbs most of the Sun's ultraviolent (uv) radiation.
- **Ozone Depletion:** There are many situation, where human activities have significant effects on the environment. Ozone layer damage is one of them. The CFC and the holons are patent ozone depletors. One of the main reason of the widespread concern about depletion of the ozone layer is the anticipated increase in the amounts of ultraviolet radiation received at the surface of the earth and the effect of this on human health and on the environment.

  The ozone layer is a layer in Earth's it atmosphere, which contains relatively high concentrations of ozone (O_3). This layer absorbs 93-99% of UV light here. Without ozone, life on earth would not have evolved in the way it has.
- **Ozone Hole:** This term applied to regions, where stratosphere ozone depletion is so severe that it fall below 200 dobson unis (D.U.). Normal ozone concentration is about 300 to 350 D.U. Such ozone loss now occurs every spring time above Antartica and Arctic region.

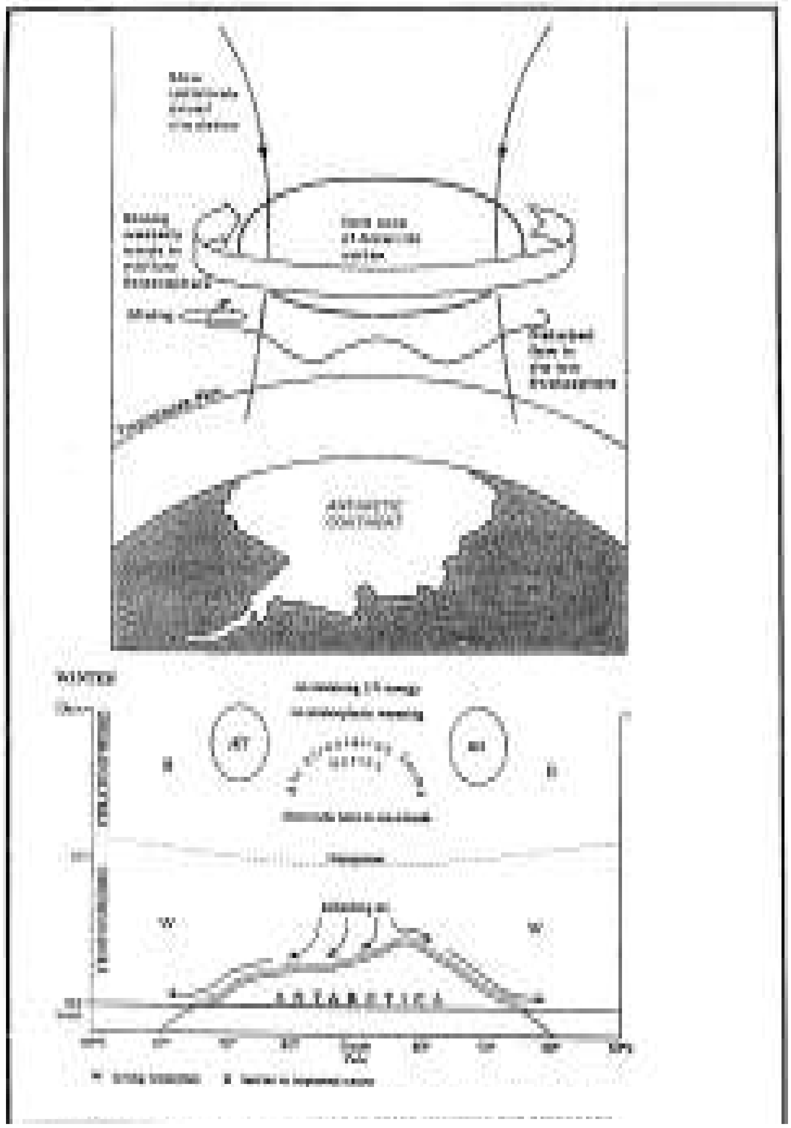

Fig. 4.2: Winter conditions related to ozone formation and destruction

- **Measuring Ozone Depletion:** The most common stratospheric ozone measurement unit in the **Dobson Unit** (D.U.), named after GMB Dobson. D.U. are measured by how thick the layer of ozone would be if it were compressed in a layer of 0°C and with a pressure of one atmosphere above it. The average amount of ozone in the stratosphere across the globe is about 300 D.U.
- **Causes of ozone depletion:** (1) Ozone is a triatomic form of oxygen (O_3). A combination of low temperature. elevated chlorine and bromine concentrations in the upper stratosphere is responsible for the distruction of ozone. The

production and emission of CFCs is the leading cause of ozone layer depletion. CFC's account for almost 80% of the total deplection.

(2) **Other ozone-depleting substances (ODS)–** include HCFCs and volatile organic compounds (VOCs). ODS are relatively stable in the lower atmosphere of earth, but in the stratosphere they are exposed to UV ray and thus they break down to release a free chlorine atom.

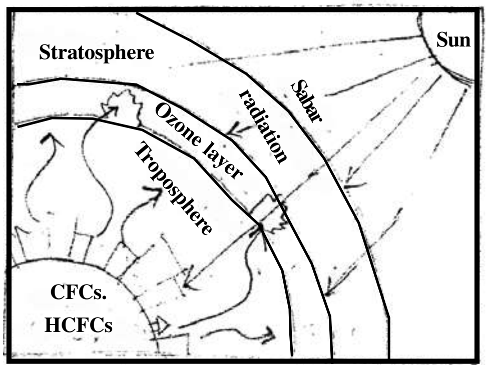

Fig. 4.3: Ozone depletion

(3) **Chlorine Monoxide (ClO)–** It is free chlorine atom reacts with an ozone molecule (O_3), and forms chlorine monoxide, and a molecule of oxygen. Now ClO reacts with an O_3 and form a chlorinc and 2 oxygen atoms. The free cl malecule again reacts with O_3 to form ClO. This process continues and results in the depletion of the ozone layer.

- **Effects of Ozone layer Deplition:** Effect on human and animal health—
- UV-B ray is likely to have profound impact on human health with potential risk of eye discases, skin cancer and infection diseases.
- UV ray is konwn to damage the cornea and lens of the eye.
- UV-B ray can affect the immune system causing a number of infections diseases.

Effects of Aquatic Ecosystems—

- Increase levels of UV exposure can have advanse impact on the productivity of aquoatic systems.
- High levels of exposure in tropics and sub-tropics may affect the distribution of phytoplanktons which form the foundation of aquotic food webs.
- UV-B can also damage to early development stages of fish shrimp, crab. and other animals.
- The most severe effect being decreased reproduction capacity.

Effect on Air Quality–

This can increase both production and destruction of ozone and related oxidants such as hydrogen peroxide, which are known to have adverge effects on human health, terrestrial plants and outdoor materials.

Effects on Climate Change—

- Ozone depletion is not a major cause of climate change.

- O_3 absorbs solar UV rays, which heats the stratosphere.
- Therefore, the climatic impact of changes in ozone concentration varies with the altitude at which these ozone changes occur.

Effects on Materials—

- UV-B ray acclerates the photo degradation rates of these materials, thus limiting their lifetimes.
- Typical damages range from discolaration to loss of mechanical integrity.
- Such a situation would eventually demand substitution of the affected materials by more photo stable plastics and other materials in future.

International Actions—

- Australian Chlorofluorocarbon Management Strategy provides a framework for the responsible management and use of CFCs in Australia.
- Environmental Protection Policy (2000) aims to minimise the discharge of ozone-depleting substances into the environment and has been extended to cover use of altarnative refrigerants.
- United Nation Environment Programme has published several assessments of the environmental effects of ozone depletion.
- Ultraviolet Index Forecast is designed to help people to minimise their exposure to dangerous levels of UV ray. It is a model to predict the amount of UV exposure.

4.7 Conclusion

The concept of greenhouse, greenhouse effect, global warming and climate change is known to all and a interesting matter of research. The facts an figures related to this phenomena is going beyond to the matter of climatologist, meteorologist. The major greenhouse gases are carbon-di-oxide, water vapour, methane and ozone. The greenhouse gases caused global warming, which intended to climate change.

4.8 Summary

- The atmosphere contains several gases - nitrogen, oxygen, carbon-di-oxide, methane etc.
- The atmospheric gases which cause the temperature rise are known as Greenhouse gases.

- The greenhouse gases caused global warming.
- The effects of global warming include sea level rise, regional changes in precipitation, more frequent extreme weather events such as- heat waves and expansion of deserts.
- Surface temperature increases are greatest in the Arctic, with the continuing retreat of glaciers, permafrost and sea ice.

4.8 Key words

Greenhouse effect, greenhouse gases, global warming, climate change

4.10 Model Questions

Short answer type:

1. Name the major greenhouse gases.
2. Write down the concentration of nitrogen and oxygen in the atmosphere.
3. Define greenhouse gases.
4. What do you mean by global warming?
5. Write the percentage of different greenhouse gases.
6. What is ozone hole?

Long answer type:

1. What are greenhouse gases?
2. How does the greenhouse gas affect global warming?
3. Describe the causes and consequences of Green House Effect.
4. Explain the formation and depletion of Ozone in atmosphere.

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MODULE-2
ATMOSPHERIC PHENOMENA AND CLIMATIC CLASSIFICATION

Module 2 : Atmospheric phenomena and climatic classification

Learning Objectives:

The objectives of the module:

1. Indentification of the condensation process.
2. Explation of the mechanism of precipitation.
3. Tracing the origin and characteristics of air mass.
4. Indentification of the fronts.
5. Explation of the stability and instability of atmosphere.
6. Analyses of the atmospheric circulation, planetary winds.
7. Explation of the formation and features of Jet Stream.
8. Analyses of the monsoon circulation and mechanism with special reference to India.
9. Indentification of tropical and temperate cyclone.
10. Analyses of the climatic classification of Koppen and Thornthwaite.

Unit 1 ❐ Condensation: Process and forms. Mechanism of Precipitation: Bergeron Findeisen theory, Collision and Coalescence Theory. Forms of precipitation

Structure

1.3 Introduction

The transformation of water vapour into water is called condensation. Condensation is caused by the loss of heat (latent heat of condensation, opposite to latent heat of vaporization). It helps to generate precipitation. Precipitation has been difined as water in liquid or solid forms falling to the earth. Precipitation includes all form of water particles that fall to the ground.

1.3 Objectives

i. To know the process of condensation.
ii. To know the different forms of condensation.
iii. To know the classification of clouds.
iv. To know the types of precipitation.
v. To know the forms of precipitation.
vi. To know the theories of formation of precipitation.

1.3 Condensation

- The transformation of water vapour into water is called condensation.
- Condensation is caused by the loss of heat (latent heat of condensation, opposite to latent heat of vaporization).
- When moist air is cooled, it may reach a level when its capcity to hold water vapour ceases. Saturation Point = 100% Relative humidity = Dew Point reached). Then, the excess water vapour condenses into liquid form. It if directly condenses into solid form, it is knows as sublimation.

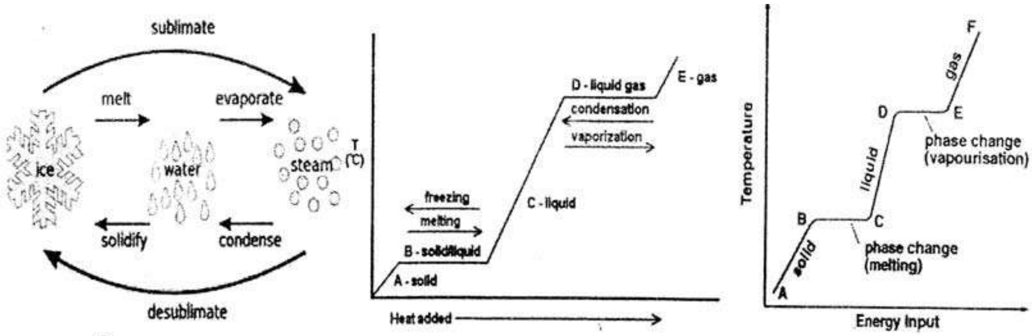

Fig. 1.1 : Process of Condensation

- In free air, condensation results from cooling around very small particles termed as hygroscopic condensation nuclei. Particles of dust, smoke, pollen and salt from the ocean are particularly good nuclei because they absorb water.
- Condensation also takes place when the moist air comes in contact with some colder object and it may also take place when the temperature is close to the dew point.
- Condensation, therefore, depends upon the amount of cooling and the relative humidity of the air.

Condensation takes place:

1. When the temperature of the air is reduced to dew point with its volume remaining constant (adiabatically).
2. When both the volume and the temperature and reduced.
3. When moisture is added to the air through evaporation.

- After condensation, the water vapour or the moisture in the atmosphere takes one of the followings forms—dew, frost, fog and clouds.
- Condensation takes place when the dew point is lower than the freezing point as well as higher than the freezing point.

Processes of Cooling for Producing Condensation

- These processes can be studied unter the headings, adiabatic and non-adiabatic.

Adiabatic Temperature Changes occur in the following situations:-

- When the air rises, it expands. Thus, heat available per unit volume is reduced and, therefore, the temperautre is also reduced. Such a temperature change which does not involve any subtraction of heat, and cooling of air takes place only by ascent and expansion, is termed 'adiabtic change'.
- The vertical displacement of the air is the major cause of adiabatic and katabatic (cold, dense air flowing down a slope) temperture changes.
- Near the earth's surface, most processes of change are non-adiabatic because horizontal movements often produce mixing of air and modify its characteristics.

Non-Adiabatic Temperature Changes occur in the folowing conditions:–

- Non-adiabatic processes include cooling by radiaton, conduction or mixing with colder air. The air may be cooled due to loss of heat by radiation.
- In case there is direct radiation from moist air, the cooling produces fog or clouds, subject to presence of hygroscopic unclei in the air.
- Cooling by contact with a cold surface produces dew, frost or fog depending on other atmospheric conditions.
- But the effect of cooling produced by radiation, conduction and mixing is confined to a thin layer of the atmosphere.
- The non-adiabatic processes of cooling produce only dew, fog or frost. They are incapable of producing a substantial amount of precipitation.

(1) Adiabatic processes:

1. Cooling by expansion is far more important than any other process so far as condensation in free air is concerned. This type of cooling is due to lifting of the air. Since an ascending air mass undergoes ever decreasing pressure exerted on it, it expands and cools.
2. Such temperature changes are brought about without any heating added to or subtracted from the rising air. These temperature changes are, therefore, called adiabatic. Unsaturated air cools at the dry adiabatic rate of 10°C per km.
3. However, after passing beyond the condensation level, the latent heat of condensation lowers the rate of cooling. This modified rate of cooling is called the wet or moist adiabatic rate.
4. The average rate of this cooling is about 6°C per km, but the actual values vary with pressure. Adiabatic cooling may be accomplished due to convection, convergence of different air masses as along the fronts, or orographic uplifting.

(2) Non-adiabatic processes:

1. Non-adiabatic processes include cooling by radiation, conduction or mixing with colder air. The air may be cooled due to loss of heat by radiation. In case there is direct radiation from the moist air, the cooling produces fog or clouds provided hygroscopic nuclei are present in the air.
2. Cooling may also be produced by conduction or advection of warm air across a cold surface. Cooling by contact with a cold surface produces dew, frost or fog depending on other atmospheric conditions. Sometimes the air is cooled due to its mixing with colder air.
3. It is noteworthy that the effect of cooling produced by radiation, conduction and mixing is confined to a thin layer of the atmosphere. The non-adiabatic processes of cooling produce only dew, fog or frost. They are incapable of producing a substantial amount of precipitation.
4. The only process capable of reducing the temperauture of deep and extensive air masses, so that cloud formation and appreciable precipitation may be possible, is the expansion associated with rising air currents or the adiabatic cooling.

Types of Condensation:

Different forms of condensation near the ground are:

I. Dew:

Dew is formed directly by condensation near the ground, when the surface has been cooled by outgoing radiation. Dew formation mainly occurs when the nights are clear and wind is calm. Generally dew forms on the grass, on leaves of the plants and any other solid object near the ground surface.

Conditions favourable for dew:

(i) Radiational cooling during night,

(ii) Calm condition/light winds,

(iii) Clear sky, cool and long nights,

(iv) Sufficient availability of water vapours,

(v) Anticyclone wind,

(vi) Cold advection.

Conditions not favourable for dew:

(i) Cloudy sky,

(ii) Strong surface winds,

(iii) Presence of cyclonic circulation,

(iv) Warm advection.

II. Fog:

Fog results from the condensation of atmospheric water vapours into water droplets that remain suspended in the air in sufficient concentrations to reduce the surface visibility. Fog is simply a cloud layer very close to the surface. It is a major hazard in the industrial area. It is very common during winter. It is also very common near coastal areas.

Conditions Favourable for Fog:

1. Excessive moisture,
2. Calm/light winds,
3. Anti-cyclonic winds, and
4. Relative humidity should be greater than 75 per cent.

Types of Fog:

(1) Evaporation Fog: Evaporation fog is caused by cold air passing over warmer water or moist land. It often causes freezing fog, when some of the relatively warm water evaporates into low air layers, it warms the air causing it to rise and mix with the cooler air that has passed over the surface. The warm, moist air cools as it mixes with the colder air, allowing condensation and fog to occur.

Evaporation fog can be one of the most localised forms of fog. It can happen when:

- Cold air moves over heated outdoor swimming pools or hot tubs, where steam fog easily forms.
- Cold fronts or cool air masses move over warm seas. This often occurs in autumn when sea temperature are still relatively warm after the summer, but the air is already starting to cool.

(a) Frontal fog: When warm rain falls through cold air, fog or stratus clouds form at the frontal surface due to super saturation caused by evaporation from warm rain into cold air.

(b) Steam fog: It is an unstable type of fog produced by intense evaporation from water surface into relatively cold air. Steam fog is found in the middle latitudes in the vicinity of lakes and rivers in autumn when water surfaces are still warm and air is cold.

(2) Cooling Fog:

(a) Advection fog: Advection fog is produced by the transport of warm moist air over a colder surface, resulting in the cooling of the surface layers below their dew points, with condensation taking place in the form of fog. It can also be produced, if the cold air mass moves across warm sea surface.

Advection fog occurs when moist air passes over a cool surface and is cooled. A common example of this is when a warm front passes over an area with snow cover. It is also common at sea when moist tropical air moves over cooler waters. If the wind blows in the right direction then sea fog can become transported over coastal land areas.

(b) Radiation fog: Radiation fog or ground fog is produced when stagnant moist air is in contact with ground that has become progressively cooler during the night because of an excessive outgoing radiation.

Radiation fog usually occurs in the winter, aided by clear skies and calm conditions. The cooling of land overnight by thermal radiation cools the air close to the surface. The reduces the ability of the air to hold moisture, allowing condensation and fog to occur. Radiation fogs usually dissipate soon after sunrise as the ground warms. An exception to this can be in high elevation areas where the sun has little influence in heating the surface.

(c) Inversion fog: It is the name given to any type of fog or stratus cloud that initially develops at the top of a moist layer, accompanied by subsidence above the inversion, intensifies the latter and produces the stratus cloud that may build down to the ground as fog.

(d) Upslope fog: Upslope fog is a stable type fog resulting from the gradual orographic uplifting of convectively stable air. The air cools adiabatically and the fog begins to form when it reaches an elevation where the air has cooled to saturation.

III. Frost:

It is not the frozen dew. Frost occurs when dew point of the air falls below freezing point (0°C). When condensation starts with temperature below 0°C, the water vapours in the air pass directly from gaseous to solid state (sublimation).

Frost may be light or havey. When the frost is heavy, crops are damaged. It is also called killing frost. Frosty nights are more common during winter season in north-west India. The crops, which are sensitive to low temperature injury, suffer a great damage.

a. Radiation frost:

It occurs on calm, clear nights when terrestrial radiation is lost to the space. The absence of clouds and heavy concentration of water vapours leads to the formation of radiation frost.

b. Advection frost:

It occurs in those areas where cold air is advected from colder areas by stronger winds. Advective frost or wind frost can occur on any time of the day or night irrespective of the sky conditions. In some cases, the advective frost may be intensified by radiation frost.

c. Hoar frost or white frost:

It is caused by the sublimation of ice crystals on objects such as tree branches, wires etc. These objects must be at a temperature below freezing as air with a dew point below freezing is brought to saturation by cooling.

d. Black frost:

It occurs when vegetation is frozen because of a reduction in the temperature of air that does not contain sufficient moisture.

Difference between Radiation Frost and Advection Frost:

In case of radiation frost, calm, clear nights and temperature inversion are the main conditions. It is of short duration. It case of advection frost, strong, winds and absence of temperature inversion are the main conditions. It is of long duration.

Frost control:

Frost should be controlled to maintain the tissues of vegetation above lethal temperature. Vegetable crops are damaged by the frost. The damage of the crop plants depends upon the type of crop. The presence of frost on the leaves hampers the normal functioning of the stomata. As a result, photosynthesis is adversely affected. Under severe frosty conditions, the crop plants may be killed. Therefore, is becomes essential to save the crops against frost damage.

Following methods may be adopted to save the crops from frost damage:

1. Selection of site,
2. Increased radiation interception (smoke screen),
3. Thermal insulation,
4. Air mixing (engine driven propellers and hot fans to drive warm air in the inversion layer downwards),
5. Direct air and plant heating,
6. Water application,
7. Soil manipulation.

IV. Smog:

It is the combination of fog and smoke which is found over big industrial cities in the middle or high latitudes. Since it persists for days together and causes so many diseases and deaths, therefore it is also knows as killer fog.

Condensation above the Ground:

During summer season, the air mass at the ground surface is heated due to intense heat energy. This air mass becomes warmer as compared to surrounding environment. Strong vertical currents are generanted, which uplifts the warm and light air mass. The rising air mass gets saturated due to cooling.

Further cooling of the saturated air mass leads to condensation. The uplift of the air mass continues even though the original cause of the uplift has ceased to be effective. Later on, upward movement of air is caused by the buoyancy force. Often the air mass sinks back to the former level. The upward and downward movement of the air mass depends upon the stability and instability of the atmosphere.

V. Clouds

- Cloud is a mass of minute water droplets or tiny crystals of ice formed by the condensation of the water vapour in free air at considerable elevations.

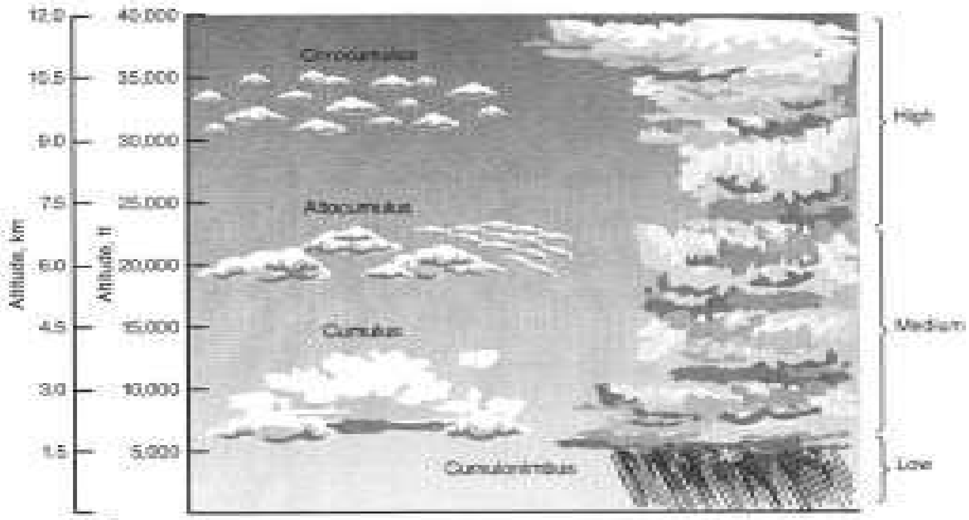

Fig. 1.2: Cumulus Cloud

- Clouds are caused mainly by the adiabatic cooling of air below its dew point.
- As the clouds are formed at some height over the surface of the earth, they take various shapes.
- According to their height, expanse, density and transparency or opaqueness clouds are grouped under four typs: **(i) cirrus; (ii) cumulus; (iii) stratus; (iv) nimbus.**

Cirrus Clouds

- Cirrus clouds are formed at high altitudes (8,000–12,000m). They are thin and detached clouds having a feathery appearance. They are always white in colour.

Cumulus Clouds–Cumulus clouds look like cotton wool. They are generally formed at a height of 4,000–7,000m. They exist in patches and can be seen scattered here and there. They have a flat base.

Stratus Clouds

- As their name implies, these are layered clouds covering large portions of the sky.
- These clouds are generally formed either due to loss of heat or the mixing of air masses with different temperatures.

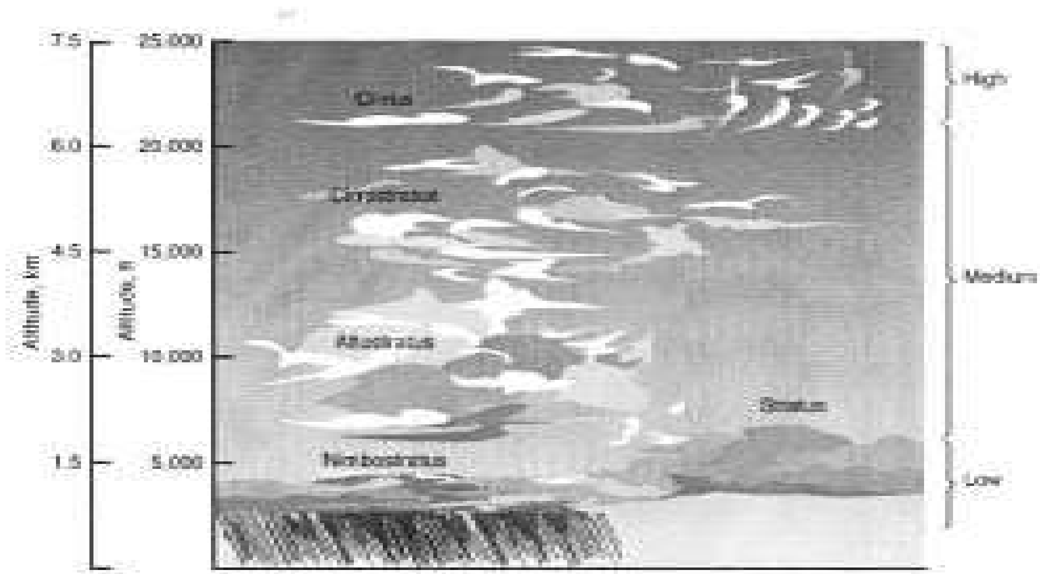

Fig. 1.3 : Stratus Clouds

Nimbus Clouds

- Nimbus clouds are black or dark gray. They from at mieddle levels or very near to the surface of the earth.
- These are extremely dense and opaque to the rays of the sun.
- Sometimes, the clouds are so low that they seem to touch the ground.
- Nimbus clouds are shapeless masses of thick vapour.

A combination of these four basis types can give rise to the following types of clouds:

1. High clouds–cirrus, cirrostratus, cirrocumulus;
2. Middle clouds–altostratus and altocumulus;
3. Low clouds–stratocumulus and nimbostratus (long, duration rainfall cloud) and
4. Clouds with extensive vertical development-cumulus and cummulonimbus (thunderstorm cloud).

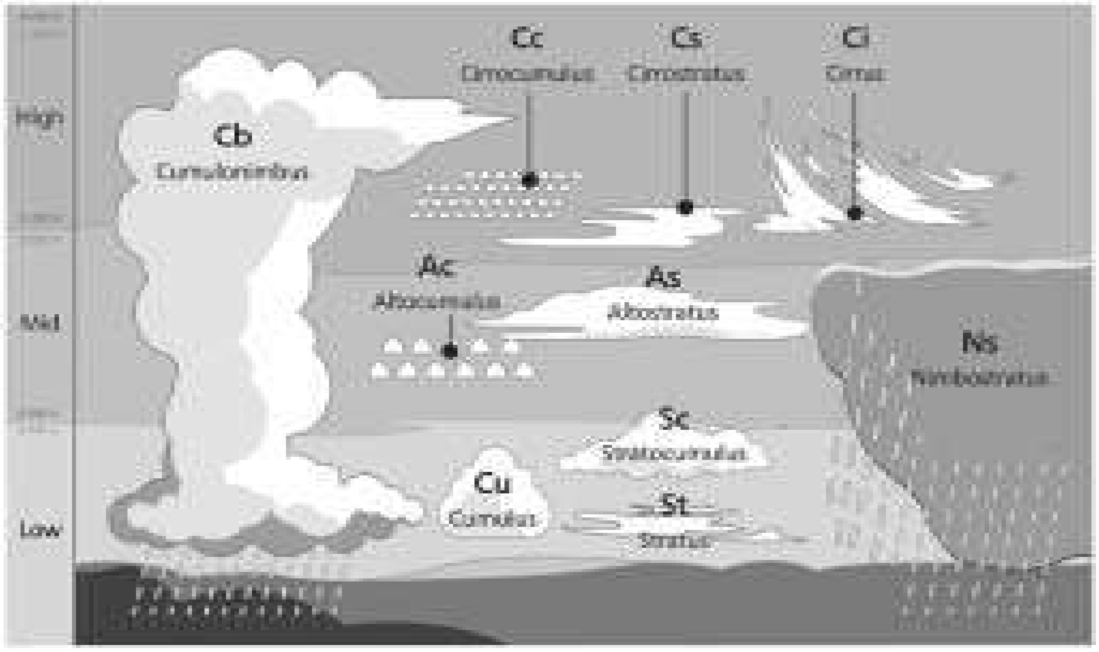

Fig. 1.4 : Clouds

1.4 Precipitation-Types and Forms

Concepts:

Precipitation has been difined as water in liquid or solid forms falling to the earth. According to Foster, precipitation in deposition of atmospheric moisture and is perhaps the most important phase of the hydrologic cycle. Precipitation includes all form of water particles that fall to the ground. It is not only rain but other forms of precipitation such as hail, sleet or fog-drip, which have considerable local significance. The forms in which precipitation in occur depends on the temperature structure of the air layer between cloud base and the ground.

1.2.1 Types of Precipitation:–

Precipitation is a product of the condensation of atmospheric water vapour that falls under gravity. The first step in precipitation is evaporation then condensation. The process of condensation involves change of water vapour to liquid, while the process of precipitation involves the falling out of that water as rain, snow, hail etc.

Types of Rainfall/Precipitation: All types of precipitation occurs from clouds and causes of clouds is the adiabatic cooling resulting from the upward movement of air.

Therefore, precipitation is classified on the basis of condition under which large masses of moist air induced to higher elevation, like–

(i) Convectional precipitation

(ii) Orographic precipitation

(ii) Cyclonic or frontal precipitation.

(I) **Convectional precipitation**–The causes of such precipitation occur through two conditions:–

i) The intense heating of surface

ii) Abundent supply of moisture in the air.

- The air on being heated, becames light and rises up in convection currents. As it rises, it expands and loses heat and consequently condensation takes place and cumulous clouds are formed. With thunder and lightering heavy rainfall takes place but this does not last long.
- Such rain is common in the summer or in one hotter part of the day. It is very common in the equatorial regions.
- Connective precipitation is less effective for crop growth than the steady rain. However, in the temperate regions, it is most effective in promoting the growth of plants.

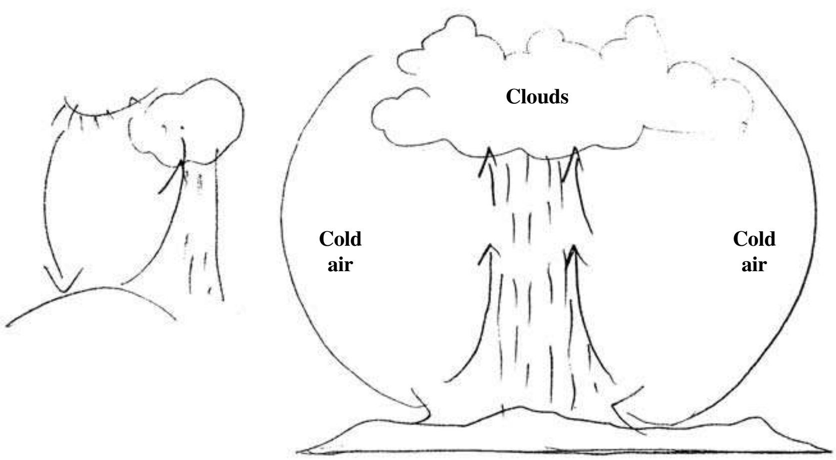

Fig. 1.5 : Convectional Precipitation

- Clouds involved in this types of precipitation are generally cumulonimbus or clouds with greater vertical development.

II) Orographic precipitation–When mountains or highlands acts as barriers to the flow of air force it to rise, and cloud forms.

- When the saturated air mass comes across a mountain, if force to ascend and as it rise it expands, the temperature falls and the moisture is condensed.
- The chief characteristic of this sort of rain is that windward side receive greater rainfall.
- After giving rain on the windward side, when these winds reach the other slope, they descend and their temperature rise.
- The capacity to take moisture increases and hense these leeward slopes remain rainless and dry.
- The area situated on the leeward side, which get less rainfall are called rain-shadow area.

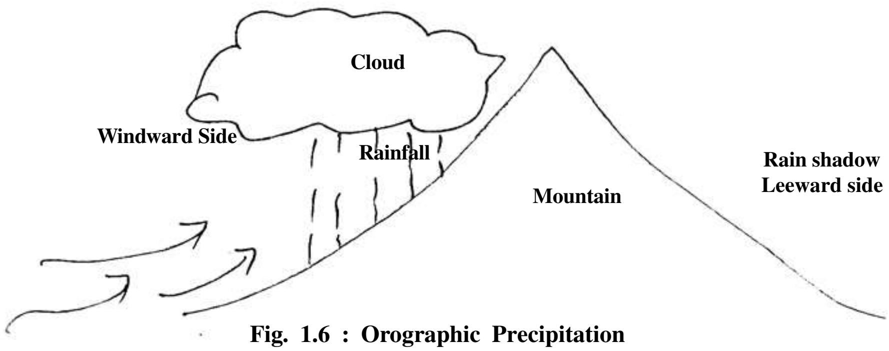

Fig. 1.6 : Orographic Precipitation

Another salient features of orographic rain is invension of rainfall. An air stream approaching the mountain ranges is given an uplift by the air masses lying close to them. Therefore, the amount of precipitation starts increasing some distance away from the mountain.

There is a continuous increase in precipitation on the windward slope upto a certain height beyond which starts diminishing. This is called inversion of rainfall.

- In India the south-west monsoon gives copious rainfall on wind ward slope of western ghats, whereas on leeward side there are extensive rain shadow area.

III Cyclonic or frontal precipitation–This rainfall occurs when deep and extensive air masses are made to converge and move upward so that their adiabatic cooling results.

Cyclonic precipation in tropical regions–When currents of air with differing temperature and moisture content meet at an angle, the warm and moist air will be forced to rise over the heavier air.

In addition, when air masses from different direction coverge toward a centre, some of the air is forced up. In both these cases of convergences, cloudiness and precipitation result.

Frontal precipitation in temperature regions: In temperate regions, the zones of contact between relatively warm and cold air masses are known as fronts. Frontal precipitation occurs when the warm and moit air gradually rises above the front created by contact with the cold air. In stable air convergence is generally attended by stratiform clouds providing a gray overlcast sky and cause steady long-continued precipitation.

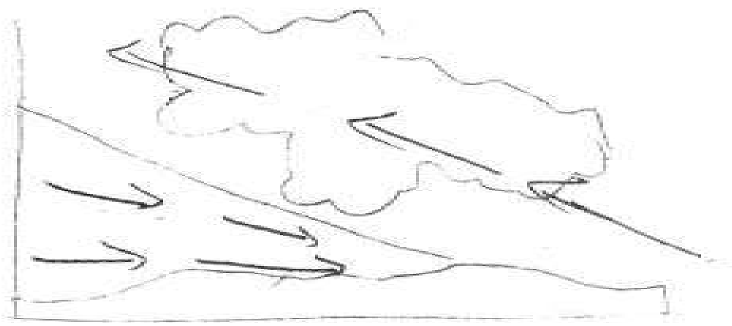

Fig. 1.7 : Frontal Precipitation

In Europe and North-America, most of the winter precipitation is frontal in origin

1.4.2 Forms of Precipitation:

Precipitation is the moisture falling on the ground into various forms which depend on the following conditions:-

(a) The temperature at which the condensation take place

(b) Types of cloud and their height from ground

(c) The processes generating precipitation

Forms of precipitation are as follows–

(1) Rain– It is precipitation of liquid water particles. The drops are larger than drizzle whenever the rain drop fall from high-altitude clouds, some of them evaporate where passing through dry air.

There are three types of rainfall–

a) Convectional rainfall

b) Orographic rainfall

c) Cyclonic rainfall

(2) **Drizzle–** Drizzle is very light rain. It is stronger than most but less than shower. They are formed in very low stratus clouds with higher water content Drizzle is associated with fog. In same place drizzle is often called mist. They arise from low stratocumulus clouds they evaporate even before reaching the ground due to their minute size. Drizzle can be presistent

is cold atmospheric temperature.

(3) **Snow–** Precipitation of solid wateris called snow. It consists of wide variety of crystal forms of ice. It may fall from pure ice clouds or from such clouds as are formed of super cooled water vapour.

In winter, when temperature are below freezing in the whole atmosphere, the ice crystals falling from the altostratus do not melt and reach the ground as snow. Heaviest snowfall is reported to occur when temperature of air from which snow is falling is not much below 0°C.

(4) **Sleet–** Sleet refers to the precipitation in the form of a mixture of rain and snow. But in American terminology sleet means a form of precipitation consisting of small pellets of transparent or tranlucent ice. Thus it refers to frozen rain in America.

Sleet is often experienced during thunderstorm. Sometime sleet may grow into hailstorms when violent vertical current are produced in the atmosphere. Sleet don't freeze into solid mass except when it combines with freezing rain.

(5) **Hail–** It is precipitation of big ball on pieces of ice with diameter ranging from 5 to 50 mm or sometime more. Hail is the most dreaded and destructive form of precipitation produced in violent thunderstorms or cumulonimbus clouds.

As this are big balls of ice due to which they are highly damaging to crops, tearing leaves apart and reducing their value. Hailstornes as formed from super-cooled droplet that slowly freeze and result in clear ice.

(6) **Sun Shower–** It is a precipitation which falls which the sun shines. It occurs when the winds bearing rain together with rain storms and blow several miles thus give raindrop into an area without cloud.

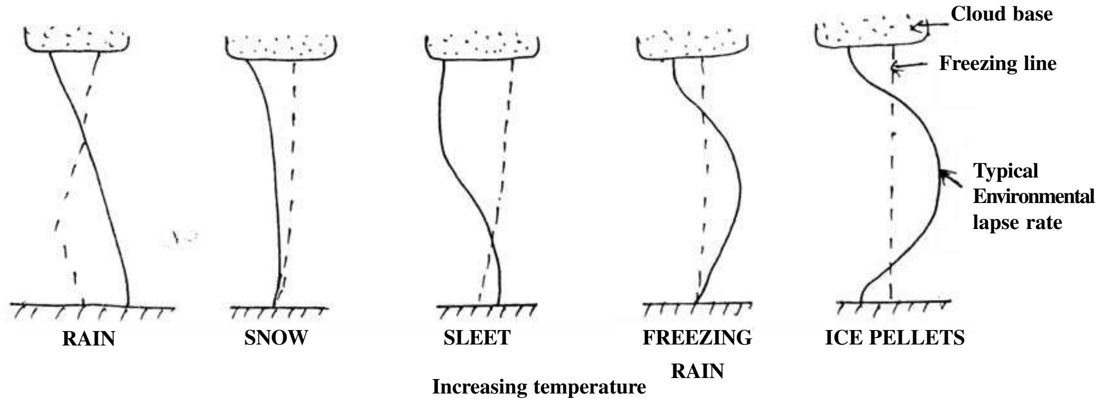

Fig. 1.8: Types of precipitation that reaches the ground

1.5 Mechanism of Precipitation

Ice Crystal Theory of Bergeron–Fiendeisen:

The ice-crystal theory to explain precipitation was propounded by Tor-Bergeron, an eminent meteorologist from Norway, in 1933. It is based on two special meteorological properties of water: Firstly,

(i) The water droplets in a cloud do not freeze at 0°C.

(ii) In the atmosphere, super-cooled water has been observed down to below-40°C.

(iii) When water remains in liquid state below 0°c, it is referred to as super-cooled. The super-cooled water tends to freeze if it is distributed.

(iv) Besides, super cooled droplets also freeze when they come into contact with the freezing nuclei.

(v) An ice crystal is often found to certain a tiny solid nucleus of about 1 micrometer in diameter. This is called **freezing nucleus**. Most of the nuclei become active at 20°C to 25°C.

(vi) However, freezing nuclei are spares in the atmosphere. Thus, when the ascending air currents rise well above the freezing level, some of the water droplets will be changed into ice and through sublimation, water vapour will enter into solid state.

According to **Taylor**, if a single ice crystal is introduced into a cloud of super cooled water droplets, the entire cloud rapidly changes over to an all-ice cloud. This abrupt change from a water to an ice cloud is caused by different vapour pressure existing over super-cooled water droplets and ice crystals at the same temperature.

Secondly,

(i) Over ice, the saturation vapour pressure is lower than what it is over water. In other words, when air is saturated with respect to water, it is supersaturated with respect to ice.

(ii) In this case, vapour diffuses rapidly from air to ice crystals so that the ice crystals being to grow at the expense of water droplets.

(iii) The growth of ice crystals is rapid enough to generate crystals large enough to fall. While falling from the cloud, the ice crystals grow by intercepting cloud droplets that freeze upon them.

(iv) Sometimes, these falling ice crystals are broken up into fragments which again become freezing nuclei for other water droplets.

(v) A chain reaction take place. The ice crystals by accretion grow further in size to become snowflakes before leaving the cloud.

(vi) Snowflakes generally meet before raching the ground and fall as rain.

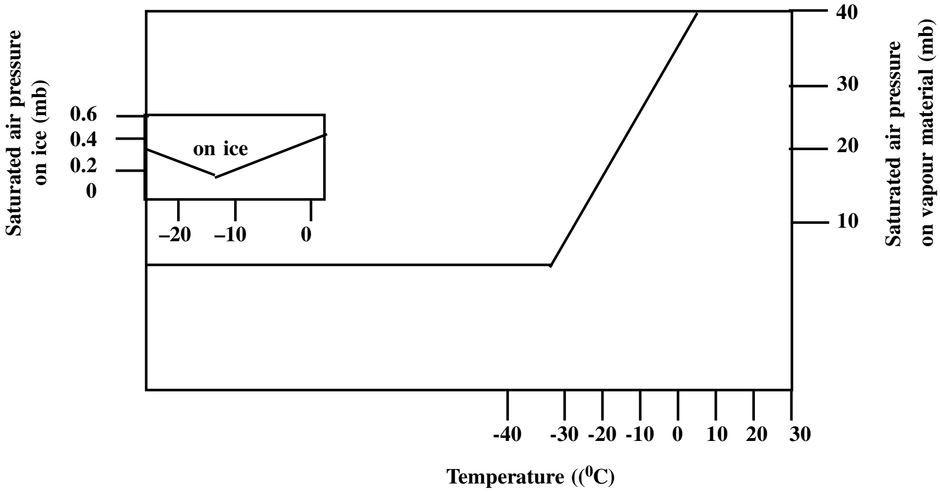

Fig. 1.9 : Ice Crystal formation

Ice Nucleus
↓
Growth by sublimation
↓
Larger cycle crystals → Coagulated with super cooled droplets
↓ ↓
Continued sublimation hailstone
↓ ↓
Large dentritic crystals melting
↙ ↓ ↓
Splintering crystal → snowflaks raindrop
coagulation

This theory is mainly emphasis on the following basis:
1) Water vapour, water particles and ice crystals exists.
2) Different level of pressure of saturated water vapour.
3) Low pressure on ice surface than water surface of the saturated water vapour.

(B) Collision–Coalescence Theory: Collision coalescence ideas were put forword by. George Simpson and Mason. It is based on the fact that clouds contain a variety of sizes of water droplets. Uniformly small droplets tend to move at the same speed in the cloud but if they are mixed with larger, slow moving droplets that have formed around hydroscopic nuclei, then this will encourage collisions and amalgamations.

These ideas were modified by **Langmuir**. He pointed out that the termainal velocities of falling drops are directly related to thier diameters. These diameters, in turn are determined by the size of the condensation nuclei. Drops that have grown on large condensation nuclei become larger. The larger drops will have a higher terminal velocity than the smaller ones and so collide with them.

Raindrops or ice crystals often stick after colliding and thus, grow in finite steps i.e. collide and coalesce. The large drops then fall faster, as they overcome air resistance more easily. By falling faster, they are able to catch up even more rapidly with other droplets and crystals. So that the larger they grow, the faster they grow.

For collision to occur, several conditions are necessary—

(a) As the larger droplets descend, they produce an air stream, a minature air current that blows the small particles out of their path i.e. smaller drops are swept away.

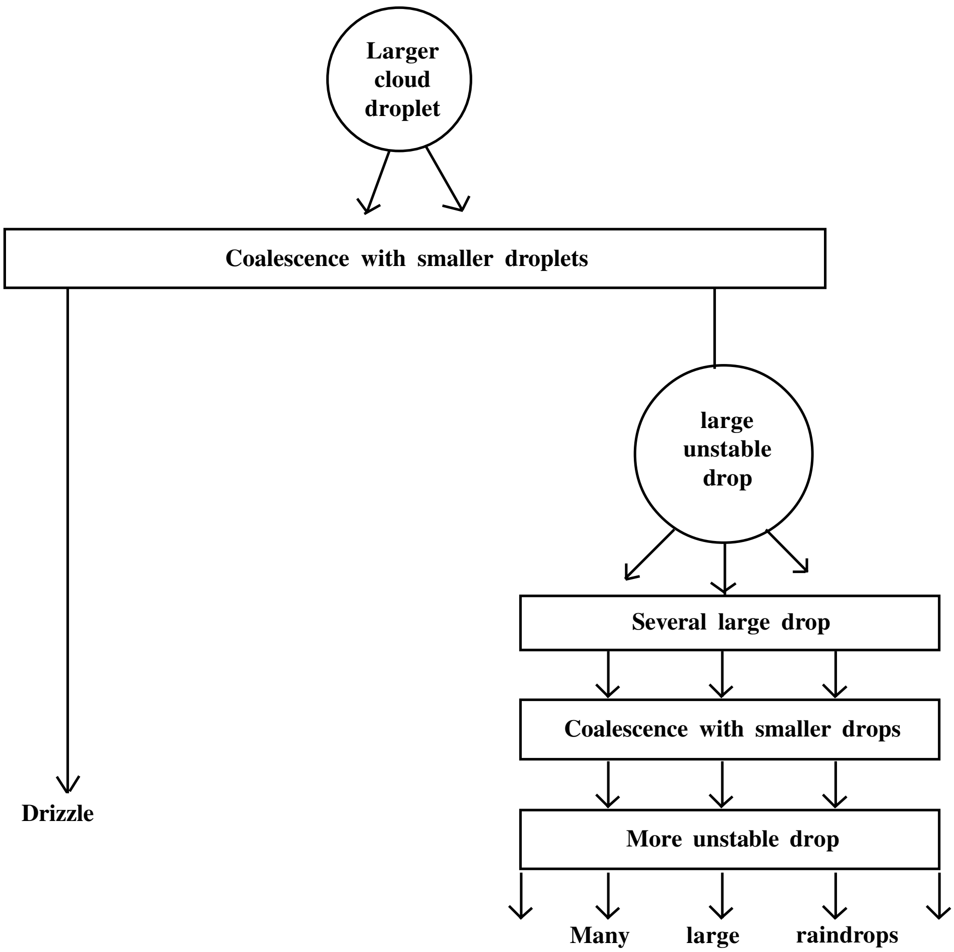

Fig. 1.10: Collision-coalescence process

(b) Colliding droplets may bounce away from each other as there is little surface tension.

Because of these two effects, the collection efficiency is very small. Thus, when both the collection efficiency and the fall rate of the droplets and crystals are taken into consideration. It is found that coalescence is almost nil until the droplets or crystals exceeds 40 microns. Once the collecting perticles are larger than this coalescence proceeds so rapidly that raindrops would offen be for larger if they did not break apart once they exceeded a few milimeter in diameter.

(c) Even with collision, growth will only occur if the two drops coalesce. This will occur most rapidly if–

(i) The drops are of considerably different sizes.

ii) Atmospheric electricity is present to hold the droplets together, if a droplet with a negative charge should collide with a positively charged droplet their electrical attraction will bind them together.

Continued collision, thus leads to coalscence resulting in many large unstable drops which on further disruption produce several large drops and its continued coalescence and further disruption leads to many larger drops.

1.6 Conclusion

Condenstion is the change of water vapour into liquid state. The condensation occurs through two process- adiabatic and diabatic process. It helps in precipitation. Precipitation includes all forms of water particles that fall to the ground. Rain is the name given to all liquid precipitation other than drizzle. The formation and growth of raindrops is a complicated and less understood process. The two process that describes the mechanism of raindrop formation are - Bergeron-Fiendiesen process and Collision-Coalescence process, which are elaborated in this unit.

1.7 Summary

- Condensation is caused by the loss of heat.
- Condensation depends upon the amount of cooling and the relative humidity of the air.
- Condensation takes place when the dew point is lower than the freezing point as well as higher than the freezing point.
- After condensation, the water vapour or the moisture in the atmosphere takes one of the followings forms-dew, frost, fog and clouds.
- The two processes of condensation are adiabatic and non-adiabatic.

- According to their height, expanse, density and transparency or opaqueness clouds are grouped under four typs: (i) cirrus; (ii) cumulus; (iii) stratus; (iv) nimbus.
- Precipitation has been difined as water in liquid or solid forms falling to the earth.
- Precipitation includes all form of water particles that fall to the ground.
- The ice-crystal theory to explain precipitation was propounded by Tor-Bergeron.
- The collision coalescence theory was put forword by George Simpson and Mason.

1.8 Key words

Condensation, adiabatic process, diabatic process, forms of condensation, forms of precipitation, ice-crystal theory, collision coalescence theory.

1.9 Model Questions

Short answer type:

1. What are the types of fog?
2. Classify clouds.
3. What are the forms of precipitation.
4. Briefly state about the types of rainfall.

Long answer type:

1. Discuss the forms of Condensation.
2. Explain the process of Condensation.
3. Elucidate the mechanism of rain drop formation in atmosphere.
4. Explain the theories of precipitation.
5. Discuss different forms of precipitation and types of rainfall.

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Unit 2 ❒ Air mass: Origin and characteristics

Structure

2.1 Introduction

Air mass is defined as an extensive portion of the atmosphere whose physical properties, especially temperature, moisture content and lapse rate are homogeneous horizontally and vertically for hundreds of kilometers. Thus, an air mass has two basic characteristics, vertical temperature distribution, i.e. lapse rate, a measure of warmth or coldness which affects it's stability; and homogeneous moisture content, which is an indication of latent heat.

2.2 Objectives

i. To know the air mass.
ii. To know the types of air mass.
iii. To know the origin of air mass.
iv. To know the dynamics of air mass.

2.3 Air Mass

Air mass is defined as an extensive portion of the atmosphere whose physical properties, especially temperature, moisture content and lapse rate are homogeneous horizontally and vertically for hundreds of kilometers. Thus, an air mass has two basic characteristics—

i) Vertical temperature distribution, i.e. lapse rate, a measure of warmth or coldness which affects it's stability; and

ii) Homogeneous moisture content, which is an indication of latent heat.

2.4 Classification of Air Mass

Air masses are classified on the basis of–

a) the location of their source region.

b) the nature of the surface over which they move towards other region.

There are two approaches to the classification of air masses, e.g.–

1) Geographical classification and

2) Thermodynamic classification

1) Geographical Classification–Trewartha has classified air masses on the basis of their geographical locations into two broad categories, viz-i) **Polar air mass (P)** which originates in polar areas. Artic air masses are also included in this category. ii) **Tropical air mass (T)**, which originates in tropical areas. Equatorial air masses are also included in this category.

These two air masses have been further divided into two types on the basis of the nature of the surface of their source region, i.e. land or water.

a) continental air mass indicated by a small letter c.

b) maritime air mass indicated by a small letter m.

It may be pointed out that a continental air mass gets modified and is transformed into maritime type while passing through ocean surface but maritime airmass is seldom transformed into continental type while passing through land surface. Based on the above facts air masses are classified into the following four principal types according to their geographical locations–

i) Continental Polar air mass (cP)

ii) Maritime Polar air mass (mP)

iii) Continental Tropical air mass (cT)

iv) Maritime Tropical air mass (mT)

2) Thermodynamic Classification–Theromodynamic modification of an air mass includes such effects as heating from below which decreases the vertical stability. On the basis of theronodynamic modification of air masses under the influence of underlying surface. They can be classified in two categories–

i) cold air mass (k)

ii) warm air mass (w)

Cold air mass is defined as one which has lower temperature than the underlying surface. It is indicated by small letter 'k'. Cold air masses originate in the polar and arctic regions. **The warm air mass** is described as one which has relatively high temperature than the temperature of underlying surface. It is denoted by small 'w' letter. Warm air masses generally originate in the subtropical regions characterised by anticyclone conditions.

Both cold and warm air masses may be stable or unstable due to different kind of modifications through exchange of temperature between overlying and underlying air. Thus cold and warm air masses may be classified also as–a) stable (s) and b) unstable (u) airmass.

i) **Continental Polar Air Masses (cP)–**These air masses have their source origin in central Canada and Siberia. These air messes have different physical characteristics during summer and winter seasons. They are extremely cold, dry and stable in winter but when they move over warm, surfaces they are heated from below and become unstable. The source areas, due to their location in high altitude, are frozen in winter season, the air mass is cold, dry and stable. In the summer, the snow cover disappeares because of the surface heating but still summer time continental polar air masses are cool and dry in their source region of Canada and Siberia. This type of air masses can be sub-grouped as under–

a) Continental Polar Cold Stable Air Mass (cPks)

b) Continental Polar Cold Unstable Air Mass (cPku)

c) Continental Polar Warm Stable Air Mass (cPws)

d) Continental Polar Warm Instable Air Mass (cPwu)

ii) **Maritime Polar Air Masses (mP)–**They are orignally continental polar air masses (cP) which have undergone modification when they move out from the source region and travel oceanic surfaces of high latitudes, their lower parts are heated from below by the relatively warm surfaces of open oceans and thus become maritime polar air masses (mP) after such modification. This modificatin increases temperature lapse rate and causes connective instability in the lower part. On the other hand the upper part is cool. This types of air masses can subgrouped as under–

a) Maritime Polar cold stable Air Mass (mPks)

b) Maritime Polar cold unstable Air Mass (mPku)

c) Maritime Polar warm stable Air Mass (mPws)

d) Maritime Polar warm unstable Air Mass (mPws)

iii) **Continental Tropical Air Masses (cT)–**These air masses have their source region in the subtropical high pressure land areas. They have high temperature and low moisture content. Subsidence and stability are found in the upper parts of these air masses in their source region.

These air masses can be subgrouped as under–

a) Continental Tropical cold unstable Air Mass (cTku)

b) Continental Tropical cold stable Air Mass (cTks)

c) Continental Tropical warm unstable Air Mass (cTwu)

d) Continental Tropical warm stable Air Mass (cTws)

iv) **Maritime Tropical Air Masses (mT)–**They have their source region over the warm oceans in both the hemisphere. They are warm moist and unstable air masses. They yield terrestial rainfall when they are forced to ascent by mountain bariers. They are asociated with connective instability, cumulonimbus rainfall when the airmass is associated with frontal activity or is forced to ascend by mountain barriers. These air masses can be subgrouped as under–

a) Maritime Tropical cold stable Air Mass (mTks)

b) Maritime Tropical cold unstable Air Mass (mTku)

c) Maritime Tropical warm stable Air Mass (mTws)

d) Maritime Tropical warm unstable Air Mass (mTwu)

Dynamic changes–Dynamic (mechanical) changse involves mixing or pressure changes asociated with the actual movement of air masses either by turbulence, high level convergence and divergence prolonged period of turbulent mixing causes substantial change in the physical properties of air masses. Dynamic changes may be brought about by a combination of one or more factors–

- Turbulent mixing at a lower level, where natural friction provides a ready mechanism for the upward transfer of the effects of thermodynamic effects by eddy formation.
- Large scale lifting resulting from forced ascent by mountain barrier or by air stream convergence.
- Sinking caused by high level convergence or by descent of air in the lee of high ground caused by pressure gradient.
- Litting caused by horizontal convergence at low level.
- Advection.

Turbulence causes thorough mixing, sometimes up to a considerable height and transfer heat and moisture up to a considerable height. Subsidence causes stable stratification in the atmosphere while lifting and ascent causes steepending lapse rate and therefore, promotes instability.

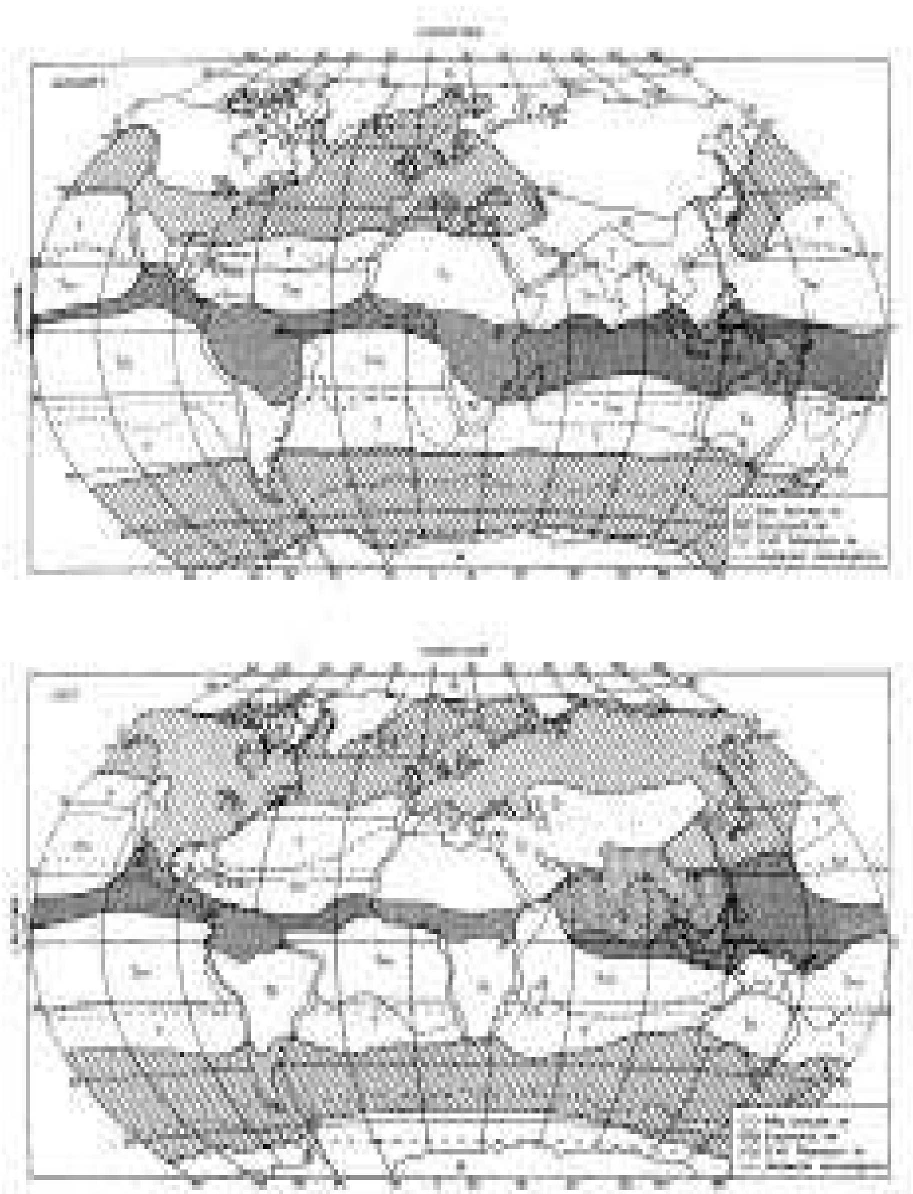
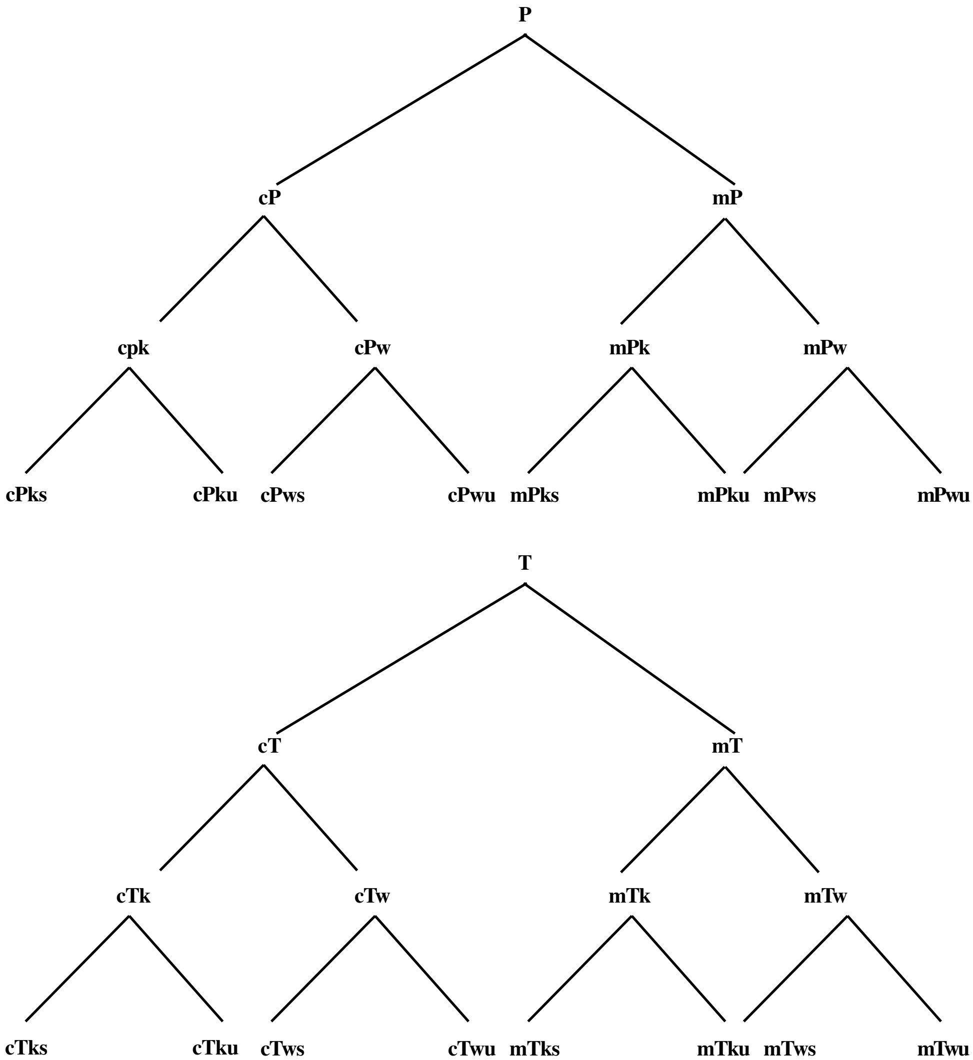


Fig. 2.1 : World Air Mass distribution. (Jannuary and July)



P = Polar | **T = Tropical**
C = continent | **m = maritime**
K = heated from below | **w = cooled from below**
S = stable aloft | **u = unstable aloft**

Fig. 2.2 : Classification chart of Air mass

Thus, thermodynamic modification causes air mass to become cold or warm represented by letters **W** for warm and **K** (from German *'Kalt'*, meaning cool) for cold. While mechanical or dynamic modification causes it to become stable **(s)** and unstable **(u)**. Although it must be strictly borne in mind that the effects of dynamic and thermodynamic modifications are clearly inseparable.

2.5 Origin of Air Mass

Indroduction-In meteorology, an **air mass** is volume of air defined by its temperature and water vapour content. Air masses cover many hundreds or thousands of square miles, and adapt to the characteristics of the surface below them. They are classified according to latitute and their continental or maritime source regions. Colder air masses are termed polar or arctic, while warmer air masses are termed tropical. Continental and superior air masses are dry while maritime and monsoon air masses are moist.

Classification

Pettersen has classfied air masses into the following five major categories on the basis of their of their source regions:

1. **Tropical air masses :** There is a chain of tropical air masses source regions that encircles the northern hemisphere and another in southern hemisphere near tropic of cancer and tropic of capricorn. These are fromed over Sahara, S.W. USA in summer, northern Mexico in summer.

2. **Polar air masses :** The polar air masses lie between 55° to 65° latitudes in both hemisphere. There are number of region for polar air in northern hemisphere, like Siberia in winter, gulf of Alaska etc.

3. **Equatorial air masses :** The trade wind converge at the equator forming inter tropical convergence zone. At some places there are regions of stagnant air that serve as source of air mass formation that are mainly formed over water in these latitude.

4. **Arctic air masses and Antarctic air masses–**This air mass forms over large area of snow and ice mainly near pole in both the hemispheres. Artic air masses tend to form in winter (December to March) in northern hemisphere and in (June to September) in southern hemisphere. According to **Byers**, there are only three major categories of air masses i.e. arctic, polar, and tropical air masses.

Trewartha, on the basis of gographical location of air masses classifies them into the following two broad categories:

1) Polar air mass (P)

2) Tropical airmass (T).

He further subdivides the two air masses into two types on the basis of the nature of the surface of their source regions i.e. land and water-the lowercase letter **m** (for maritime) and the lowercase letter **c** (for continental).

Air masses are commonly classified according to four basic source regions with respect to latitude.

Continental Polar (cP) air masses usually forms during the cold period of the year over extensive land areas such as central Asia and northern Canada. It is likely to be stable and is characteristically free of condensation forms. When heated or moistened from the ground with strong turbulence, this type of air mass develops limited convective stratocumulus cloud forms with scattered light rain or snow showers. In summer strong continental heating rapidly modifies the coolness and dryness of the CP air mass as it moves to lower latitudes. Daytime generation of cumulus clouds in the rule, but the upper-level stability of the air mass is usually such as to prevent rain showers.

Maritime Polar (mP) air masses develop over the polar areas of both the Northern and the Southern hemispheres. They generally contain considerably more moisture than the cP air masses. As they move inland in middle and high latitudes, heavy precipitation may occur when the air is forced to ascend mountain slopes or is caught up in cyclonic activity.

The **Continental Tropical (cT)** air mass originates in arid or desert regions in the middle or lower latitudes, principally during the summer season. It is strongly heated in general, but its moisture content is so low that the intense dry convection normally fails to reach the condensation level. Of all the air masses, the cT is the most arid, and it sustains the belt of subtropical deserts worldwide.

The Maritime Tropical (mT) is the most important moisture-bearing and rain-producing air mass throughout the year. In winter, it moves poleward and is cooled by the ground surface. Consequently, it is characterized by fog or low stratus or stratocumulus clouds, with drizzle and poor visibiliy. A steep lapse rate aloft in regions of cyclonic activity ensures the occurrence of heavy frontal and convective rains. In summer, the characteristics of the mT air mass over the oceans and in zones of cyclonic acitivity are basicaly the same as in winter. Over warm continental areas, however, the air mass is strongly heated so that, instead of fog and low startus clouds, widely scattered and locally heavy afternoon thunderstorms occur.

Air Masses and Source Regions: Origin

The principal source regions of the earth may be classified according to the nature of surface (land or water) and the latitude of the region. Thus, the source regions are classified as under:

The Article source regions are located in the high latitudes, where the surface is permanently covered with snow and ice. Thus, they are the coldest regions on earth. The polar source regions do not mean the regions around the geographic poles.

The area situated between the Arctic source regions and the sub-tropical highs. None that the Arctic source regions are colder than the polar source regions. The tropical source regions occupy the subtropical high pressure belt. The equatorial source regions are located around the equator between the trade winds of the northern and southern hemispheres.

The following discussion relates to the major air masses that form during the winter and summer months in different regions of the world:

(1) Winter time continental polar (cP) air masses:

These aur nasses have their source regions in the central Canada and Siberia. They are extremely cold, dry and stable. Since the surface is completely frozen and is snow-or-ice-covered, these air masses are the coldest wintertime air masses.

They produce intense cold waves when they move out to some other regions. Because of extreme dryness of the air, there are no clouds in these air masses.

However, after these air masses move out of their source regions, they are modified while they pass over a warm surface. When cP air mass becomes cPK after modification, cumulus or stratocumulus is not uncommon.

(2) Summer time continental polar (cP) air masses:

These air masses have their source regions in the central parts of high-latitude contitents. Central Canada offers a typical example of such a source region. Because of the surface heating, snow cover disappears.

Summer time, cP air masses in their source regions are cool and dry, but not necessarily stable. Actually these are the modified forms of the winter-time cP air masses which have been heated in the lower layers.

Their lapse rates are comparatively less steep. When cPK air mass moves out to oceanic surface, it is modified into cPW air mass with haze, fog and low stratus clouds.

(3) Winter time maritime polar (mP) air masses:

These air masses are cool and moist and form over the open oceans in the higher latitudes. They are originally cP air masses which have undergone extensive modification over the open oceans. These air masses contain few clouds in their source regions.

But when they are dragged into cyclones or are forced to ascend mountain barriers, extensive precipitation is produced by them.

Their lower layers are moist and unstable, but they are dry and cold in their upper parts. The convective instability in the lower layers of these air masses produces showry, squally weather.

(4) Summer time maritime polar (mP) air masses:

These air masses originate in the source regions of mP air masses. They are cool and moist in the lower parts, but dry aloft. A temperature inversion in produced sometimes with moisture discontinuity. They are stable upto moisture discountinuity.

Air-mass typical characteristics									
	Iropical Continental (Tc)		Polar Continental (Pc)		Tropical Maritime (Tm)		Polar Maritime (Pm)	Arictic Maritime (Am)	Returning Polar Maritime (rPm)
	Summer	Winter	Long Sea Track	Short Sea Track	Exposed	Sheltered			
Temp	Very worm or hot	Average	Cold	Very cold	Near Sea tem	Warm	Rather cold	Cold (colder than porn)	Warm (warmer than Pm)
Humidity	Relatively dry	Rather moist	Moist in lowest layers	Very dry	Very moist	Moist	Moist	Fairly moist (not as moist as pm	Fairly moist (not as moist as Pm)
Change of Lapse Rate	Little change	Cooled from below	Heated from below	Little change	Cooled from below	Warmed in summer	Heated from below	Heated from below	Heated from below
Stability	Generally stable	Stable	Unstable	Stable	Stable	Stable aloft	Unstable	Un stable	Unstable
Weather	Clear occasional thundery showers	Clear	Rain or snow showers	Clear	Low cloud drizzle	Broken cloud dry	Variable cloud, showers	Showers (mainly costal)	Showers (mainly coastal)
Visibility	Moderate or poor	Moderate or poor	Good	Moderate or poor	Often poor with coasta fog	Moderate	Good	Very good	Very good

Fig 2.3 : Typical characteristics of air mass

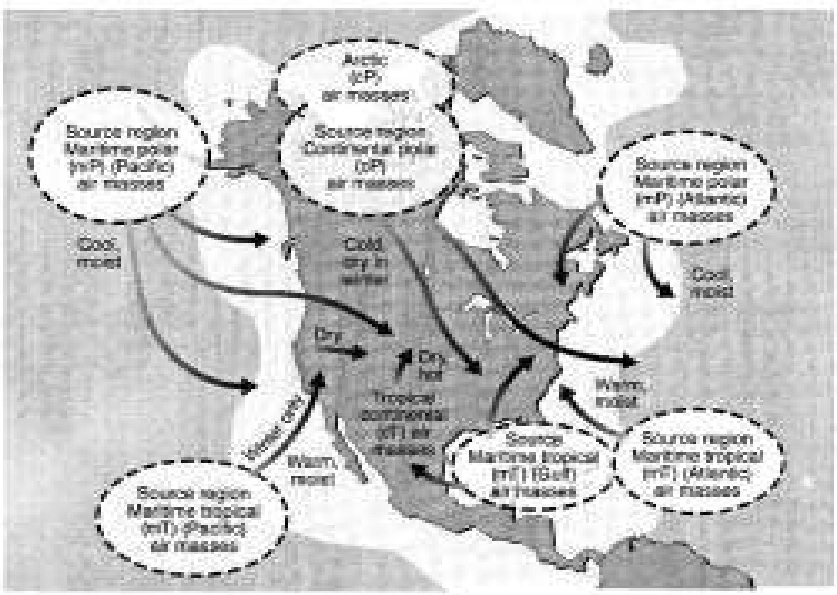


Fig. 2.4 : Source regions of air masses

The general temperature is slightly higher than that in the mP air masses.

(5) Winter time tropical maritime (mT) air masses:

They have their source regions over the warm oceans in both the hemispheres. They are warm, moist and unstable. They release abundant precipitation whenever they ocur.

The lapse rates in the lower levels often approach the dry-adiabatic rate, and the lapse rates are steep up to tropopause. Moisture is well distributed to high levels. When these air masses are lifted over fronts or high mountains, they produce heavy precipitation.

(6) Summer time tropical maritime (mT) air masses:

The source regions of these air msses are located in the belt of the great semi-permanent highs of the tropical oceans including the Caribbean Sea. The mT air masses are very warm and moist and highly unstable. These are masses have convective instability.

(7) Continental tropical (cT) air masses:

These air masses have their source regions in the subtropical high pressure land areas. They have high temperatures and low moisture content. The tropical continental air does not spread extensively beyond its source regions.

In the United States these air masses are important only in the sumer season. They are dry both in winter and summer. In summer they are very hot. Subsidence and stability are found in the upper parts of these air masses in their source regions.

When cT air is found aloft over warm, moist air at the surface, the atmosphere becomes convectively unstable, and violent thunderstorms or tornadoes are produced.

2.6 Conclusion

The airmass is volume of air defined by its temperature and water vapour content. Air masses cover many hundreds or thousands of square miles, and adapt to the characteristics of the surface below them. They are classified according to latitute and their continental or maritime source regions. Colder air masses are termed polar or arctic, while warmer air masses are termed tropical. Continental and superior air masses are dry while maritime and monsoon air masses are moist.

2.7 Summary

- Air masses cover many hundreds or thousands of square miles.
- Pettersen has classfied air masses into the following five major categories on the basis of their of their source regions.
- Trewartha has classified air masses on the basis of their geographical locations into two broad categories, - Polar air mass (P) & Tropical air mass (T).
- According to Byers, there are only three major categories of air masses i.e. arctic,

polar, and tropical air masses.

- Dynamic changes involves mixing or pressure changes asociated with the movement of air mass.
- Colder air masses are termed polar or arctic, while warmer air masses are termed tropical.
- Continental and superior air masses are dry while maritime and monsoon air masses are moist.

2.8 Key words

Airmass, Polar airmass, Tropical airmass, dynamic changes of airmass, modification of airmass

2.9 Model Questions

Short answer type:

1. What is air mass?
2. Classify air mass.
3. State the characteristics of air mass.

Long answer type:

1. Classify different air masses and account for their modification.
2. Explain the source regions of the major air masses forms during winter and summer season.

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Unit 3 ❐ Fronts: Warm and Cold; frontogenesis and frontolysis

Structure

3.1 Introduction

Front is three-dimensional boundary zone formed between two converging air masses with different physical properties. Fronts are the typical features of mid-latitudes temperate region. They are uncommon in tropical and polar regions. The two air masses don't merge readily due to the effect of the converging atmospheric circulation, relatively low diffusion coefficient and a low thermal conductivity.

3.2 Objectives

i. To know the front.
ii. To know the types of front.
iii. To know the origin of front.
iv. To know the features of front.
v. To know about frontolysis.

3.3 Fronts: Characteristics of warm and cold fronts

Introduction :

Fronts are the typical features of midlatitudes weather (temperate region: 30°–65° N and S). They are uncommon (unusual) in tropical and polar regions.

Front is three-dimensional boundary zone formed between two converging air masses with different physical properties (temperature, humidity, density etc.).

The two air masses don't merge readily due to the effect of the converging atmospheric circulation, relatively low diffusion coefficient and a low thermal conductivity.

Characteristics

1: Temperature

Larger differences in the air temperature are recorded across a front. But the changes in the temperature may be abrupt or gradual depending on the nature of the opposing air masses. Larger the temperature difference, the thinner the frontal zone and the vice versa. Besides, the fronts are always characterized by the temperature inversion layers.

2: Air pressure

The wedge formed by the bending of the isobars across the front always points toward the higher pressure. It is noteworthy that mostly the fronts lie in the trough of the low pressure.

3: Winds

South-westerly wind in a tropical air mass gives way to the north-westerly wind in the polar air mass across the front. The lines of the abruptly shifting winds were formerly knows as windshift lines.

4: Cloud and precipitation

The type of the clouds and the precipitation falling from the depend on the slope of the front and the amount of the moisture in ascending mass of the air.

Types of Weather Fronts

When large masses of warm air and cold air meet, the boundary zone between them is called front. They do not mix. Instead, they form a front, usually hundreds of miles long. When a front passes, the weather changes.

1) **Cold front-**A cold front originates between the centers of high and low pressure. Pressure difference cause the flow of air from high pressure to low pressure. Typically colder air from the high pressure flows towards low pressure, where the warm air rises.

   With large pressure diffrences, the speed and amount of air flow increases. Thereby larger amounts of cold air are put into motion and aggregate into a large front of several hundred kilometers of width.

Weather: It brings thunder which can form thunderstorm as the moisture in the warm air mass rises, cools, and condenses. As the front moves through, cool, fair weather is likely to follow.

Characteristics of Cold Front

i) Cold fronts are boides of air with cooler temperatures than the surrounding air.
ii) They normally move from northwest to southeast.
iii) The temperature shift between cold and warm fronts can be drastic, from freezing.
iv) On a weather map, cold front are shown as curved blues lines with traingles pointing in the direction that the front is moving.
v) Drizzle rainfall occur.
vi) Clouded sky is observed.
vii) Low temperature is noticed.
viii) The stope varies from 1 : 5 to 1 : 100.

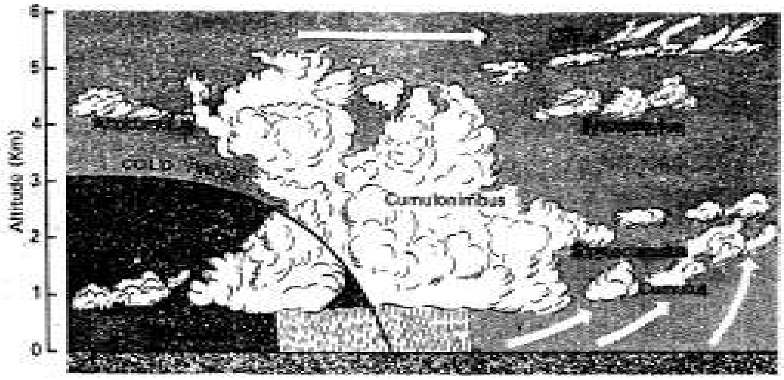

Fig. 3.1 : Vertical cross-section of a cold front and associated clouds and precipitation

2) Warm front–Warm fronts are at the leading edge of a homogeneous warm air mass, which is locted on the equtorward edge of the gradient in isotherms, and lie within broader troughs of low pressure than cold fronts. A warm front moves more slowly than the cold front which usually follows because cold air is denser and harder to remove from the earth's surface. Thi s also forces temperature differences across warm fronts to be broader in scale.

***Weather*:** As the warm air mass rises, it condenses into a broad area of clouds. A warm front brings gentle rain or light snow, followed by warmer, milder weather.

Clouds ahead of the warm front are mostly stratiform and rainfall gradually increases as the front approaches. Fog can also occur preceding a warm frontal passage.

Characteristics of Warm Front

Weather fronts are responsible for the majority of our clouds and precipitation. In the case of a warm front, you should definitely break out your umbrella and rain gear.

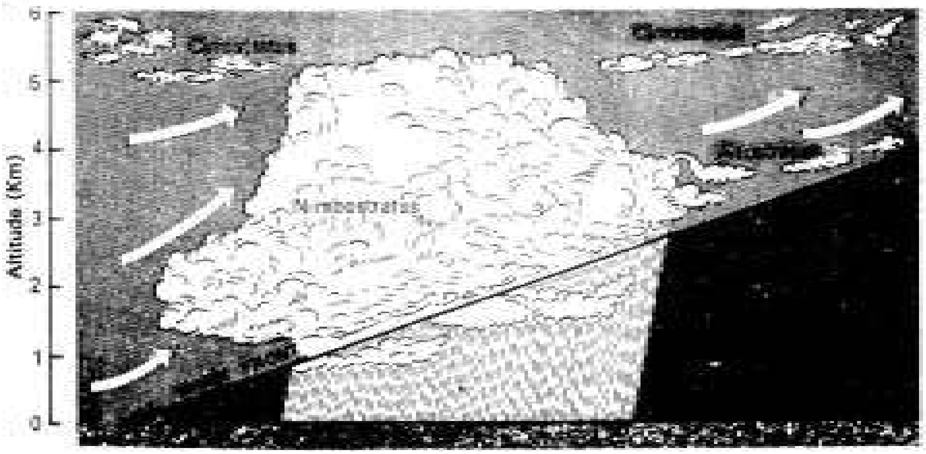

Fig. 3.2 : Vertical cross-section of a worm front and associated clunds and precipitation.

i) Warm Front Basis

Fronts represent the boundaries between collinding air masses. Warm fronts represent the transition zone where warm air is replacing colder air. These fronts typically form east of a center of low pressure. Warm fronts generally move from the southwest to the northeast.

ii) Structural and Behavioural Characterisitics

As the warm air advances, the cold air acts as a gently sloping ramp. This ramp gently uplifts large areas of the warmer, less dense air. The slope of a typical warm front is 1:200, compared with the much steeper 1:100 slope of a cold front.

This is why warm fronts are charrracterized by a much large area of cloud cover and precipitation. Because the advancing warm air is less dense, it has a difficult time pushing the heavier cold air back. This is way warm fronts over more slowly than cold fronts, and contribute to the longer periods of clouds and precipitation.

iii) Cloud and Precipitation Characteristics

Clouds and precipitation can extend for hundreds of miles both in advance and behind the warm front precipitation associated with a warm front is typically steady and light to moderate in intensity. Warm fronts can occasionally produce thunderstorms with more intense precipitation.

iv) Additional Characteristics

Warm fronts are typically characterized by a transition from south-easterly to south-westerly winds. Unlike cold fronts, winds along the front itself are generally light and variable. Warm fonts, as their name implies, are also characterized by a rise in temperature, but also humidity. Warm fronts are generally characterized by poor visibility due to low layers of overcast and steady precipitation.

v) Clear weather followd hy warm front.

vi) High temperature arround the warm front.

3) Stationary front– From when warms and cold air meet and front reamin stationary is called stationary front neigher air mass has the force to move the other. They remain stationary, or 'standing still.'

A stationary front is a non-moving (or stalled) boundary between two air masses, neither of which is strong enough to replace the other. They tend to remain essentialy in the same area for extended periods of time, usually moving in waves. There is normally a broad temperature gradient behind the boundary with more widely spaced isotherm packing.

A wide variety of weather can be found along a stationary front, but usually clouds and prolonged precipitation are found there. Stationary fronts may bring snow or rain for a long period of time.

Weather : Where the warm and cold air meet, clouds and fog form, and it may rain or snow. Can bring many days of clouds and precipitation.

4) Occluded front– An occluded front is formed when a cold front overtakes a warm front, and usually forms around mature low-pressure areas. The cold and warm fronts curve naturally poleward into the point of occlusion, which is also known as the triple point.

A wide variety of weather can be found along an occluded front, with thunderstorms possible, but usually their passage is accociated with a drying of the air mass. Within the occlusion of the front, a circulation of air brings warm air upward and sends drafts of cold air downward, or vice versa depending on the occlusion the front is experiencing.

Precipitations and clouds are associated with the *trowal*s (Short for through of warm air aloft), which are formed when a warm air mass gets caught between two cold air masses. The warm air mass rises as the cool air masses push and meet in the middle.

There are two types of occlusion: (a) cold front type occlusion and (b) warm front type occlusion.

(a) *Cold front occlusion.* It occurs when the cold air chich overtakes the warm air is colder than the retreating cold air. It is illustrated in Fugure 3.3. In the initial stages of the cold fron type occlusion, the weather system of the warm front still persists. Later on, when the warm front has been pusbhed-further upward it has little effect on weather conditions. At the later stages the weather conditions resemble those of the cold front. Cold front type occlusion is the most common type.

(b) *Warm front occlusion.* The warm front type occlusion occurs when the retreating cold air mass is colder than the advancing cold air mass. In this case the advancing cold air being relatively less dense overrides the retreating cold air mass (Fiture 3.4). This type of occlusion generally takes place when the retreating cold air becomes progressively colder by radiation, and when the advancing cold air mass is of the maritime polar type.

Weather: The temperature drops as the warm air mass is occluded, or "cut off," from the ground and pushed upward. Can bring strong winds and heavy precipitation.

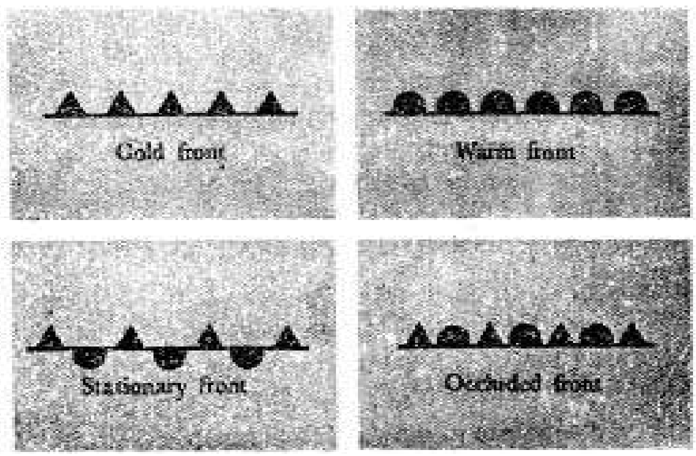

Fig. 3.3 : Frontal symbols used on weather maps.

3.4 Frontogenesis

Frontogenesis is a meteorological process of tightening of horizontal temperature gradients to produce fronts. In the end, two types of fronts form: cold fronts and warm fronts. A cold front is a narrow line where temperature decreases rapidly. A warm front is a narrow line of warmer temperatures and essentially where much of the precipitation occurs., frontogenesis is, devided from Latin word, means 'creation of altogether new fronts' or 'the regeneration of decaying fronts already in existence.

Features–1) **Tor Bergeron** was the first to use the term 'frontogenesis' for the creation of new fronts.

2) Frontogenesis occurs as a result of a developing baroclinic wave.

3) Frontogenesis is likely to occur when the wind blows in such a way that the isotherms become packed along the leading edge of the intruding air mass. Convergence of the wind toward a point or contraction toward a line augments the process of frontogenesis.

4) Divergence of the wind from a point or dilation from a line is helpful to the process of frontolysis.

5) When contrasting air masses have convergent movement, the frontogenesis occurs. The temperature contrast in the converging air masses is most important for the process of frontogenesis to occur.

Conditions for Frontogenesis: When the distribution of frontogenesis was studied, it was noticed that this process doesn't occur everywhere. Frontogenesis requires certain characteristics for processes to occur. They are:

1. Temperature Difference: The two opposing air masses that converge to form a front must have a contrasting temperauture. If one air mass is warm, moist and light, a front can only be created when the other air mass is cold, dry and dense. This also explains why no frontogenesis takes place in the equatorial region. Two air masses also converge at the equator (trade winds) buu the temperature of both these air masses is uniform. So, the temperature difference is the missing factor here because of which no frontogenesis takes place at the equator.

2. Convergence of Air Masses: In the very definition of frontogenesis, the word 'convergence' has been used and thus it is understood that it is the pre-requistite for the frontogenesis process. When two air masses having different temperature converge, leads to the formation of the fronts. For frontolysis to occur, the air masses have to diverge or get diluted by mixing and the contrast being removed.

By Frontogenesis four types of fronts occurs–

1) cold fronts

2) warm fronts

3) stationary fronts

4) occuluded front

3.5 Frontolysis

Frontolysis in meteorology, is the dissipation or dying or weakening of an atmospheric front.

In contrary to areas of ''Frontogenesis'', the areas where air masses diverge are called areas of frontolysis.

Features:

1) When contrasting air masses lose their characteristics and difference decay occurs.

2) In other words, when the air masses move away from each other or when the temperature contrast between the adjacent air masses, diminishes due to one reason or another the fronts start declining.

3) The dissipation of fronts takes place in three ways:

(a) through front's stagnation over a similar surface;

(b) as a results of both the air masses cold and warm moving on parallel tracks at the same speed;

(c) by the system entering air of the same temperature.

4) Frontolysis happens in the area of Siberia, Northern America etc.

5) It is mostly occur when fronts move into a regions on divergent air

6) It is mostly found in sub-tropical high-pressure region

7) When the air masses move away from each other fronts may dissipate

8) The dissipation of a front or frontal zone.

In general, a decrease in the horizontal gradient of an air mass property, density, and the dissipation or dying of the accompanying features of the wind field.

Conditions Necessary for Frontolysis

1) Frontolysis, or the dissipation of a front, occurswhen either the temperature difference between the two–

   a) air masses disappears or the wind carries the air

   b) particles of the air mass away from each other.

Frontolytical process are more common in the atmosphere then are frontogenetical processes.

2) Frontolytical processes are most effective in thelower layers of the atmosphere since surface heating and turbulent mixing are the most intense of then on conservative influences on temperature.

Frontogenesis and Frontolosis

Front is that sloping boundary which separates two opposite air masses having contrasting characteristics in terms of air temperature, humidity, density, pressure and wind direction. An extensive transitional zone between two converging air masses is called **frontal zone** or **frontal surface** which represents zone of discontinuity in the properties of opposing contrasting air masses.

Frontogenesis–The process of formation of front is frontogenisis. Infact the process of birth and growth of fronts is known as **frontogenesis**. Frontogenesis is a latin derived word which means ‘creation of altogeather new fronts’ or ‘the regeneration of decaying fronts already in existence.’

Frontolysis–On the contrary, **Frontolysis** means the process of destruction or dying of fronts. It is the process of warking of the thermal gradient at a frontal zone. This is produced in the reverse conditions of frontogenesis i.e with surface divergence of air. If convergence of wind towards a point or contraction towards a line arguments the process of frontogenesis, the divergence of the wind from a point or dialation from a line is helpful to the process of ‘frontolysis’.

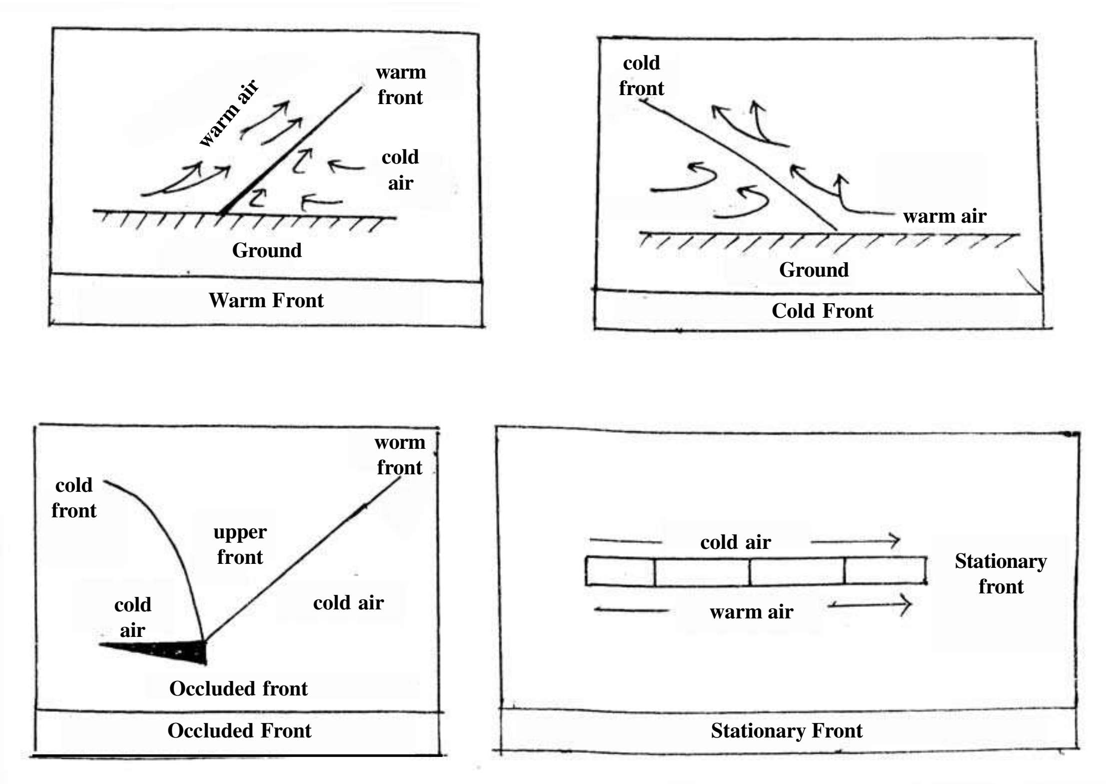

Fig. 3.4 : Types of fronts

3.6 Classification of Fronts

Fronts are classified into four principal types on the basis of their different characteristic features, like–

1) Warm front
2) Cold front
3) Occluded front
4) Stationary front.

1) **Warm front–**A warm front is defined as a gently sloping frontal surface in which there is active movement of warm air over cold air. The average slope of warm fronts in middle latitudes ranges between 1:100 to 1:200. The gradually rising warm air along the gently sloping warm front is cooled adiabatically, gets saturated and after condensation precipitation occur over a relatively large area.

2) **Cold front–**Cold front is that sloping frontal surface along which cold air becomes active and aggressive and invades the warm air territory and being denser

remain at the ground but forcibly uplifts the warm and light air the slope of cold front varies from 1:50 to 1:100. A cold front is associated with bad weather characterized by thick clouds, heavy downpower with thunderstorms etc.

3) **Occluded front–**Occluded front is formed when cold front overtakes warm front and warm air is completely displaced from the ground. The cold front moves faster than the warm front with the result the warm sector is progressively reduced in size. Warm air is fully uprooted from the ground. It overlies the cool and colder air masses, ultimately the cold and warm front combine into one. There are two types of occlusion:

a) cold front occlusion and

b) warm front occlusion.

4) **Stationary front–**Stationary front is formed when two contrasting airmasses converge in such a way that they become parallel to each other and ther is no ascent of air. It's ground position does not now either forword or backword but reamin stationary.

3.7 Conclusion

The extratropical cyclone which is actually a mid latitude depression, plays a very significant role in transfer of energy from equator to poles. The orgin and depletion of front, different types of front, salient features and associated weather with different front are very significant so far the climatic condition of temperate region is concerned.

3.8 Summary

- Front is that sloping boundary which separates two opposite air masses having contrasting characteristics in terms of air temperature, humidity, density, pressure and wind direction.
- Fronts are classified into four principal types on the basis of their different characteristic features.
- The process of birth and growth of fronts is known as frontogenesis.
- Tor Bergeron was the first to use the term 'frontogenesis' for the creation of new fronts.
- Frontogenesis occurs as a result of a developing baroclinic wave.
- Frontolysis is the dissipation or dying or weakening of an atmospheric front.
- The areas where air masses diverge are called areas of frontolysis.

3.9 Key words

Front, Frontogenesis, Frontolysis, Warm Front, Cold Front, Occulded Front, Stationary Front

3.10 Model Questions

Short answer type:

1. State about the types of front.
2. State about the characteristics of fronts.
3. What are the conditions responsible for frontogenesis and frontolysis?
4. Distinguish between warm front and cold front.

Long answer type:

1. State the concept of Frontogenesis and Frontolysis.
2. Classify and discuss fronts.

3.11 References

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Unit 4 ❐ Weather Stability and Instability

Structure

4.1 Intruduction

The ascent of the air depends largely on the conditions of atmospheric stability and instability. Both of these condition affect the atmospheric conditions. It largely depends on the lapse rate and related issues.

4.2 Objectives

i. To know the atmospheric stability.
ii. To know the atmospheric instability.
iii. To know the process of atmospheric stability.
iv. To know the types and process of atmospheric instability.

4.3 Stability

The ascent of the air depends largely on the conditions of atmospheric stability and instability.

When the air remains in its original position and resists vertical movement, then the air has the same temperature as its surroundings, it is the **stability**.

Airmass is most stable when colder and drier air underlines warmer air. Airmass in which a temperature inversion exists has a high degree of stability.

Stability may occurs—

i) Air mass is cooled from below to a cold underlying surface, then the density of lower air is relatively increased and the stability increases.

ii) When air is subsiding and spreading laterally producing high pressure, then the process of stabilistions occurs.

Process: The environmental lapse rate (ELR) is less than dry adiabatic lapse rate (DALR) and saturated adiabatic lapse rate (SALR), then the **absolute stability** of weather occur. The air, when rising or falling, experience temperature change then, it results the same temperature as its surroundings, wheather become **stable.**

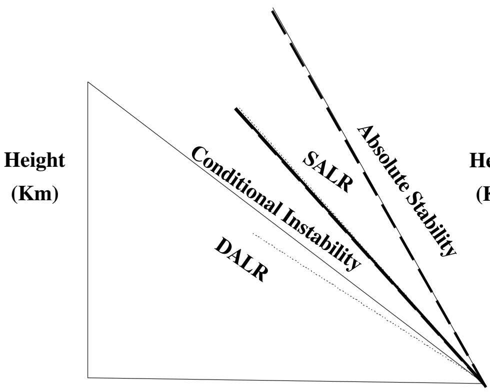

Fig 4.1 Stability

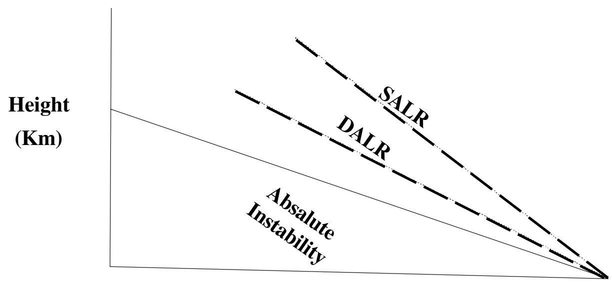

Fig 4.2 Instability

4.4 Instability

When, the air becoming increasingly warmer than its surroundings, then the **instability** occur.

When, the air displaced vertically, then it has a tendency to move upward a condition of instability prevalis. Instability prevails, taken the lapse rate is greater than adiabatie rate.

Instability may be developed–

i) When convergence takes place, the warm air rises.

ii) When the air becomes lighter than its surroundings.

iii) When, air is and forced to rise over some obstacles.

Types and Process:

i) **Absolute Instability:** In it, ELR is greater at every level than the DALR.

ii) **Conditional Instability:** Humid air is forced to rise over mountain barrier or over colder wages of air, then conditional instability occur.

iii) **Potential Instability:** When larger air masses undergo bodily lifting, then dry upper part will experience drop in temperature at DALR while the lower parts become saturated and cool at SALR. This different rate of colling of different parts alters the stable situation into unstable, in known as potential instability.

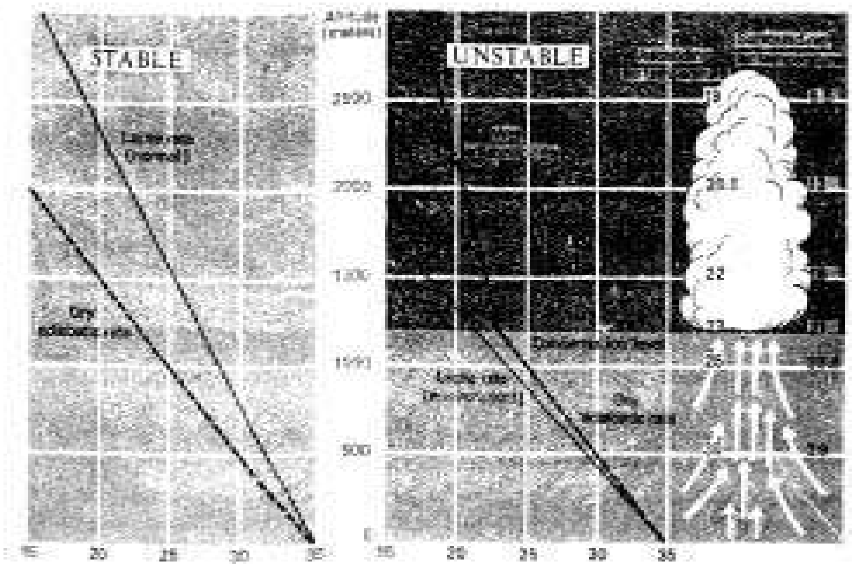

Fig. 4.3 and 4.4 : Stability and instability of the atmosphere. The lapse rate less than the dry adiabatic rate means stable air. When the lapse rate exceeds the dry adiabatic rate the air is unstable.

4.5 Conclusion

The temperature changes occur when the air rises and falls. The ascent of the air will depend on the condition of atmospheric stability and instability. The dry and saturated adiabatic lapse rates are closely associated with these atmospheric condition.

4.6 Summary

- When the air remains in its original position and resists vertical movement, then the air has the same temperature as its surroundings, it is the stability.
- When, the air becoming increasingly warmer than its surroundings, then the instability occur.

4.7 Key words

Stability, instability

4.8 Model Questions

Short answer type:

1. What is atmospheric stability?
2. What is atmospheric instability?

Long answer type:

1. Differentiate stability from instability of atmosphere.
2. Briefly explain the concepts of lapse rate. State the stability and instability of atmosphere.

4.9 References

- Barry, R. G. and Chorley, R. J. (1998): Atmosphere, weather and climate, Routeledge, London (7th Edition)
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Unit 5 ❐ Circulation in the atmosphere: Planetary winds, Jet Stream

Structure

5.1 Introduction

Wind is a part of the energy system and most of the wind motion take place horizontally east-west and north-south while vertical motion is also important as it helps to formulate precipitation. The large scale wind motion is known as general wind circulation of the atmosphere. Most of the atmospheric circulation occurs due to imbalance in energy. The tri-cellular model of wind circulation describes the pattern of circulation from equatorial to polar region. It is closely related with the planetary wind belts and the distribution of global atmospheric pressure belts. In this context, the features of jet stream affect the wind circulation very interestingly and attract the keen interest of the geographers, meteorologist and climatologist.

5.2 Objectives

i. To know the general wind circulation pattern.
ii. To know the controlling factors of general wind circulation.
iii. To know the planetary wind belts.
iv. To know the global atmospheric pressure belts.
v. To know the factors controlling atmospheric pressure.

vi. To know the tri-cellular meridional wind circulation.
vii. To know about jet stream.

5.3 General Wind Circulation: Controlling Factors

Introduction–Atmospheric Circulation is the large scale movement of air and together with ocean circulations by which thermal energy is redistributed on the earth surface. The global atmospheric circulation varies from year to year, but large scale structure of wind or atmospheric circulation remains constant.

Factors Controlling Wind Circulation:

There are two types of forces on atmosphere to produce wind–

1) **Driving force**–It includes vertical forces such as gravity and pressure gradient force and the horizontal pressure gradient force.

2) **Steering force–**It arises as the motion of air begins. This includes coriolis force, frictional force and centripetal force.

Various types of Drivins forces–

1) Gravity–The gravity is net effect of two forces when they work together.

(i) The force of attraction between the earth and other object.

(ii) When centrifugal force imparted to all objects because of spins of earth's axis, the two forces combined to produce the force of gravity, which accelarates a unit mass of any object downward at the rate of 9.8 meters/ seconds.

The force of gravity always acts downward perpendicular to earth's horizontal surface. The gravity is more at pole than equator.

2) **Pressure gradient force**–A pressure gradient exists whenever there is a difference in air pressure from one place to other.

- In this regard, difference in pressure can be caused by contrast in air temperature or difference in water vapour concentration.
- Closely spaced isobar means air pressure change rapidly with distance and it is steep and strong and when the isobar are not close pressure gradient is weak. Thus when air has steep and strong pressure gradient in one side and weak on other cause imbalance and create high pressure and low pressure and thus wind blow due to difference in pressure gradient.

Various types of Steering forces–

1) **Coriolis force–**This cause due to the rotation of earth on its axis and has effect is on every moving object. The coriolis force is zero (0) at the equator

and maximum at poles. All free moving objects including winds are deflected to the right path of motion in the northern hemisphere and left in southern hemisphere. The rate of curvature of moving air is directly related to velocity of wind and the latitude.

Characteristics of coriolis force–

1) It always directed at right angles to the direction of airflow or moving air. Therefore, wind blowing right to northern hemisphere and left sourthern hemisphere.
2) It only affected wind direction not wind speed.
3) It is affected by the wind speed, the strong the wind, the greater is deflecting force.
4) It is strongest at pole and weak at equator.

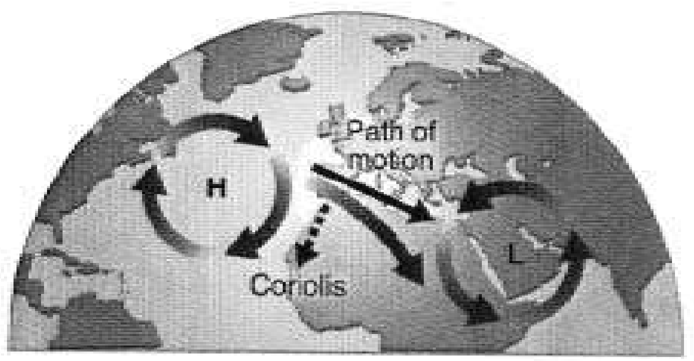

Fig. 5.1 : The Coriolis Effect.

2) **Friction**—It work opposite to pressure gradient to reduce wind velocity and subsequently the coriolis effect.

In lower troposphere, the horizontal wind is strong as it contact with ground and blow against the object. The rougher the surfaces, the greather the frictional resistance.

- The atmospheric zone in which frictional resistance is essentially confined is called friction layer.
- On clear day, when earth is headed their is turbulent mixing of air in lower atmosphere some of the air near the surface sloved down by friction and mixed with the faster moving air above.

Two effects are there:

1) air aloft slow down
2) surface air get speeded up

- After sunset no turbulent mixing of air takes place and causes solar heading. The wind near the surface, thus die out after sunset and frictional effect seen at 2 or 3 km.

3) **Centrifugal action of wind**–It is caused by flow of winds around curved isobar. It tends to deffect the motion inward, toward the centre of rotation.

4) **Buys Ballot's Law–**

- The law is named after Christoph Hendrik Diedrik Buys Ballot (1817–1890).
- It show the relation between wind and horizonal pressure gradient. The movement of air mass from an area of high pressure to an area of low pressure is wind.
- Besides pressure, centain other forces like, coriolis force, the deviation due to the Earth's rotation, and a centrifugal forces come into play. What we see is a balance between these forces.
- Buys Ballot Law states that in the Northern Hemisphere, if a person stands with his back to the wind, the amospheric pressure is low to his left, high to his right. This is because wind travels anticlockwise around low pressure zones in the Northern Hemisphere and is reversed in the Southern Hemisphere, but the angle between the pressure gradient force and wind is not a right angle in low latitudes.
- In a local 'dust devil' (ghurni) during summer, one sees wind rotating anti-clockwise around a low-pressure spot on the ground.

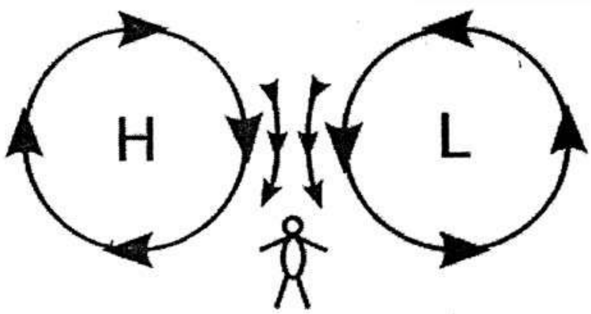

Fig. 5.2 : Buys Bllot's law

- It's not applicable in the equatorial region because of zero coriolis force. In Meteorology, this law acts as simple thumb rule for locating cyclone centres.

Difference between geostrophic wind and gradient wind–

	Geostrophic wind	**Gradient wind**
Definition–	Wind whoes direction and speed are determind by balance of pressure gradient force and coriolis force.	It is a horizontal wind flow in the same direction as geostrophic wind.
Isobar	They blow parallel to the isobar and isobars are straight lines.	The wind blow along the curved isobar.
Low pressure	In low pressure system, geostrophic wind move at more speed than gradient wind.	In low pressure. system, gradient wind move at less speed than geostrophic wind.
High pressure	In high pressure or in ridges geostrophic wind move at lesser speed.	In high pressure or in ridges gradient wind move at higher speed
Velocity	Velocity depend on pressure gradient and coriolise force.	Velocity depends. pressure gradints, coriolise force as well as centripetal force and centrifugal force.

5.4 Planetary Wind Belts

Introduction–Atmospheric circulation is largest movement of air, along with oceanic circulation of the thermal energy is redistributed on Earth surface. The circulation has both vertical and horizontal, components and mass between the high and low latitudes.

The Planetary Wind Belts–The pattern of the movement of the planetary winds is called the general circulation of atmosphere. The general circulation along with oceanic circulation intluence the earth's climate.

There are four wind belts that can be seen:

1) **Inter Tropical Convergence Zone (ITCZ)–**It is low pressure generally situated near the equator. ITCZ represent the convergence of two trade wind system. It's average location is 5^{o}S to 5^{o}N latitudes. Mostly there is vertical movement in the atmospher in this zone. The atmosphere is hot, oppressive, sticky. As the sailors found themselves calmed, it is became to known **Doldrums.**

2) **The trade winds–**This belts are found roughly from 5^{o} to 30^{o} N and S of latitude. The trade winds originate because of pressure of the pressure gradient from the tropical belts of high pressure to equatorial belt of low pressure. In the Northern hemisphere, the wind are north easterly direction and are called **North east trade wind** and for southern hemisphere the wind move in south easterly direction and are called **South east trade wind.** The zone of trade winds is called the **Hadley cell,** because it resemble the connective model use by **Hadley.**

   Horse latitude–In this zone we found horse latitude. As when the sailors take horse on the ship while going to Westindes. The usually stuck in these calm waters and for lighter up the ship they had to throw their horse into the water and to conserve drinking water for themselves and this led to the term horse Hadley.

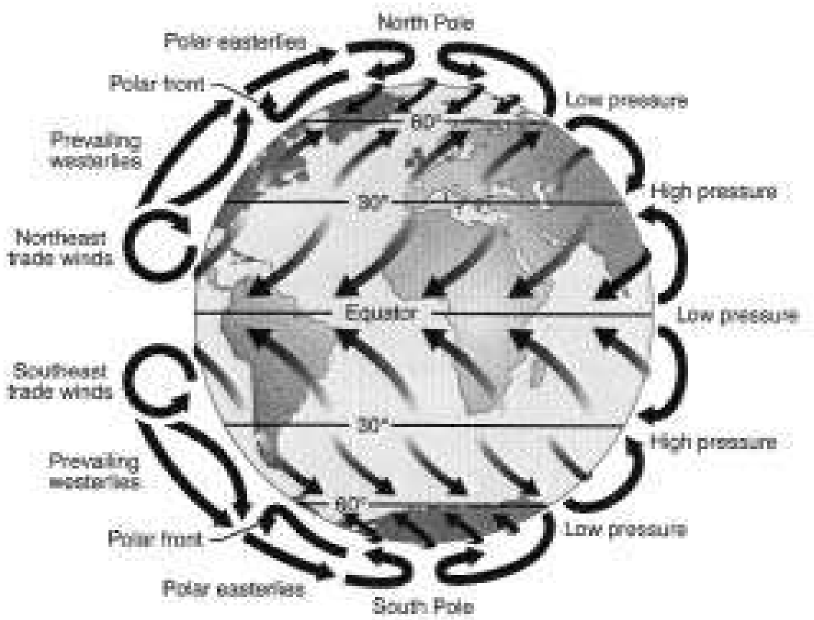

Fig. 5.3 : The general circulation of the atmosphere.

3) **Westerlies–**This belt is lies between 30° and 60° latitude in both hamispher. They originated from the high pressure area in horse latitudes and moues found poles. Under the effect of coriolis force they become the south westerlies in Northern hemisphere and North westerlies in sourthern hemisphere.

As south hemisphere there is more ocean as a result westerlies blow with greater force in south hemisphere. These are associated with extra-tropical cyclones.

Ferrel cell–It can found in westerlies. This movement is the reverse of airflow in the Hadley cell.

In southern hemisphere, as there is all water, sailore use expression as—

40°–Roaring forties.

50°–Furious fifties.

60°–Screaming sixties.

4) **Polar Easterlies–**It blow from the polar high pressure belts toward temperate low pressure belts. This wind are observed from anticyclone in Siberian and Canada. They are found between 70°N and 60°S latitude.

Polar cell–The cold polar easterlies move towards equator and clash with warm westerlies and the zone of convergent is known as polar front.

Polar cells have tendency to move northward and southward with the shifts of pressure belts. The upper air flow is westerly and surface flow is easterly.

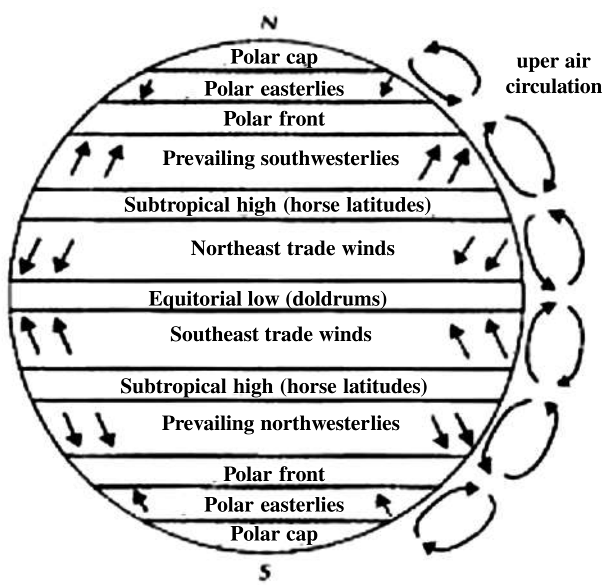

Fig. 5.4 : Planetary winds

Mechanism of General Circulation of Atmosphere

Since the atmospheric circulation is due to imbalance in the energy it include the following facts–

1. We can observed wind direction throughout the depth of troposphere.
2. It maintain the heat balance of atmospher. The mechanism by which heat is transferd showed be taken into account.
3. There must be close balance between precipitation and amount of evaporation. There are area where precipitation is more such as equatorial region and areas here evaporation is more in desert region.
4. The circulation must take the earth's angular momentum.

5.5 Global atmospheric pressure belts

Introduction–The unequal heating of earth and its atmosphere by the sun, because of revolution of earth on its titled axis causes difference in pressure and form the pressure belts.

Pressure belts of Atmosphere–

a) **Equatorial low pressure belt–**At equator as the insolation receive by the earth is maximum as a result the air got heat and it rise up and form low pressure area at the surface. This zone shifted northword during summer and move southward during winter.

b) **Sub-tropical high pressure belt–**The warm air rises up at the equator and it bend down toward pole. Due to coriolis force, the air descends at 30^0–35^o latitude and create sub tropical high pressure belt. This zone is characterized by anticyclonic condition and most of

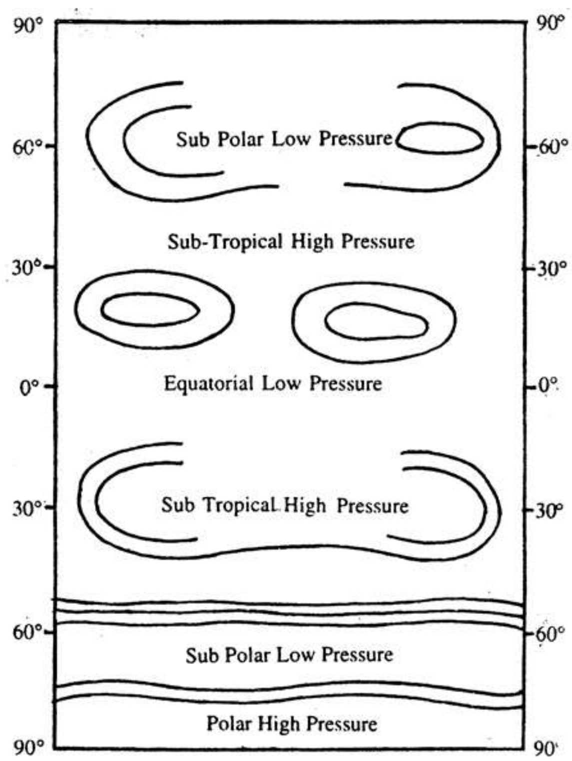

Fig. 5.5 : Generalized distribution of air pressure

the hot desert of the world are present.

c) **Sub polar low pressure belt–**This belt is located at 60°–65° in both the latitude. The surface water spread outward from this zone due to rotation of earth and produce low pressure. This belts are more dominant in southern hemisphere due to the existence of more water.

d) **Polar high Pressuer belt–**High pressure at the pole on both the hemisphere due to low temperature. As a result density of air increases. In northern hemisphere, the belt is called the north polar high pressure belt and in southern hemisphere, the belt is called south polar high pressure belt.

The wind from these belts blow toward sub polar low pressure belts.

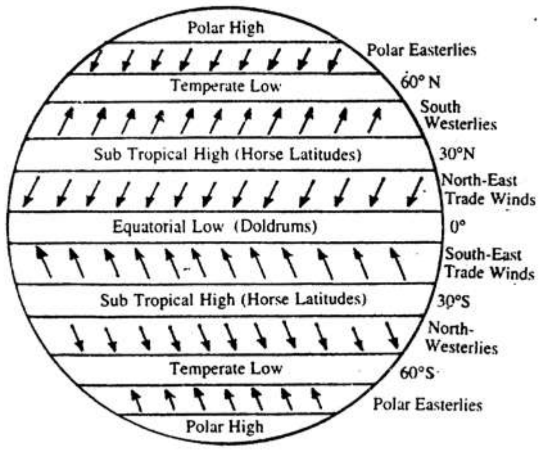

Fig. 5.6 : World Pressure belg and Planetary winds

Oscillation of Pressure Belts–

(i) **January Condition**– In January, as the sun move south-ward, the equatorial low pressure belt shifts a little south of the mean equatorial position.

Area of lowest pressure oceurs in South America, South Africa and Australia because land heated up faster than water. Subtropical high is over the southern oceans and is broken into three cells. There may be some evidence of low pressure over Antarctica.

North hemisphere–A well develop high pressure cell occurs in the interior part of Eurasia as land cools more rapidly than oceans.

The temperature lower down in winter than surrounding seas.

In northern hemispher, two cells develop over North Atlantic and North Pacific.

2) **July Condition–**In July, the equatorial low pressure belt shifts toward north of mean equatorial position, because of northward movement of sun.

All pressure belts shift northward in July. The polar high disappeared from map due to warm up of Arctic Ocean in summer in Asia a lower pressure develop.

Southern hemisphere–Subtropical high seams to be strongly developed over ocean than over cold continents.

The subpolar low is continuous belt at about 65°S to 75°S latitude.

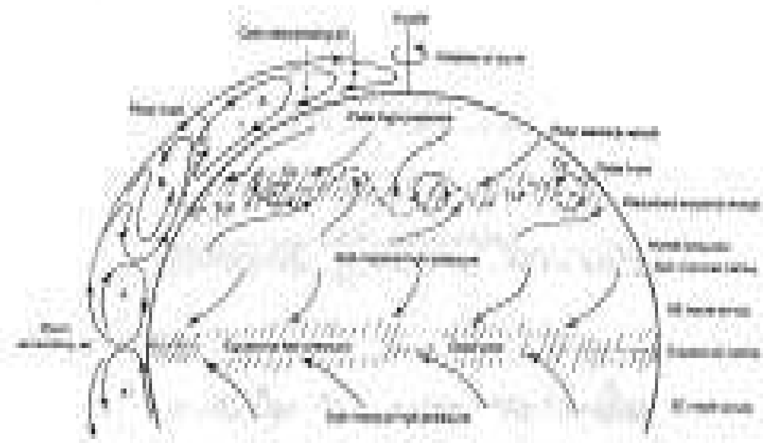

Fig. 5.7 : A schematic model of the general circultions of the atmosphere in plan.

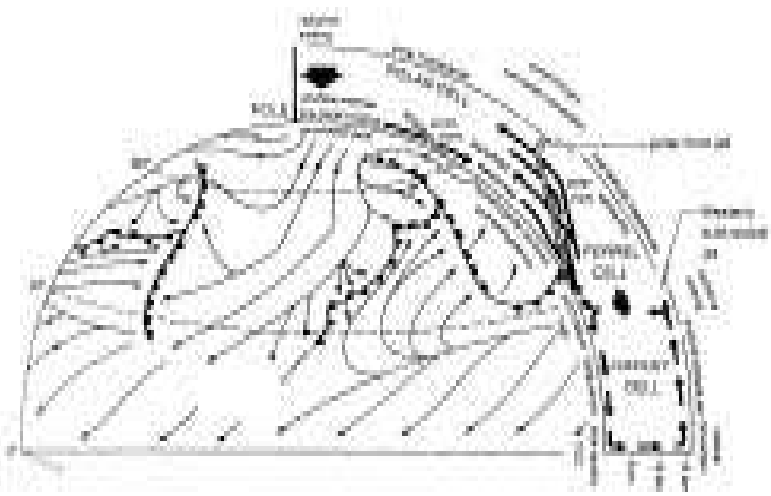

Fig. 5.8 : A schematic model of the generation circulation of the atmosphere (in Northern Hemisphere) in cross section showing the Hadley, Ferrel and Polar Cell.

Factors Controlling Pressure Systems:

There are two main causes, thermal and dynamic, for the pressure differences resulting in high and low pressure system.

1) Thermal Factors:

An important factor while studying the pressure systems in temperature and its variations from equator to the poles, since a chain of events takes place due to heating and cooling of the earth's surface and its atmosphere.

When air is heated, it expands and hence, it's density decreases. This naturally leads to low pressure. On the contrary, cooling results in contraction. This increases the density and thus leads to high pressure. Formations of equatorial low and polar highs are examples of thermal lows and thermal highs respectively.

2) Dynamic Factors:

The formation of pressure belts may be explained by dynamic controls arising out of pressure gradient forces and rotation of the earth. The warm equatorial air rise and cool and after reaching in the upper layers, it starts moving towards the pole. It further cools and begins to subside in a zone between 20^{o} and 35^{o} latitude. Two factors are responsible for the general subsidence of air in this belt: First, cooling of the air results in increased density, which accounts for its subsidence. Second, owing to the rotation of the earth, the poleward directed winds are deflected eastwards, which is also called the Coriolis force. The rate of deflection increases with the distance from the equator.

3) Seasonal Distribution of Pressure:

In January, the equatorial low pressure belt shifts a little south of its mean equatorial position, due to the apparent southward movement of the sun. The lowest pressure occur on the land masses of South America, South Africa and Australia, because land masses become much hotter than the adjoining oceans. Sub-tropical high pressure belt of the southern hemisphere is broken over the continents and remains confined to the oceans only.

It's development is maximum in the eastern parts of the oceans where the cool ocean currents are effective. In the northern hemisphere, a well-developed sub-tropical high pressure area extends over the continents.

Finally, sub-polar low of the southern hemisphere extends as a trough whereas in the northern hemisphere, there are two cells of low pressure extending over the North Atlantic and the North Pacific. These are known as the Icelandic low and the Aleutian low respectively.

In July, the equatorial low pressure belt shifts towards the north due to the movement of the sun. This shift is maximum in Asia.

The landmasses of the northern hemisphere become excessively hot and low pressure areas develop over them. The sub-tropical high pressure belt of the southern hemisphere extends continuously. In contrast, in the northern hemisphere, it is broken over the continents and remains confined to the North Atlantic and North Pacific Oceans.

Sub-polar low is deep and continuous in the southern hemisphere, while in the northern hemisphere there is only a faint oceanic low.

4) Diurnal Variation of Pressure:

The atmospheric pressure shows a definite rhythm when observed diurnally. Insolation heating and terrestrial radiation are mainly responsible for diurnal variations in pressure.

During the equinoxes, the maximum occurs at 10 A.M. and 10 P.M. and the minimum at 4 A.M. and 4 P.M. In the tropic, higher diurnal range occurs at places located at sea level and a lower range occurs at places located at higher altitudes.

The continents experience a larger range during daytime and a smaller range during the night. The oceans and coasts have a large diurnal range. The irregularities in the diurnal range occur due to cyclones, anti-cyclones and other atmospheric disturbances. These irregularities are larger and more pronounced in mid-latitudes and less pronounced in high latitdues.

Characteristies of major global winds

	Latitudinal sone	Sea level pressure conditions	Surfaces over which most distinctly developed	Average direction near to surface	Average velocity near to surface	Seasonal varitation	Consistency of velocity and direction
Doldrums	Equatorial–may be displaced 20° from the Equator, particularly in the Northern Hemilsphere	Generally low pressure with slack presure gradients	Over ocean surfaces as a discontinuous zone	Highly variable	Less than 3 ms^{-1}	Contigulty of the doldrum zone varies, most extensively developined in March and April; disjoined in August	Highly variable
Equatorial Westelies	Equatorial, extending to 28° particulary over the Indian sub-continent	Low, particularly monsoonal (summer) pressure conditions	Primarily ocenic, but of major importance over land areas of West-Africa and India	SW in Northern Hemisphere; NW in Southern Hemisphere	Less than 6 ms^{-1}	Best developed in the summer hemisphere	Locality very consistent in speed and direction
Trade winds	40° to Equator, reaching greatest velocity 5^0 to 20^0	Subsiding air associated with subtropical anticyclone	Core areas located in eastern parts of major oceasn but also blowing over subtropical and surface	NE in Northern Hemispher; SE in Souther Hemisphere	5 to 8ms^{-1}	Core areas most extensive in winter hemispheres but greatst velocities in summer	Remarkcably consistent; core areas over 70% recorded win direction from east; over 50% in most other trade win areas

5.6 Tri-cellular Meridional Circulation

The three cell model of the northern hemisphere or the meridional circulation is a model prepared by Palmen in 1951. The model makes it clear that there are two possible ways of transporting heat and momentum:

(a) By circulation in vertical plane

(b) By horizontal circulation

The three meridional circulation cells are–

– Tropical cell (Hadley cell)

– Polar front cell (Ferrel cell)

– Sub polar and polar cell

(1) **Tropical Cell–**This cell is also called Hadley Cell after G. Hadley who put forward his own explanation in 1735.

The circulation cell is located between the equator to 30° latitude. It rotate anticlockwise. Due to high rate of heating at equator, resulting the warm air moves up then cumulanimbus clouds with great vertical height form. The warm air moves from tropical cell to poleward direction. The poleward flow of air in this cell and this are not affected by surface friction. These air again blow towards the equator where they again heated.

2) **Polar Front cell–**This cell are also called Ferrel Cell. In this mid latitude cell, the surface air flow is directed toward the pole and becasue of coriolis force. The wind blow almost from west to east. They move from pole ward to equator ward. These wind descent near horse latitudes. After decending the winds again blow poleward as surface westerlies and compute cell is form. It rotate clockwise.

3) **Polar Cell–**This cell are located between 60° latitude and the poles. The polar easterlies blow from polar high pressure area to mid latitude low pressure belt. The general direction of surface polar wind become eastal, due to ceriolis force. The polar eastern winds move equator ward and cloud with warm westerlies in temperate regions and form polar front. The pole ward upper air decent at poles and the polar high pressure form polar cell.

5.7 Jet Stream

Introduction–It is defined as fast moving air that is usually several thousand miles long and wide but relatively thin. They found in the upper atmosphere between troposphere and stratosphere. It was discovered during second world war.

Properties of Jet Stream

1. The circulation of jet stream is from west to east but only tropical easterly jet stream moves from east to west.
2. On an average, jet stream measure thousands of kilometers in length, a few hundread kilometers in width and a few kilometers (2–4) in depth.
3. The circulation is observed between pole and 20^{o} latitudes in both the hemispheres.
4. Their circulation path is wavy and meandering.
5. There is seasonal charge in the wind velocity in jet stream. Wind velocity increase twice in summer season (480 km per hour).
6. Jet Stream narrow down during summer season because of their northward shifting.

Types of Jet Streams–

1. **Polar front Jet Stream–**This is formed above the convergence zone of the surface polar cold airmass and tropical warm air mass. These move in easterly direction but are irregular.
2. **Subtropical Westerly Jet Stream–**It move in upper tropesphere to the north of subtropical surface high pressure belt. The circulation is from west to east in more regular manner.
3. **Tropical Easterly Jet Stream–**This develop in upper troposphere above surface easterly trade winds over India and Africa.
4. **Polar Night Jet Stream–**This also known stratospheric subpolar jet streams. This develop in winter season. This jet stream become strong with high wind velocity during winter and low velocity during summer.
5. **Local Jet Stream–**This formed locally due to local thermal and dynamic condition and have limited local importance.

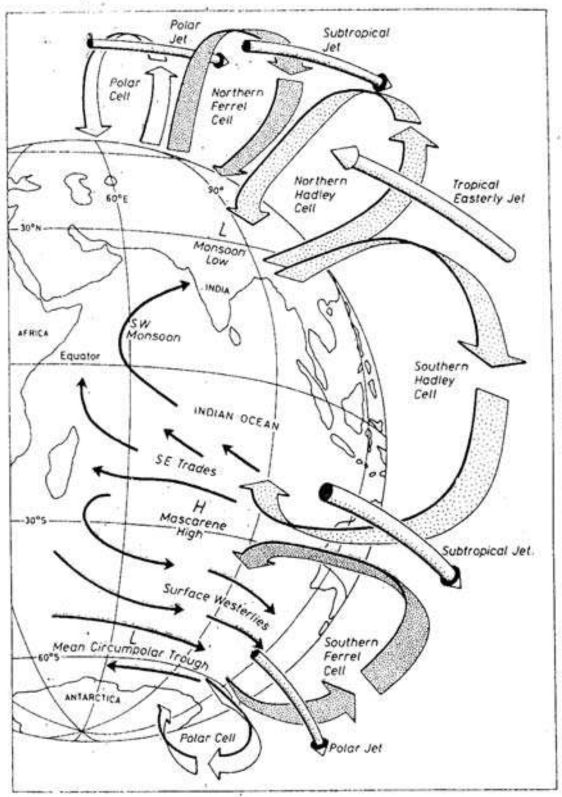

Fig 5.9: Various types of Jet Stream.

Importance of Jet Stream

1. Jet Stream cause horizontal convergence and divergence in upper troposphere. Convergence cause anticyclone and due to divergence air cyclone develop.
2. The vertical circulation of air in jet stream occurs in two ways. Cyclonic pattern is characterized by upward vertical air movement and anticyclonic patter is characterized by downward vertical air movement. This transfer anthropoganic pollutants.
3. The monsoon of South Asia is largely affected of controlled by Jet streams.
4. Sub-tropical westerly jet stream is responsible for one on set of monsoon.
5. Jet stream's location is used by meteorologist to help them in weather forecasting. They are responsible for pushing weather all over the world and control the behaviours of terrestrial atmosphere.

Index Cycle of Jet Stream (Formation and Development of Jet Stream) :

There are changes in the position of exent of jet stream from pole towards equator. The heavy jet stream is called Rossby waves. The period of transformation of straight path to weavy path is called index cycle. It has four stages:–

(A) First Stage–The position of jet stream is near the poles and is separated by polar cell air mass in north and warm westerlies in the south. The westerlies in this stage have shifted towards higher latitudes where cyclonic activity take place. The circulation of jet stream is almost straight path from west to east. There is steep pressure gradient across this strong upper air westerly circulation and general high zonal index.

(B) Second Stage–Grandully the amplitude of wave increase. The straight path of jet stream transformed into wavy path. The whole jet moves toward the equator. This stage is the begining of development of Rossby waves.

(C) Third Stage–This stage is characterized be fully developed meanders cores of jet stream as the bending become sharp and amplitude increase there tropical air mass move north and cold polar air moves to south. Jet stream near equator and exchange of tropical and polar air masses take place on large scale and temperature gradient is directed from east to west.

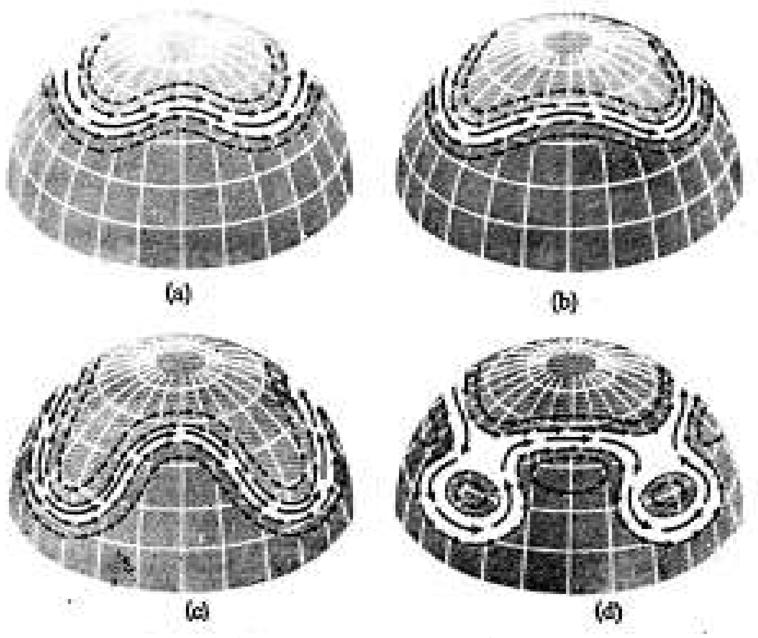

Fig. 5.10 : Index cycle of Jet stream

(D) Fourth Stage–In this stage the giant size meanders of the jet streams are cut off from the main stream caused due to meridional circulation. In the upper atmosphere of higher latitudes, the tropical air masses are entrapped by the colder air. This is called the low zonal index of jet stream and the zonal character of the upper level westerlies is no longer existence. They are fragment into number of cells.

5.8 Conclusion

The general wind circulation pattern, tri-cellular model of it along with the controlling factors of wind circulation are very significant to understand the global scenario of planetary winds. Moreover, global atmospheric pressure belts and the salient features of jet stream help to understand the regional climatic conditions related to wind and pressure.

5.9 Summary

- The global atmospheric circulation varies from year to year, but large scale structure of wind or atmospheric circulation remains constant.
- The equatorial region has zero coriolis force.
- The geostrophic wind blows parallel to the isobar.
- Globally there are four wind belts.
- In southern hemisphere, sailore use expression for the different latitudes as: 40^o-Roaring forties; 50^o -Furious fifties; 60^o -Screaming sixties.
- The three cell model of the northern hemisphere is prepared by Palmen in 1951.
- The three meridional circulation cells are: Tropical cell (Hadley cell); Polar front cell (Ferrel cell); Sub polar and polar cell.
- The stronger flow of winds than normal in narrow cores are known as jet stream.
- The monsoon of South Asia is largely affected by jet streams.
- The jet stream is measured on an average, thousands of kilometers in length, a few hundread kilometers in width and a few kilometers (2-4) in depth.

5.10 Key words

Wind circulation, tri-cellular model, planetary winds, pressure belts, jet stream, coriolis force, Hadley cell, ferrel cell, polar cell, roaring forties, furious fifties, screaming sixties, horse latitude, geostrophic wind, doldrum, ITCZ

5.11 Model Questions

Short answer type:

1. State the factors controlling general circulation of winds
2. What is geostrophic wind?

3. What is coriolis force?
4. What is Byes ballot law?
5. Differentiate geostrophic wind from gradient wind.
6. State the factors factors controlling pressure belts.

Long answer type:

1. Explain the general pattern of distribution of planetary winds.
2. Give an account of the global pressure belts with diagram.
3. Discuss the relation between the global pressure belts and planetary winds.
4. Describe the tri-cellular (meridional) models of wind circulation.
5. Discuss the types and development of jet stream.
6. Highlights the properties and importance of jet stream.

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Unit 6 ❒ Tropical and Mid-Latitude Cyclones

Structure

6.1 Intruduction

Henry Piddington first used the term 'cyclone' in 1840, as a derivation from the Greek word 'Kyklon' which means moving in a circle, like the 'coil of the snake'. In this portion, we came to know about two cyclones of two different regions. Cyclones lying between the tropics of capricorn and tropics of cancer are called tropical cyclones and cyclones observed in the temperate region uniformly are known as extratropical cyclones.

6.2 Objectives

i. To know about tropical cyclones.

ii. To know the features, favourable conditions of tropical cyclones.

iii. To know the formation and structure of tropical cyclones.

iv. To know about extratropical cyclones.

v. To know the salient features of extratropical cyclones.

vi. To know the formation and weather condition associated with extratropical cyclones.

6.3 Tropical Cyclone

Introduction–Henry Piddington first used the term ‘cyclone’ in 1840, as a derivation from the Greek word ‘Kyklon’ which means moving in a circle, like the ‘coil of the snake’. Cyclones developed in the regions lying between the tropics of capricorn and cancer are called tropical cyclones which are not regular and uniform like extratropical or temperate cyclones. They vary in form, shape, size, velocity and weather conditions.

Types of tropical cyclone—Generally they are divided into four major types–

i) Tropical distrubance or easterly wave.

ii) Tropical depression.

iii) Tropical storm.

iv) Hurricanes or Typhoons.

On the basis of intensity they are divided into two principal types and four sub types—

i) Weak cyclones:

a) Tropical disturbance b) Tropical depressions

ii) Strong and furious cyclones:

a) Hurricanes and typhoons b) Tornadoes

1. Favourable conditions—The exact mechanism for the origin of tropical cyclones is still poorly understood. Sometimes, it is said that they have been occured due to development of a front like situation between land and sea wind. But more acceptable concept in this regard is it's thermal origin over warm tropical sea, development of which is related to the release of latent heat of condensation. The general conditions necessary for the origin and development of tropical cyclones can be summerized as follows:–

i) There should be continuous supply of abundant warm and moist air. Tropical cyclones orignate over the warm tropical ocean where the surface temperature is above 27°C during summer season.

ii) Presence of higher value of coriolis force is rewired to give spiral motion to the inflow winds. Infact, coriolis force causes cyclonic circulation of air. That is why tropical cyclones are particularly absent in a belt of 5°–8° wide on both sides of the equator where coriolis force is minimum. Most of the cyclones are limited to a belt of 5°–20° Notth in the western parts of the oceans.

iii) They are associated with Inter-Tropical Convergence (ITC) which extendes from 5° to 30° North latitudes during summer season.

iv) Pre-existing weak tropical disturbances and intensity ultimately develop high intensive violent tropical cyclones.

v) There should be anticyclonic circulation at the height of 9000–1500m above the surface distrubance. The upper air anticyclonic circulation sucks the air from the ocean surface above and thus the upward movement of air in accelerated and low pressure centre at the surface is further intesified.

vi) Tropical cyclones develop around small atmospheric vertices in the Inter-Tropical Convergence Zone (ITCZ).

2. Characteristics–

i) **Size**–Tropical cyclones vary in size considerably. Their average diameter is from 80 km. to 300 km. But some of them may be having just 40 to 5 km. in diameter.

ii) **Velocity**–They advance with varying velocities weak cyclones move at the speed of about 32 km per hour whille hurricanes attain the velocity of 180 km. per hour on more.

iii) **Vigorous–**Tropical cyclones become more vigorous and move with very high velocity over the oceans, but become weak and feeble while moving over land areas and ultimately die out after reaching the interior portion of continents.

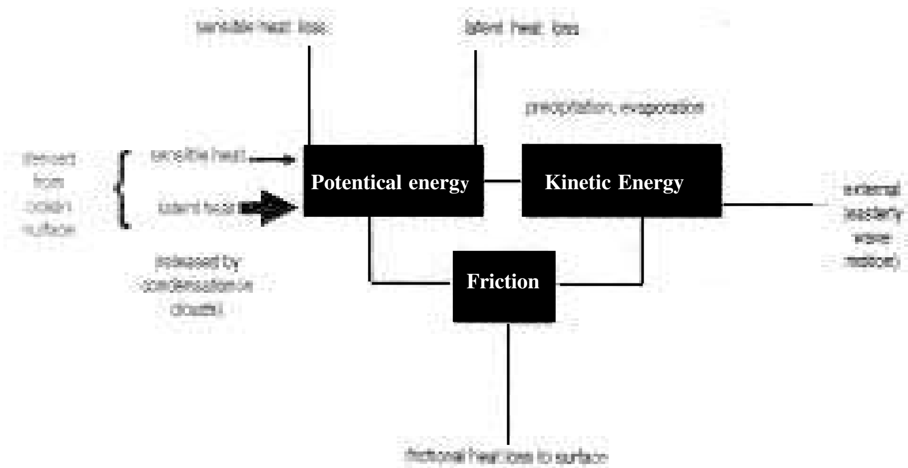


Fig. 6.1: Tropical Cyclones as an energy system.

iv) **Pressure–**The centre of the cyclone is characterised by extremely low pressure called 'eye' of the cyclone.

v) **Temperature variation–**Like temperate cyclones, tropical cyclones are not characterized by temperature variations in their different parts as they do not have different fronts.

vi) **Rainfall cell–**There are no different rainfall cells in the tropical cyclones as is the case of temperate cyclones and hence each part of the cyclones yields rainfall.

vii) **Flood deluge–**Tropical cyclones are not always mobile. Sometimes, they become statinoary over a perticular place for several days and yield heavy rainfall causing flood deluge and environmental disaster.

viii) **Movement–**Normally, they move from East to West under the influence of trade winds. These cyclones weaken when they enter subtropical region.

ix) **Time–**Tropical cyclones are confined to a particular period of the year, mainly during summer season.

x) **Energy–**Tropical cyclones derive their energy from the latent heat of condensation.

3. Natural hazard–Tropical cyclones become disasterous and natural hazard due to their high wind speed (180–400 km/hour), high tidal surges, high infall intensity, very low atmospheric pressure causing unusual rise in sea level and their presistence for several days cause several damages to the affected regions.

4. Regional Distribution–These clyclones are mostly develop over the occean surface between 5^o–15^o latitudes in both the hemisphere. There are 6 major regions of the tropical cyclones e.g.–

1. Tropical North Atlantic Ocean.
2. Western part of the tropical North Pacific Ocean.
3. Eastern part of the tropical North Pacific Ocean.
4. The Bay of Bengal and the Arabian Sea.
5. The South Indian Ocean.
6. The Western South Pacific Ocean.

5. Formation and Development/Life cycle:

Pre-conditions:

i) A continuous supply of abundant heat and moisture.

ii) A suitable heat source, usually a large tropical water surface.

iii) Low level convergence, turbulent vertical motion of air and strong anticyclonic circulation in upper troposphere.

iv) High coriolis deflection to generate a cyclonic movement.

v) Weak vertical wind shear.

vi) Existence of weak tropical disturbance favouring intensification the storm etc.

A) **Formation stage:**

i) These phase develop over the sea with huge area.

ii) It concentrating on the low pressure, wind from the high pressure area comes to the low pressure zone.

iii) The value of low pressure zone between 915 to 950 mb.

B) **Developing stage:**

i) The pressure radient fall and the wind velocity increases in this phase.

ii) Wind rotate anticlockwise in the northern hemisphere and clockwise in the southern hemisphere.

iii) The isobers line become rounded with the difference of 2–3 ml and closely located.

iv) wind speed 25–40 km/hr colled depression.

C) **Mature stage: Divided into four parts–**

i) Eye of the cyclone (10-30 km. radius)

ii) Wall of eye of cyelone (wind speed. 90km/hr)

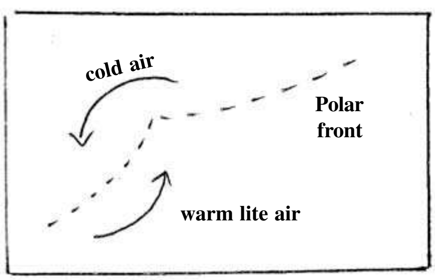
iii) Heavy rainfall with high wind velocity (80–150 km/hr)

iv) Turbulence zone.

v) Asymmetrical wind.

d) **Dissipating stage:**

i) Last stage of the phase.



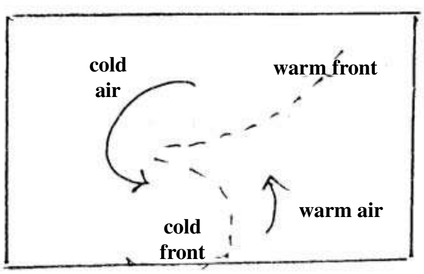


Fig. 6.2 : Formation of Tropical Cyclone

ii) It is the dacaying phase of cyclone.

iii) Wind speed falls at 2–40 km./hr.

6. Structure: The horizontal structure of the cyclone, included fine parts–

1) **The eye of the cyclone–(i) The eye** is the centre of the storm, which is more or less circular with 5–50 km. diameter. The lowest pressure, the highest temperatures and the highest relative humidities of the storm are found within the eye. The air at the outward edge of the eye is dragged upward and outward by the surrounding air.

ii) **Eye wall–**The eye is surrounded by a wall of cumulonimbus clouds known as **eye wall,** which is a more or less circular region of about 10-20 km wide. The

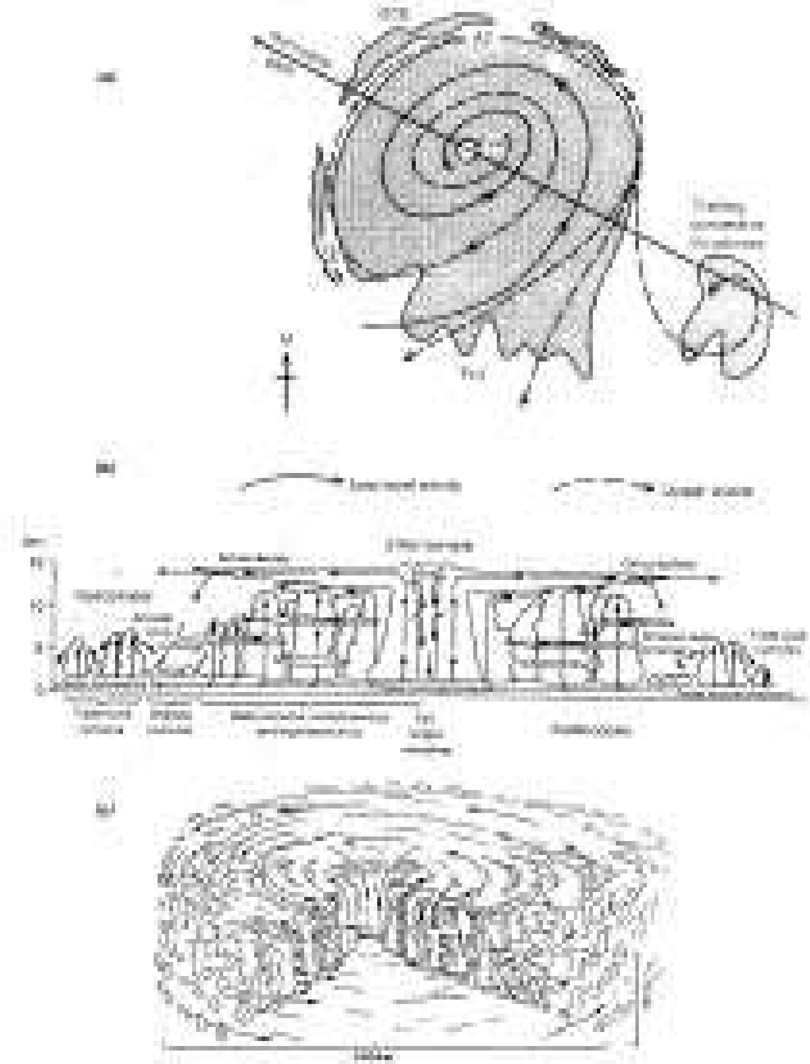


Fig. 6.3: Tropical cyclones in plan (a); profile (b); and three dimension (c).

strongest winds are found within the eye wall and it consists of an almost continuous ring of intense thunderstorm involving explosive cumulonimbus growth with violent vertical motion. As a result, the most intense rainfall occur in this region.

3) **Spiral Band**–Away from the eye wall there are two spiral bands which give the cyclone the appearance of galaxy from the space. These spiral bands are also called rainbands or feederbands. It contains many individual thunderstorm which produce heavy rainfall spiralling towards the centre in a cyclonic sense.

4) **Annular Zone–**The annular zone has suppressed cloudiness, high temperatures and low humidities. This is because of subsidence of air from aloft at the outer limits of the cyclone.

5) **Outer connective band–**The outer connective band occurs at the edge of the main cloudmass and consists of an outer fringe of deep connective cloud produced as a result of instability which is consequent upon convergence of subsident outflow.

The vertical structure of the cyclone include three parts–

i) **Inflow layer–**The inflow layer is the lowest layer extending upto 3 km. It is this layer which drives the storm and liberates latent heat.

ii) **Middle layer–**Middle flow layer extending between 3 to 7 km. Thus, the main cyclonic circulation of the storm takes place in this region. The airflow is circular in form.

iii) **Outflow layer–**The outflow layer is from 7 km. upward to the tropopause. The air motion is anti-cyclonic and helps in divergence of the air.

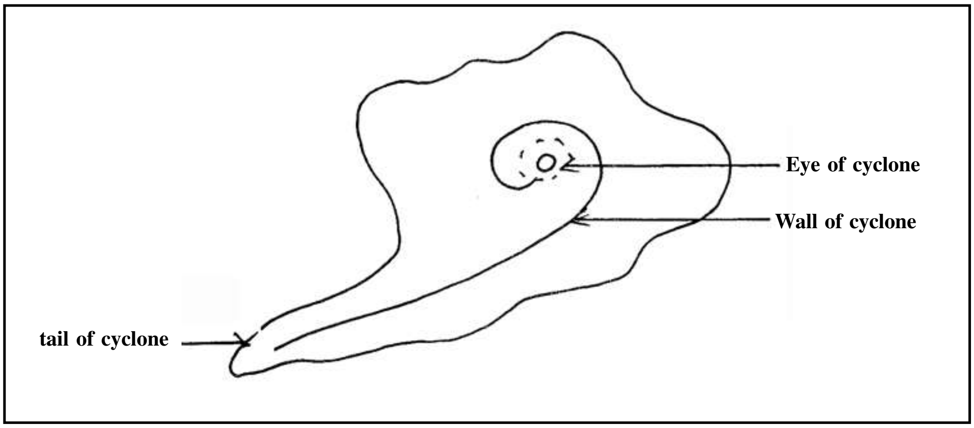


Fig. 6.4: Structure of Tropical cyclone

6.4 Mid-Latitude or Extra-tropical Cyclone

Introduction–The term extra-tropical cyclones, temperate cyclones or depressions are inter changeably used to denote these moving cyclones in the mid-latitude zone.

Extratropical cyclones arise through a process called cyclogenesis, in which cold and warm air masses interact in an unstable environment. Colder air to the north and warmer air to the south flow toward each other creating an area of low pressure between them.

Location–Extra-tropical cyclones develop in the regions lying between 30° and 65° north and south latitudes in both the hemispheres near the Asian coast and the Atlantic, near Greenland and the North American coasts. Stroms affecting Europe typically originate to the east of North America or Greenland and subsequently move eastward across Europe. It is in these latitude zones that the polar and tropical air masses meet and form what is known as the polar fronts.

Characteristics–

1) Size and Shape

- The temperate cyclones are asymmetrical and shaped like an inverted 'V'.
- They stretch over 500 to 600 km.
- They may spread over 2500 km over North Americal (Polar Vortex).
- They have a height of 8 to 11 km.

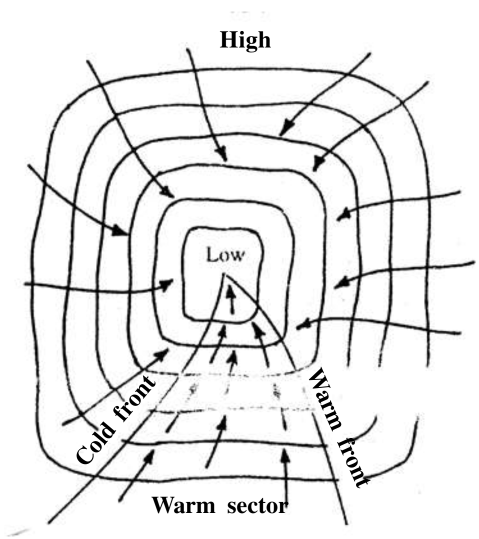


Fig. 6.5 : Temperate cyclone of northern hemisphere

2) Wind Velocity and Strength

- The wind strength is more in eastern and southern portions, more over North America compared to Europe.
- The wind velocity increases with the approach but decreases after the cyclone has passed.

3) Orientation and Movement

- Jet stream plays a major role in temperate cyclonogeneis.
- Jet streams also influence the path of temperate cyclones.
- Since these cyclones move with the westerlies (Jet Streams), they are oriented east-west.
- If the storm front is directed northward, the centre moves towards the north,

but after two or three days, the pressure difference declines and the cyclone dissipates.

- When the storm front is directed southwards, the centre moves quite deep southwards-even up to the Mediterranean region and cause the Mediterranean cyclones or **Western Disturbances** (They are very important as they bring rains of North-West India–Punjab, Haryana).

4) Structure

- The north-western sector is the cold sector and the north-eastern sector is the warm sector (Because cold air masses in north and warm air masses in south push against each other and rotate anti-clockwise in northern hemisphere).

Source Region–The most frequent temperate cyclone areas are between 35^o-65^o latitudes in both the hemisphere. Some favourable storm tracks are—

i) After originating from noth Pacific of the north-east and eastern coasts of Asia move in easterly and north easterly directin towards the gulf of Alaska and ultimately merge with Aleutian Low and then follow southerly directin and reach as far south as Southern Californai.

ii) Sierra Nevada Range, Eastern Colorado, East of CAnadian Rocky Mountains, Great Lakes region in North America.

iii) Gulf of Mexico is also the chief centre of its origin.

iv) North-west North Atlantic of the north-east coast of North America, from here cyclone enters the north western part of Europe.

v) Area between Iceland and Barents Sea.

5) Stages of the life cycle of an extra-tropical cyclone:

The four stages in the life cycle of an extra-tropical cyclone are: (1) the initial state, (2) the incipient stage, (3) the mature stage, and (4) the occlusion stage.

i) The initial stage:

In the initial stage the polar and the tropical air currents which are on the opposite sides of the polar front blow parallel to the isobars and the front is created.

In the cold air mass to the north of the polar front flow air from east to west. In the warm air mass to the south of the front flow the air from west to east and the wave disturbance is produced the front is in perfect equilibrium.

The wedge of cold air mass lies under the warm air. These is complete absence of wind shift. The weather is fine. However, along the slanting surface of discontinuity where the opposing air currents meet, there is a sudden change in the direction of wind. This is called wind-shear.

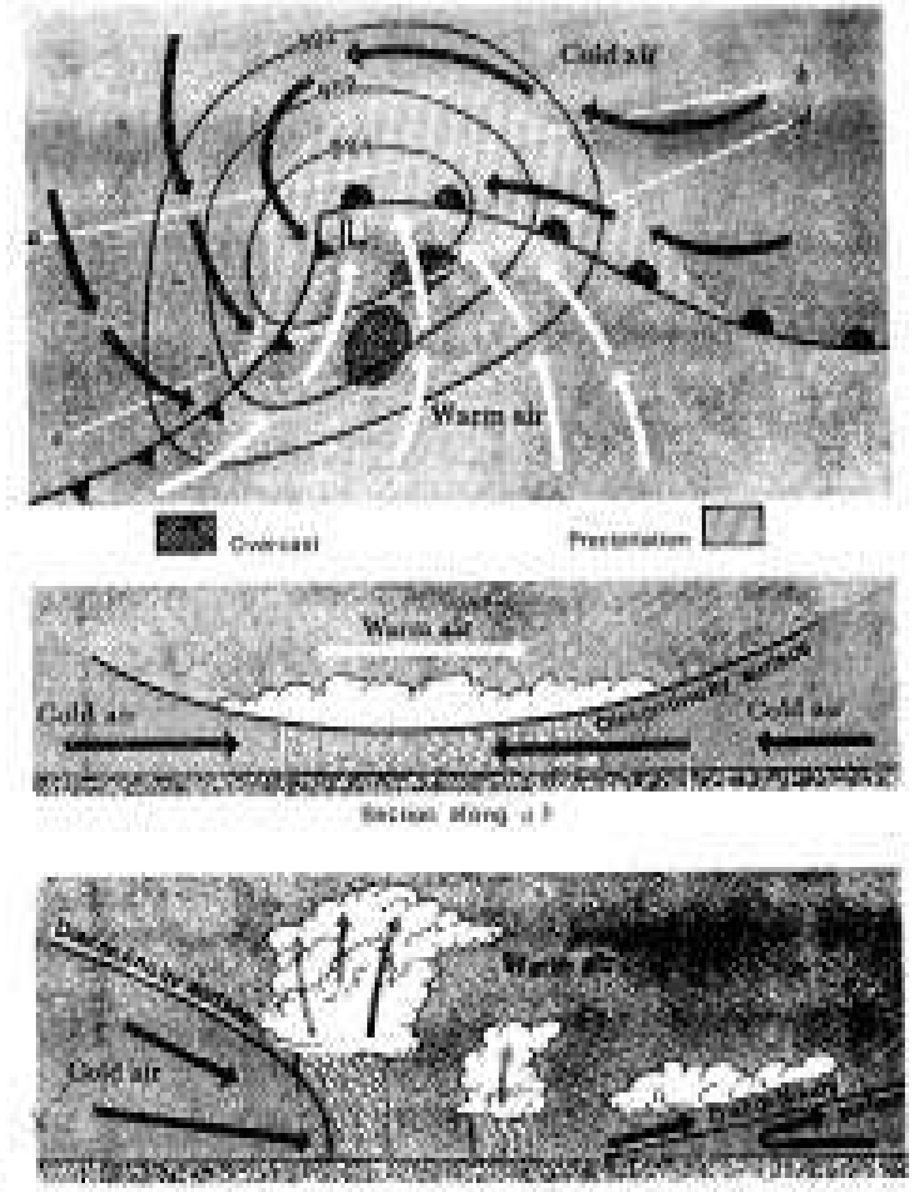


Fig. 6.6 : Cyclone model: upper drawing shows the idealized circulation of a mature cyclone; middle and lower drawings are vertical cross-sections along a-b and c-d respectively.

ii) The incipient stage:

In the second stage a wave has formed on the front. Cold air is turned in a southerly direction and warm air in a northerly direction.

A wave like unstable front was created due to the penetration of warm and cold air masses into one another territory. This results in the readjustment in the pressure field as a result of which the isobars become almost circular in shape.

A cyclonic circulation is initiated around a low centre at the apex of the wave. The whole cyclonic vortex is carried along with the winds prevailing in the warm-air region at approximately the speed of the geostrophic component of the wind.

It may be pointed out that the new depression developing at the crest of the wave is called the nascent cyclone. The process of the birth of a new cyclone is commonly called cyclogenesis.

iii) The mature stage:

In the third stage the intensity of cyclone increases. The curvature and amplitude of the wave also undergo a marked increase. The air in the warm sector starts flowing from the southwest towards the colder air flowing from the southeast.

Now, the cyclone is fully developed. There are well marked warm and cold sectors. The warm air in this stage moves faster than the cold air.

The direction of movement is perpendicular to the warm front. In fact, the warm air is moving into a region previously occupied by the cold air. In the rear of the cyclone cold polar air is under-running the air of the warm sector, thus a cold front is generated there.

Throughout the cyclone, there is an ascending air along the entire surface of discontinuity. If the rising air mass is moist, there will be cloudiness and precipitation along the warm as well as cold fronts as shown by the shaded areas.

The precipitaion released at the warm front is more widespread and steady, whereas the cold front precipitation is confined to a narrow zone.

Since the position of the cold front advance faster than the warm front, the warm sector becomes progressively narrower. This is the beginning of occlusion. This particular phenomenon marks the maturity of the cyclone.

iv) The occlusion stage:

In the final stage the advancing cold front ultimately overtakes the warm front which results in the formation of an occluded front. Occlusion starts first near the apex of the wave where warm front is closest to the cold front. Gradually the process of occlusion comes down to the more open part of the two fronts. Thus, the warm sector is slowly pinched off and finally the two cold air masses mix across the front. This eliminates the occluded front. Now, the cyclone dies out. The life span of a single frontal cyclone is normally about five to seven days.

6) Origin of Extra-tropical cyclones:

i) Ploar front theory—

- This theory, as stated earlier, is also called the frontal theory or the wave theory of the origin of extra-tropical cyclones. It was developed by V. Bjerknes.
- This theory recognizes that the polar front, separating polar and tropical air masses, gives rise to cyclonic disturbances that intensify and move along the front and proceed through a somewhat predictable life cycle.
- Cyclones, according to Bjerknes, from along a front where polar and tropical air masses with contrasting physical properties (temperature and density) are moving parallel to it in opposite directions.

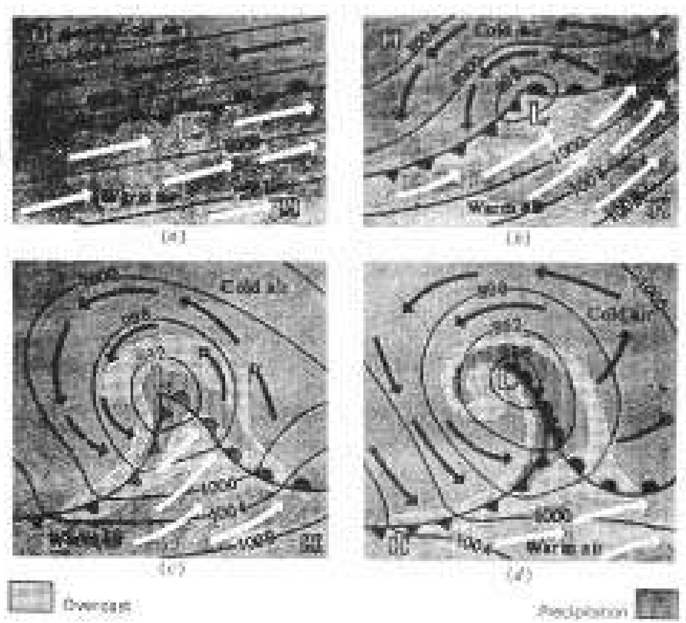


Fig. 6.7 : Stages in the life cycle of an extratropical cyclone (a) Initial state (b) Incipient state (c) Mature state (d) Occlusion state

- However, it is to be pointed out that the middle latitudes are an area of convergence and it is here that unlike air masses such as the cold polar air and warm tropical or subtropical air generally meet. It may be noted that the polar front is not a permanent line.
- According to the polar front theory, as the cold polar air is deflected equator-ward and the warm tropical air pole-ward, a cyclone-forming wave is formed along the front. The wave thus formed and is divided into two parts:-

  The eastern part of the wave where the warm air advancing towards the east ascends over a wedge of cold air mass is called the warm front.

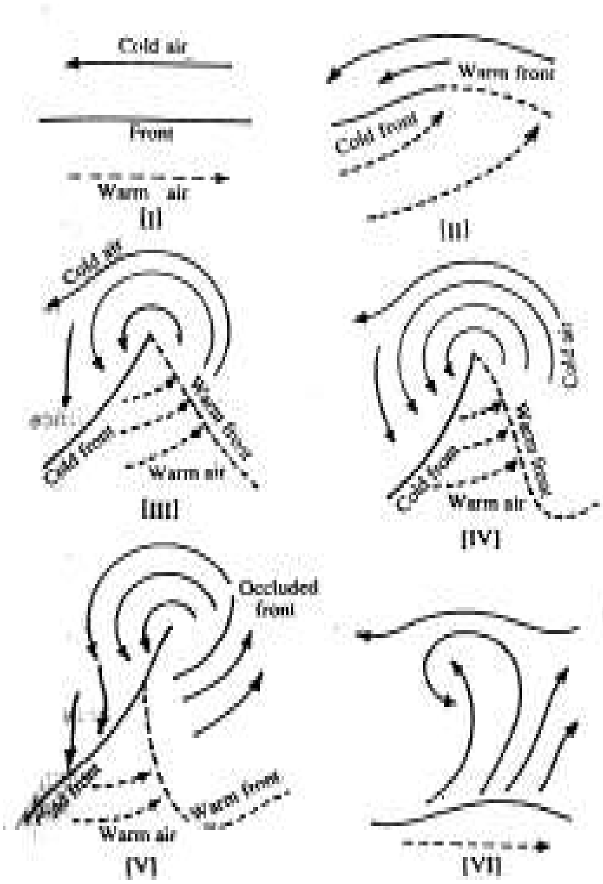


Fig 6.8 : Life cycle of a Mid latitude cyclone

The western portion of the discontinuity, where cold polar air is replacing the warm air by under-running the warm and lighter tropical air mass, is the cold front.

- Now, the process of occlusion starts. Whether it is warm-front or cold-front type of occlusion, the warm-air sector is raised aloft, and cold air behind the cold front now meets the cold air in advance of the warm front. It is at this critical point that the cyclone is said to have reached maturity.
- It is noteworthy that when warm and cold fronts are combined into one a long backward-swinging front is formed. This is called an occluded front.

ii) Baroclinic wave theory—

- This theory is based on the fact that cyclones of the extra-tropical regions may form even with out pre-existing front between on polar and tropical air masses.
- The most important feature is that it evolved through the use of mathematical techniques and numerical analysis of weather forcasting.

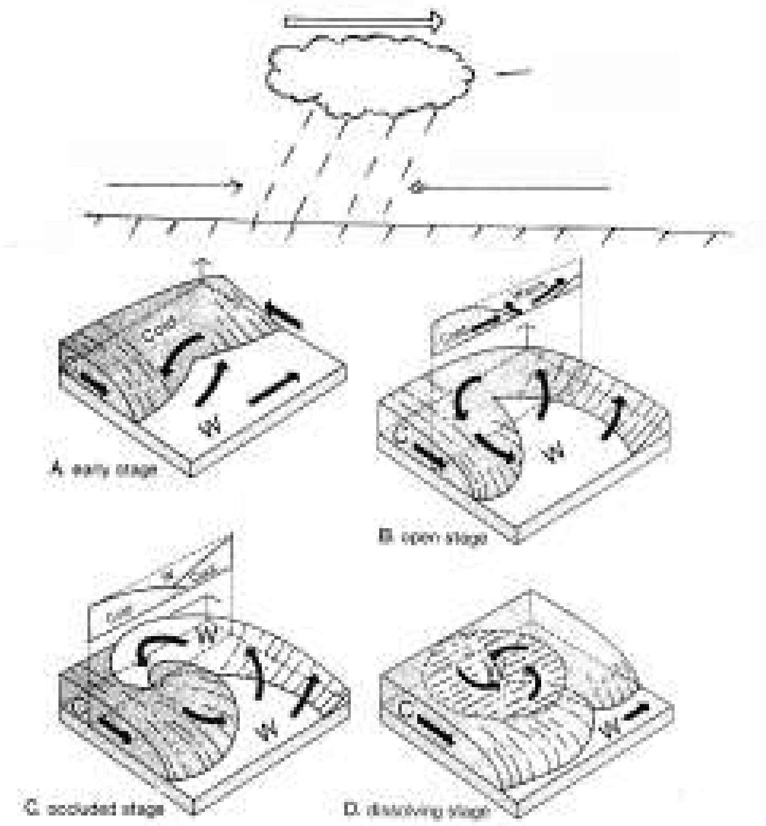


Fig. 6.9: Stages of Extra-tropical cyclone: The Polar Front Theory (after Bjerknes)

- Baroclinicity state the stratification in the atmosphere in which surfaces of constant pressure interest surface of constant density.
- Barotrophy state the stratification in the atmosphere in which surface of constant pressure and constant density are parrallel.
- According to baroclinic theory, cyclones and anticyclenes on the temparate region form, as a result of one the baroclinic stability.
- According to this theory, the north-south temperature gradient makes the middle-latitude upper air flow unstable. The air flow assumes wavy flow, which under special circumstances breaks into cyclones and anticyclones.
- Through these atmospheric disturbances, the greater heat exchange in the mid latitude region is made possible cyclones and anticyclones. According to this they are non-frontal on origin and may be taken to be a part and parcel later.

Types: According to Humphreye's, it can be divided into–

1. **Thermal cyclone**: In it, the depression which are formed due to inequalities of temperature and barometric pressure.
2. **Insolation cyclones:** Caused by relatively warm land. In this case intense

insolation cause low pressure area and the shape of isobars become oval. The winds begins to move spirally and cyclones developed.

3. **Migratory cyclones:** Which are temporary in duration and whose origin is due to thermal convection. These are short lived. And during the short live, they are maintained by the latent heat released at the time of condensation.

7) Associated Weather

- The approach of a temperate cyclone is marked by fall in temperature, fall in the mercury level, wind shifts and a halo around the sun and the moon and a thin cover of cirrus clouds
- Rainfall stops and clear weather prevails until the cold front of an anticyclonic character arrives which causes a fall in temperature. After this clear weather is established.
- The temperate cyclones experience more rainfall when there is slower movement and a marked difference in rainfall and temperaute between the front and rear of the cyclone. These cyclones are generally accompanied by anticyclones.

6.5 Conclusion

The weather of tropical region is largely effected by tropical disturbance, which may take a variety of forms. Among which the most important and common types are tropical cyclones and easterly waves. The tropical cyclone includes all cyclonic circulations origination over tropical water and strongly impacted on the weather of the region. The extratropical cyclone which is actually a mid latitude depression, plays a very significant role in transfer of energy from equator to poles.

6.6 Summary

- Tropical cyclones orignate over the warm tropical ocean where the surface temperature is above 27oC during summer season.
- They are associated with Inter-Tropical Convergence (ITC) which extendes from 5o to 30o North latitudes.
- Tropical cyclones known by diverse name in different regions of the world.
- Tropical cyclones have very high wind speed.
- Tropical cyclones have horizontal and vertical structures.
- The center of the tropical cyclones is known as Eye of cyclone.
- Extratropical cyclones arise through a process called cyclogenesis.
- The temperate cyclones are asymmetrical and shaped like an inverted 'V'.
- The most frequent temperate cyclone areas are between 35o- 65o latitudes in both the hemisphere.

- The polar front theory (also known as frontal theory or the wave theory earlier) that described the origin of extra-tropical cyclones was developed by V. Bjerknes.
- According to baroclinic theory, temparate cyclones form as a result of one the baroclinic stability.

6.7 Key words

Tropical cyclones, Extratropical cyclones, Eye of cyclone, ITCZ, polar front theory, baroclinic wave theory, cyclogenesis, front

6.8 Model Questions

Short answer type:

1. State about the structure of tropical cyclone.
2. What are the favourable conditions for tropical cyclone?
3. State about the Baroclinic wave theory and polar front theory of mid latitude cyclone.
4. What are the salient features of mid latitude cyclone?
5. What is anti-cyclone?
6. Differentiate cyclone from anti-cyclone.
7. Differentiate Warm front from Cold front.
8. What is Occluded front?
9. Distinguish between Frontogenesis and Frontolysis.
10. State about the regional distribution of tropical cyclone.
11. Classify tropical cyclones.

Long answer type:

1. Explain the growth, origin and structure of tropical cyclone.
2. State the origin and development of the extra-tropical cyclone.
3. Distinguish between the tropical and extra-tropical cyclone.

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Unit 7 ❐ Monsoon Circulation and Mechanism with reference to India

Structure

7.1 Introduction

In meteorology, monsoon signifies the directional shifting of winds from one season to other. The term Monsoon is arrived from a Arabic word 'Mowsim' which means 'season'. The monsoon climate is the characteristics of the whole India. Through the monsoon is dominated over India but its influence is observed in East-South Asia, owing to the greater size of the continent and consequently a greater seasonal extremes of temperature. East-South Asia is considered to be the classical monsoon region. The Indian monsoon has two branches, Arabian branch and Bay of Bengal branch. The origin of monsoon with special reference to India is very interesting and a matter of debate. Jet strem has a strong impact on the origin of monsoon. The sub-tropical jet stream plays a significant role in both hindering the monsoon winds as well as in quick onset of monsoons.

7.2 Objectives

i. To know about monsoon.
ii. To know about Indian monsoon.
iii. To learn about branches and features of the Indian monsoon.
iv. To know about the relation of Indian monsoon with jet stream.
v. To know about the theories of origin of Indian monsoon.

7.3 Indian Monsoon

Introduction: The name monsoon is said to be derived from the Arabic word 'Mausim' meaning winds over the Arabian Sea which blow approximately 6 months from the North East and 6 months from the South East.

As the word monsoon is commonly used in climatological literature, however it innoines not only a seasonal wind reversal but also one of the thermal origin arising from the differential heating of extensive land water surface. According to this move restricted point of view (monsoon are result of the earth's surface being non-homogeneous in character of such monsoon couldn't develop if the earth's surface were composed of either all land or all water.

Characteristics: The main characteristics of the Indian summer monsoon are as follows–

1) The summer monsoon sets in over the extreme south of Indian peninsular on the 1st of June. The arrival of the monsoon is a gradual process with a period of transition, a spread over a week or more.
2) Subsequently the monsoon advances along West Bengal and Assam in North-East India. The Bay of Bengal Branch is deflected by the orientation of the mountains into the Indo Gangetic plain of North India.
3) The normal duration of the monsoon varies from a 100–120 days. It begins to withdraw from India by mid September.
4) Over 70% of the India's annual rainfall is recorded is summer monsoon months. Much of the rainfall is caused by the maintain barriers but connective phenomena play an important role.
5) The variability of monsoon rain is highest over New India and Rajasthan. There are the areas which receives small amount of monsoon rain.
6) North-West India is an area of low barometric pressure. During the monsoon the region of low pressure coincides with the thermal high which gradually builds up over new india into the premonsoon months of May and June.
7) An extension of the seasonal low into the Indo Gangetic plain is known as the Monson through. The axis of the monsoon shows preiodic movements to the North and to the South of the Indo-Gangetic plain.
8) Above the monsoon winds, the Indian subcontinents is dominated by an extensive anticyclonic circulation. The reversal of the wind field occurs at about 6 km.
9) Along the southern end of anticyclones a narrow belt of strong winds of about

16 km above sea level is encountered. This is well known as the easterly jet stream of the Tropics. For to the North of Himalayas the sub tropical jet blowing from the West to East. The aixs of the jet is located along the southern slopes of the Himalayas in winter but suddenly shifts Northwards with the advent of monsoon.

10) A region of high temperature is usually observed over tibet. This prevides the heat source and ascent for Hadley cell, subsequently the air spreads southwards wided by the upper tropospheric anticyclone over Tibet.

Influence of Monsoon:

Through the monsoon is dominated over India but its influence is observed in East-South Asia, owing to the greater size of the continent and consequently a greater seasonal extremes of temperature. East-South Asia is considered to be the classical monsoon region.

According to the standard explanation of thermally induced monsoon, such a system of wind is simply a convectional system of gignatic scale. The chain of events is from temperture through pressure and winds to rainfall. In the high sun period the land surface becomes warmer than the surface of the surrounding seas and this thermal contrast tends to set up surface pressure difference in low centre over the land and high pressure over the adjacent areas. As a consequence the summer monsoon is a sea to land wind, the maritime air binging to the land on abundance of moisture cusing heavey rainfall. But there is some duobt, however weather the above described monsoon system of winds in its pure form, actually is a common occurance. And according to P.K. Das—'It is a restless of sea of motion, out there with great waves of disturbances'. The elements that make up the weather–wind, temperature air pressure and water vapour are in a state of constant flex. Every few km. upwards the wind blows in reverse direction. Air temperature and pressure and engaged in a sea-saw war for supremacy as nature strives to achieve a choatic balance. It is out of this chaos that the monsoon is born. The process begins when gently tilled earth rotate towards the summer solstice as a summer breaks over the Northern Hemisphere (which includes India). The landmass of the Asian continent heats up faster than the ocean. Giant low pressure areas or hotspots develop over Rajasthan at central India. The winds reverse direction dramatically and blows in carring rain bearing clouds. Meteorologists have discovered that if the crest of an upper air wind system moves southern, it imerits good monsoon. They also discover a dramatic burst of kinetic energy characterized by strong winds of the west coast just before the onset of monsoon. They further noticed an unusual cooling of Arabian sea by an ocean current (somale current) moving from E. Africa. The process seems simple enough but now as one meteorologist puts in 'we begin to oscillate'.

Meteorologist usually predict the course of monsoon by monitoring the temperature over Rajasthan and East coast during March. They have noticed that whenever it has been of few degrees above normal on these not spots. It indicates good monsoon. What keeps them guessing is that on many occasions the monsoon have failed deposite the temperature being favourable. They have now focussed their alternation on role of Tibetan Plateau on monsoonal rain. Traditionally the snow cover over the Himalayas is still monitered because it is believed that the greater it is, the poorer is the monsoon. But the Tibetan plateau begins as high as 5 km. above sea level acts an elevated over producing several atmospheric anamolis.

Meteorologists believe that the Tibetian High belts due to many uexplained phenomenan. They knew the jet streams of the air are narrow on land and high speed wind into the upper atmosphere region, the criss-cross the country. Towards the May, the westerly jet streams that usually blows over the Himalayan slope moves northwards. This drag is said to be caused by the Tibetan High. As the Himalayan stream shifts towards the easterly jet stream over the southern peninsular and stay on till the monsoon weaves.

While the rate of the jet stream including monsoon are still unchased. Meteorologists have been monitoring huge high pressure or anticyclone zones that from a few kms below them. The crest or ridge of the high pressure zone usually have over S. Goa. They have noticed that of the ridge moves slightly southwards towards Karnatak, it does not prove well for the monsoon. The reason that it appears as the high pressure zones act as a giant boulders of air that provents the low flowing south westerly monsoon from intersifying over the west coast.

7.4 Circulation of Monsoon and relation with Jet Stream

Relation between Jet Streams and Monsoon:

- Jet streams have distinct peaks (ridges) and troughs.
- Ridges occur where the warm air mass pushes against the cold air mass. Troughs occur wheater cold air mass drops into warm air.
- The region on earth below the trough is at low pressure and the region below ridge is at high pressure.
- This condition occurs due to weakening of jet streams due to lesser temperature contrast between sub-tropics and temperature region.
- Troughs create due to upper level divergence which is associated with convergence at the surface, (low pressure–cyclonic conditions) and ridges create due to upper level convergence which is associated with divergence at

the surface (high pressure–cyclonic conditions).

- These ridges and troughs give rise to jet streaks which are also responsible for cyclonic and anticyclonic weather conditions at the surface.
- The winds leaving the jet stream are rapidly diverging, creating a lower pressure at the upper level (Tropopause) in the atmosphere. The air below rapidly replaces the upper outflowing winds. This in turn creates the low pressure at the surface. This surface low pressure creates conditions where the surrounding surface winds rush inwards. The coriolis effect creates the cyclonic rotation (cyclonic vortex) that is associated with depressions (low pressure cells).
- The winds entering the jet stream are rapidly converging because of the high preussure at the upper level (Tropopause) in the atmosphere. This convergence at upper troposphere leads to divergence (high pressure at the surface (anticyclonic condition).
- The Coriolis effect creates the anticyclonic rotation that is associated with clear weather.

Influence of jet streams on Indian Monsoon:

Indian Monsoon Mechanism–Role of Sub-tropical Jet Streams (STJ)

- Sub-Tropical Jet stream plays a significant role in both hindering the monsoon winds as well as in quick onset of monsoons.

Sub-Tropical Jet Stream

- Sub-Tropical Jet stream is narrow band of fast moving air flowing from west to east [Westerlies].
- STJ in northern hemisphere flows between 25^o to 35^o North in the upper troposphere at a height of about 12–14 km. (Here we will consider STJ only. Polar Jet has no influence on Indian monsoons).
- The wind speeds in a westerly jet stream are commonly 150 to 300 km per hour with extreme values reaching 400 km per hour.

  The burst of monsoons depends upon the upper air circulation which is dominated by STJ, Seasonal Migration of Sub-Tropical Jet Stream,
- In winter STJ flows along the southern slopes of the Himalayas but in summer it shifts northwards, rather dramatically and flows along the northern edge of Himalayas in early June and in late summer (July-August) especially along the northern edge of the Tibetan Plateau.
- The periodic movement of the Jet stream is often the indicator of the onset (STJ shits to the north of Himalayas in a matter of days) and subsequent withdrawal (STJ returns back to its position-south of Himalayas) of the monsoon.

- Northward movement of the subtropical jet is the first indication of the onset of the monsoon over India.

Sub-Tropical Jet Stream (STJ) in Winter

- Westerly jet stream blows at a very high speed during winter over the sub-tropical zone.
- This jet stream is bifurcated by the Himalayan ranges and Tibetan Plateau.
- The two branches reunite off the east coast of China.
- The northern branch of this jet stream blows along the northern edge of the Tibetan Plateau.
- The southern branch blows to the south of the Himalayan ranges along 25^{o} north latitude.
- A strong latitudinal thermal gradient (differences in temperature), along with other factors, is responsible for the development of southerly jet.

Fig. 7.1 Winter monsoon (After Nieuwolt).

Western Disturbances–

- Meteorologists believe that southern branch of jet stream exercises a significant influence on the winter in India.
- The upper jet is responsible for streering of the western depressions [Western Disturbances] from the mediterranean.
- Some of the depressions continue eastwards, redeveloping in the zone of jet

stream confluence about east cost of China.

- Winter rain and heat stroms in north-western plains and occasional heavy snowfall in hilly regions are cause disturbances.
- These are generally followed by cold waves in the whole of northern plains.
- The southern branch is stronger, with an average speed of about 240 km compared with 70 to 90 km per hour of the northern branch.
- Air subsiding beneath this upper westerly current gives dry blowing to the northerly winds from the subtropical anticyclone over northwestern India and Pakistan.

Cause of absence of south-west monsoons during Winter:

- **Reason 1:** The winds that blow over India are mostly offshore—land to land or land to ocean—so they carry no moisture).
- **Reason 2:** During winter, the southern branch of STJ is strong and is to the south of Himalayas. The ridge of the Jet lies over north-western India and is associated with strong divergence of winds and creates a high pressure region sub-tropical high pressure belt) over entire north India. *(This is how the mechanism of jet streams influence Indian Monsoons in winter season.)*
- **Reason 3:** There is already a strong high pressure over Tibet. [High Pressure due to STJ + High Pressure over Tibet = strong divergence = no rainfall]

Sub-Tropical Jet Stream (STJ) in Summer

- With the beginning of summer in the month of March, the STJ (upper westerlies] starts their northward movement.
- The southerly branch of STJ remains positioned south of Tibet, although weakening in intensity.
- The weather over northern India becomes hot, dry and squally due to larger incoming solar radiation and hot winds like loo.
- Over India, the **Equatorial Trough (ITCZ)** pushes northwards with the weakening of the STJ [upper westerlies] south of Tibet, but the burst of the monsoon does not take place until the upper-air circulation has switched to its summer pattern.
- By the end of May the southern jet breaks and later it is diverted to the north of Tibet Plateau and there is sudden burst of monsoons (the ridge moves northwards into Cental Asia = high pressure over north-west India moves northwards into Central Asia = way for south-west monsoon winds). An Easterly jet emerges over peninsular India with the northward migration of STJ.

- The upper air circulations are reversed with the emergence of Easterly jet [convergence in upper layers is replaced by divergence = divergence in lower layers is replaced with convergence = high pressure at lower layers is replaced by low pressure system]. The easterly winds become very active in the upper troposphere and they are associated with westerly winds in the lower troposphere (south-west monsoon winds).
- Western and eastern jets flow to the north and south of the Himalayas respectively. The eastern jet becomes powerful and is stationed at 15°N latitude.
- This results in more active south-west monsoon and heavy rainfall is caused.

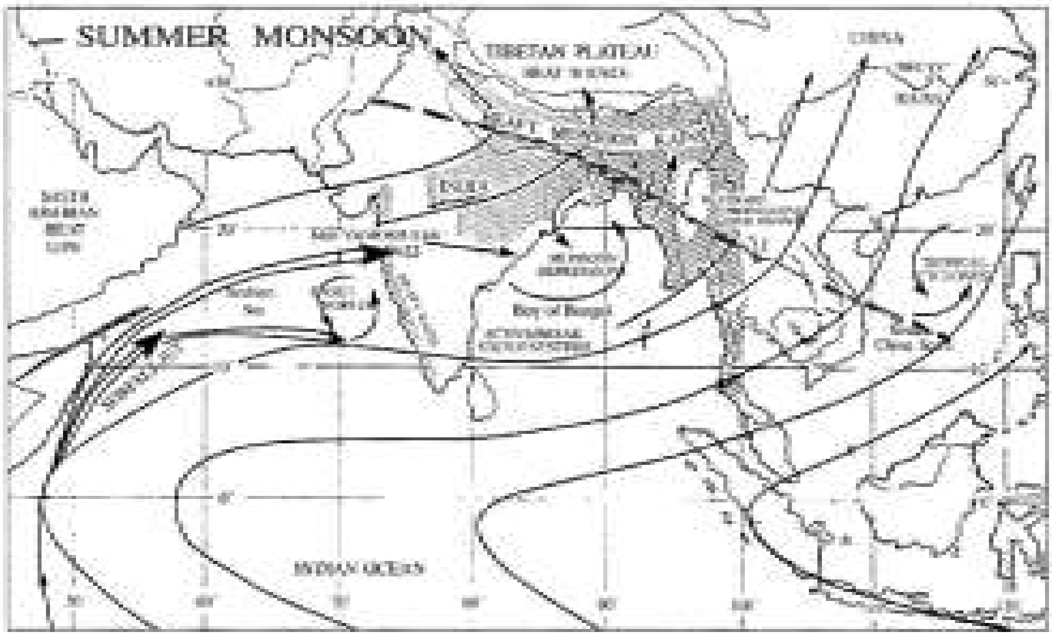

Figure: 7.2 Summer Monsoon

Cause of absnece of south-west monsoons in March-May (Summer):

- There is good sun's insolation from March-May but still there is no s-w monsoons.

  Reason: The ridge region of Southern branch of STJ creates strong divergence (high pressure) in north-west India. The deverging air blocks incoming winds and prevents strong convergence of winds along ITCZ.
- During the summer season in the Northern Hemisphere, low pressure areas develop at the ground surface near Peshawr (Pakistan) and north-west India due to intense heating of ground surface during April, May, and June.
- As long as the position of the upper air jet stream is maintained above the

surface low pressure (to the south of Himalayas), the dynamic anti-cyclonic conditions persist over north-west India.

- The winds descending from the upper air high pressure [because of the ridge of STJ] obstructs the ascent of winds from the surface low pressure areas, with the result that the weather remains warm and dry.
- This is why the months of April and May are generally dry and rainless in spite of high temperatures (low pressure of land) and high evaporation.

Branches of Monsoon:

The Arabian Sea Branch:

- This branch of the south-west monsoon strikes the highlands of the Western Ghats at aolmost right angles. The windward slopes of the Western Ghats receive heavy orogenic precipitation. Although the western currents of the monsoon penetrate further into the Indian mainland and the intesity of rainfall goes on decreasing on the leeward side.
- While the windward slopes of the Western Ghats are the areas receiving the highest rainfall, the leeward slopes form a well-marked rain-shadow belt which is drought-prone. For instance, the average annual rainfall at Mumbai and Pune is 188 cm and 50 cm respectively, despite the fact that they are only 160 km apart.
- The most characteristic feature of the distribution of rainfall on the windward slope is that the amount of rains is hevier higher up the slopes. However, the heavy rains are concentrated in a narrow strip along the Western Ghats.
- After crossing the Western Ghats, the rain-bearing air current descend the eastern slopes where they get warmed up adiabetically. This result in a pronounced rain-shadow area. The higher the mountains, the larger is the rain-shadow effect. Towards the north, where the Western Ghats are not very high, the difference in the amount of rainfall between the windward and leeward side is rather negligible.

Cause of no precipitation in Kutch and Western Rajasthan:

- There is no mountain barrier to tap the advancing winds. As the Aravallis have an almost north-south axis, they fail to block the passage of these monsoon currents (which rather blow parallel to the Aravallis and lift them).
- The monsoon currents heading towards Rajasthan are rather shallow and are superimposed by stable anti-cyclonic air.
- The hot and dry continental air masses from western Pakistan (Baluchistan) are drawn towards the thermal low developed in this region. These air masses check the ascent of air and absorb its moisture.

- These conditions are unfavourable for precipitation in Kutch and western Rajasthan where desert conditions prevail.
- Some of the current from the Arabian Sea branch manage to proceed towards Chotonagpur plateau through the Narmada and Tapti gaps. These currents ultimately unite with the Bay of Bengal branch.

  Although a few air currents from the main Arabian Sea branch are diverted northward towards Kutch and the Thar desert, these currents continue upto Kashmir without causing rain anywhere on their way. In fact, an east-to-west line drawn near Karachi in Pakistan practically marks the limit of the monsoon rainfall.

Bay of Bengal Branch:

- This branch is active in the region from Sri Lanka to Sumatra Island of the Indonesian archipelago. Like the Western Ghats of India in the case of the Arabian Sea branch, the windward slopes of the West Coast Mountains of Myanmar. (Arakan and Tenasserim mountains) get heavy rainfall when the main monson currents of this branch strike the Myanmarese coast.) Akyab on the west coast records 425 cm during the June-September period. As in case of the leeward sides of the Western Ghats in India, here too, the rain shadow effect is pronounced on the leeward side.
- A northern current of this branch strikes the Kashi hills in Meghalaya and causes very heavy rains. Mawsynram (near Cherrapunji), situated on the southern slopes of Khasi hills, has the distinction of recording the highest annual average precipitation in the old.
- This is because of its peculiar geographical location. Mawsynram if flanked on all sides by the Garo, Khasi and Jaintia hills except for a gap through which the rain-bearing winds enter and are forced to rise, thus yielding the heaviest rainfall. Shillong, a mere 40 km away on top of the Khasi hills, receives only about 140 cm of rainfall during June-September.
- Another current of the Bay of Bengal branch takes a left turn at the eastern end of the low pressure trough (roughly the Bengal delta). From here, it blows in a south-east to north-west direction along the orientation of the Himalayas. This current causes rainfall over the northern plains.
- The monsoon rainfall over the northern plains is assisted by west-moving monsoon or cyclonic depressions called 'westerly disturbances.' These are formed in the Bay of Bengal and move along the southern fringe of the northern plains causing copious rains there which are vital for the rice crop.
- The intensity of rainfall decreases from east to west and from north to south

in the northern plains. The decrease westwards is attributed to the increasing distance from the source of the moisture. The decrease in rainfall intensity from north to south, on the other hand, is due to increasing distance from the mountains which are responsible for lifting bird moisture-laden winds and causing orogenic rainfall in the plains, especially in the foothills.

The two main branches of the monsoon winds follow different courses:

- The two main branches of the monsoon set out to fill the intense low pressure void created in the north-west of the subcontinent. The two branches meet at the Chhotanagpur Plateau. Of the total moisture carried by the two branches, only 20 per cent falls as precipitation. The Arabian Sea branch is more powerful of the two because of two reason—one, the size of the Arabian Sea is bigger and two, most of the Arabian Sea branch falls over India, while most of the Bay of Bengal branch goes to Myanmar, Malaysia and Thailand.

Retreating or North-East Monsoon:

- Towards the end of September, the low pressure centre in the north-west begins to disintegrate and eventually shifts to the equatorial region. The cyclonic conditions are replaced by anti-cyclonic ones. As a result, winds start blowing away from the northern region. Similar anti-cyclonic winds blow from the Tibetan highlands and beyond.
- This is also the time when the sun makes an apparent movement south of the equator. The ITCZ also moves equatorwards. Now the winds the dominate the subcontinental landscape are the ones which move from the north-east to the south-west.
- These conditions continue from October till mid-December and are known as the retreating monsoons or the north-east monsoons. By December end, the monsoons have completely withdrawn from India. The retreat of the monsoons is markedly gradual in contrast to the 'sudden burst' of the south-west monsoons.
- The retreating monsoons over the Bay of Bengal pick up moisture on their way which is dropped over eastern or coastal Orissa, Tamil Nadu and parts of Karnataka during October-November. This is the main season of rains over these areas as they almost lie in the rain-shadow area of the south-west monsoons.
- During October, easterly depressions occur at the head of Bay of Bengal which move southwards and in November get sucked into Orissa and Tamil Nadu coasts causing heavy rain–sometimes with destructive cyclonic winds in coastal and interior areas. The depressions weaken southwards and towards the interiors.

Winter Monsoon:

- The stable, dry anti-cylonic winds prevailing over the subcontinent after the retreat of the south-west monsoons are not capable of causing precipitation because they are free of moisture. Instead, these winds produce dry and fine weather. However, certain areas in the north get winter precipitation.
- The north-western parts of India–Punjab and Ganga plains–are invaded by shallow cyclonic disturbances moving from west to east and having their origin in the Mediterranean Sea. These are called 'Westerly Disturbances' which travel across West Asia and Afghanistan before they reach India. These disturbances come with cloudiness and rising temperature in the front and cold wind in the rear.
- These disturbance cause upto 5 cm rainfall in Punjab and Kashmir and up to 2.5 cm over the Uttar Pradesh plains. These showers are very good for the rabi crop, especially wheat and gram, and are very effective because of less runoff, less evaporation (because of low winter temperatures) and the fact that moisture from these showers is confined to the root area of the crops.

7.5 Mechanism of Monsoon

Introduction–The term Monsoon is arrived from a Arabic word 'Mowsim' which means 'season'. The word monsoon is applied to such a circulation which reverses its direction every six months i.e. summer to winter and vice-versa. The term was first applied by Arab nevigators to explain winds over Arabian sea between Arab and India, which blow North-East and from South-West for six months from other six months.

In meteorology, monsoon signifies the directional shifting of winds from one season to other. In summer, there is a warm and moist wind blowing from the ocean towards the land, while during the winter a cold and dry wind originating on land blows seaward. Monsoon circulation involves a change of 180 degrees in the direction of wind.

(1) Classical concept of Monsoon Origin:

This classical theory of Indian monsoon proposed and put forward by Admand Hally in 1686. He explained the origin of Indian monsoon which was earlier proposed by Arab Geographer Siddique Ali after experiencing the behavioural pattern of Asiatic wind system on his visit to India.

According to the classical concept of Indian monsoon, monsoonal winds are land and sea breezes on a large scale which are produced and controlled by unequal and differential heating of contiguous of continental and oceanic areas of the Indian subcontinent. Under this process, during the northern winter when sun rays fall vertically over tropic of Capricorn, the gigantic land mass of Asia cools rapidly than the sounding ocean generating a high pressure area over Asia while there is low pressure centre on the Indian ocean. As a result of this air pressure differential over land and ocean there is an out flow of air from high pressure to low pressure, consequently the surface winds started to flow from land to sea. This wind pattern is commonly known as north-east monsoon which is often dry due to lack of moisture and hence do not precipitate.

On other side of this, the temperature and pressure conditions are reversed during the northern summer season on the occasion of summer solstice. In this time period sun rays fall vertical on tropic of cancer which passes through the middle of Indian subcontinent. Due to excess heating of huge land mass of Asia, a low pressure area develop over it. However, presence of the Himalayas bifurcate this low pressure areas into north-west Indian low and Baikal low. Conversely, high pressure centre is developed in the Indian Ocean due comparative low thermal conditions here. As a result of this winds started flowing from high pressure area over ocean to low pressure area over Indian subcontinent. This pattern of wind flow is popularly known as southwest monsoon in India and as simple monsoon througthou the world. Due to on shore nature of southwest monsoon it bears and produces rainfall wherever it is obstructed by various topographical barriers.

(2) Traditional Convection Current Theory:

It is well known fact that from a high pressure region the wind has an tendency to flow out and in a low pressure zone the wind has a tendency to flow in. Thus the weather pattern is influenced by the formation of high and low pressure cells.

In winter, the north of the Himalayas becomes a centre of high pressure by the cooling of the surface. Wind blows outwards from the land, over which air is subsiding. Over India this air is cool and dry and flows through the entire stretch of the Gangetic plain, crossing the Bay of Bengal and when it had picked up enough moisture, it pours it down in the eastern coastal region.

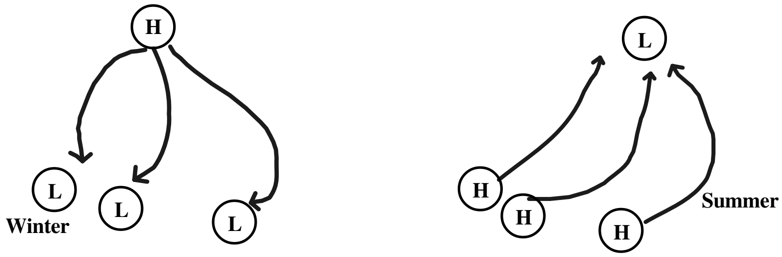

Fig. 7.3 The traditional view on the origin of Indian Monsoon

In summer, with the thermal shifting of the equator the whole scene changes. The high pressure vanishes and a low pressure centre is created in the north-western part of India. The trade winds while reaching to fill this low pressure zone cross the entire zone of Arabian sea and the Indian Ocean. This makes these winds moisture and thus they cause heavy downpour when they strike the Western Ghats and Himalayan ranges. This is by definition, the south-west monsoon.

(3) Dynamic Concept of Indian Monsoon: This concept was proposed and presented by Flohn in 1951 which is based on dynamic origin of Indian monsoon that say monsoon is none other than and is only the seasonal migration of planetary winds and pressure belts following the position of sun in relation to earth.

It opined that during summer solstice sun rays fall vertically over tropic of cancer, hence all wind and pressure belts of globe shift towards north. At this time the zone of inter tropical convergence (ITC or Doldrum) moves northwards and its northern boundary is extended upto 30 degree north that is south and southeast Asia. It is due to relatively larger changes of seasonal temperature and pressure conditions over the land in these areas which help in shifting of these belts. Due to this shifting major part of Indian subcontinent comes under impact of equatorial westerlies blowing in doldrum which are called southwest monsoon in India.

Since ITC is associated with tropical disturbances which dominate the surface weather. On the other hand in winter planetary wind system and pressure belts move to southwards due southward movement of vertical sun rays. As a result of this northeast trade winds reestablished over the Indian subcontinent which are often dry and devoid of rain as they come from land.

(4) Thermal Concept–It was Halley who propounded the thermal concept of the origin of monsoon. According to this theory, the monsoons are considered to be gigantic convectional systems produced by differential seasonal heating of continental and oceanic areas. The origin of Asiatic monsoon may be ascribed to the thermal difference between land and sea.

During winter the landmass of Asia cools more rapidly than surrounding oceans creating a high pressure over land and low pressure over sea. So air travels from landmasses to oceans.

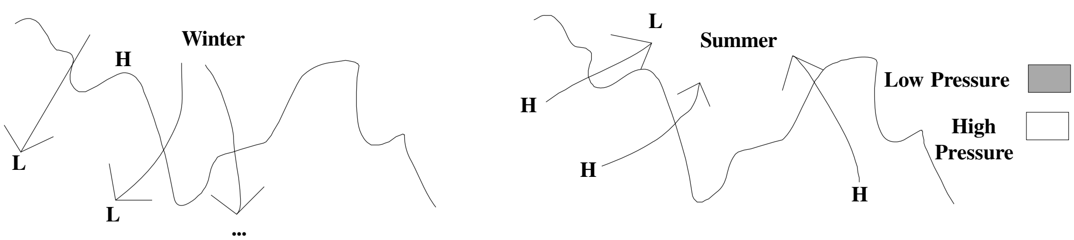

Fig. 7.4 : Origin of monsoon [according to thermal concept]

During summer the landmass became more warm than the surrounding ocean creating a world of low pressure over landmass, so the surrounding cold air blow towards the sea.

(5) Role of Jet Stream-Jet Strem has a strong impact on the origin of monsoon. In 1951, F. Fohn created this concept about the role of jet stream in the origin of monsoon. By the observation of the apparent speed of the sun, he confirmed the locational shift of the wind as jet stream. In norther hemisphere, during summer all the constant winds are shifted to the north and in winter they shifted back to the south. For this, in every year in the intermediate area between the zones of two constant winds there are arrival of Jet stream. In low latitudes seasonal change of direction in wind flow causes the arrival of jet streams.

(6) Jeffry's concept-In different season, jet stream blow from different directions. According to the season, the direction of jet stream may change 102^{o}, Jeffery proposed a mathematical view or formula on the reversal flow of jet steams.

According to him, air pressure decreases with the increasing height. Wind blows according to the slope of the air pressure. He expressed about the context of the changing direction of reasonal air that–'If the air blows from the west in the lower atmosphere, then the air will blow from the east above the height of 6 km.'

(7) MONEX–The mechanism of Indian monsoon in south to be explained by the shifting by the inter-tropical convergence, the north ward movement of westerly jet stream and its replacemnet by easterly jet stream and the upper air ciculation over tibet. The World Meteorological Organisation (WMO) conducted monsoon experiment (MONEX) over the Arabian sea and the Bay of Bengal to observe the mysteries about the monsoon. Inspite of all these attempts, the working of the monsoon continue to be not fully understood.

Criticism: (1) In low latitudes, where the jet streams are created, a scorcity in the Geostrophie balance can be noticed. But in Jeffery's concept there is no reference about this. (2) Mare importances are given to the differential temperature in Jeffery's concept. (3) The origin of the monsoon was not fully discovred. (4) Some the theories have a great contribution to discover the concept of monsoon but one the only can't able to describe the varieties of monsoon.

7.6 Conclusion

The climate of India is known as monsson climate, which is stronghly impacted by the monsoon. The two branhes of Indian monsoon have individual salient features, which controls the distribution of rainfall all over the India. Moreover, the climatic conditions of India during summer is also influenced by the monsson. The Indian monsoon is strongly connected with jet stream. Thus, the vagaries of monsson impacted largely on the Indian climate and economy.

7.7 Summary

- The term Monsoon is arrived from a Arabic word 'Mowsim' which means 'season'.
- The Indian monsoon has two branches, Arabian branch and Bay of Bengal branch.The Arabian branch of the south-west monsoon strikes the highlands of the Western Ghats at aolmost right angles.
- A northern current of the is Bay of Bengal branch strikes the Kashi hills in Meghalaya and causes very heavy rains.
- Mawsynram (near Cherrapunji), situated on the Khasi hills, has the distinction of recording the highest annual average precipitation.
- Over 70% of the India's annual rainfall is recorded is summer monsoon months.
- These conditions continue from October till mid-December and are known as the retreating monsoons or the north-east monsoons.
- The north-western parts of India are invaded by shallow cyclonic disturbances moving from west to east and having their origin in the Mediterranean Sea, are known as 'Westerly Disturbances'.
- This classical theory of Indian monsoon proposed and put forward by Admand Hally in 1686.
- The dynamic concept of monsoon origin was proposed by Flohn in 1951.
- Jet strem has a strong impact on the origin of monsoon.
- Meteorologists believe that southern branch of jet stream exercises a significant influence on the winter in India.
- The sub-tropical jet stream plays a significant role in both hindering the monsoon winds as well as in quick onset of monsoons.
- The World Meteorological Organisation (WMO) conducted monsoon experiment (MONEX) over the Arabian sea and the Bay of Bengal to observe the mysteries about the monsoon.

7.8 Key words

Monsoon, Arabian branch, Bay of Bengal branch, Burst of monsoon, westerly Disturbances, origin of monsoon, WMO, MONEX, jet stream

7.9 Model Questions

Short answer type:

1. What is burst of monsoon?
2. What is retreating monsoon?
3. What are the branches of Indian Monsoon?
4. State the influence of monsoon on Indian climate.
5. What is the classical concept of monsoon?

Long answer type:

1. Discuss the salient features of Indian Monsoon.
2. Explain the monsoon circulation over the Indian subcontinent.
3. Explain the monsoon mechanism.
4. Explain how the mechanism of jet stream influences Indian monsoon.

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Unit 8 ❐ Climatic Classification after Köppen and Thornthwaite

Structure

8.1 Introduction

There is a infinite variety of climate is observed over the globe and climate of every place is slightly different in some aspect from each other. The climatic classification of the world climate helps us to understand the nature of such variations and distinctiveness. The homogeneous set of climatic conditions is operated in a certain climatic region; therefore to facilitate identification and description of that region, it is necessary to classify climate. Here we are going to know about such types of climatic classification as put forward by Koppen and Thornthwaite.

8.2 Objectives

i. To know the climatic classification of Koppen.

ii. To know the climatic classification of Thornthwaite.

8.3 Köppen's Climatic Classification

Classification is a process basic to all sciences consisting of recognizing individuals with certain important characteristics in common and grouping them into the classes. One of the first and simplest classification of climate was derived from the ancient Greek who divided each hemisphere into three broad belts or zones:

1. Winterless tropical region where temperature is high throughout the year.
2. Polar region with low temperature.
3. The broad intermediate belt of temperature zone where seasonal contrast in temperatre is marked.

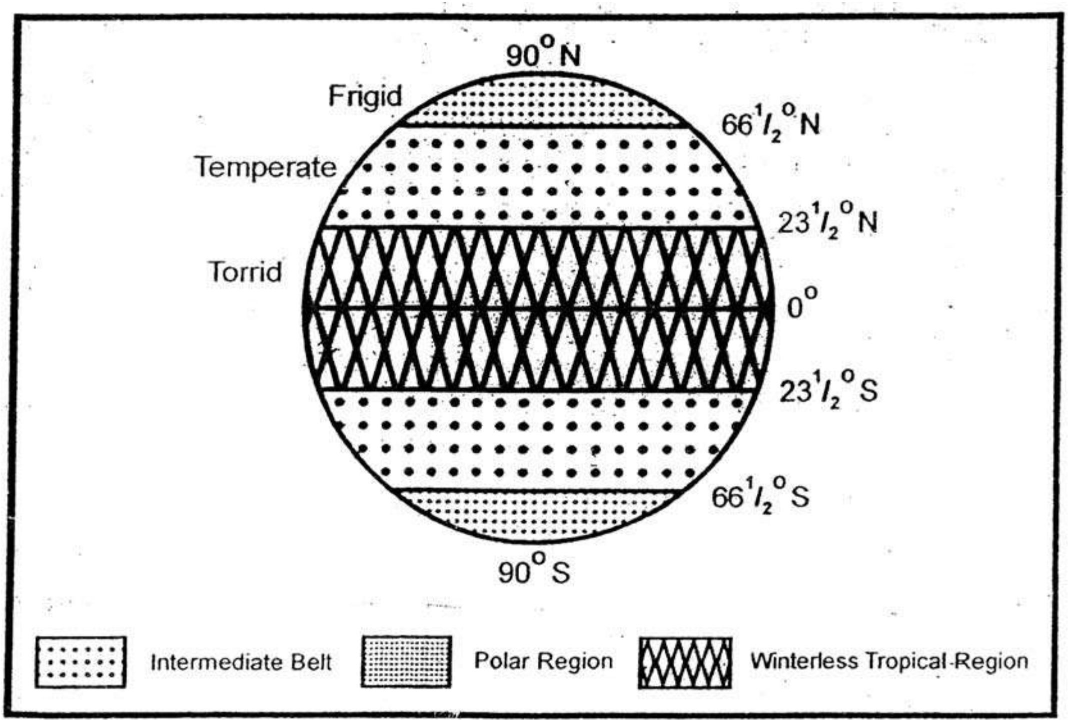


Fig. 8.1 Climatic Classification

This was very simple and generalized classification. Later the most popular and well accepted classification of climate was made by Köppen in 1918. He was a biologist and his classification was based on monthly and annual mean of temperature and precipitation. Köppen believed that the distribution of natural vegetation is the best expression of the totality of climate.

Köppen accepted Candolle's five fold classification of vegetation which recognizes the following divisions:

1. **Megatherm:** Which coincides with the tropical rainforest region.
2. **Mesotherm:** Which coincides with the mid-latitude temperate region.
3. **Microtherm:** Which coincides with the deciduous and steppe region.
4. **Xerophytes:** Which coincides with the semi-arid steppe and desert region.
5. **Hekistotherms:** Which is the vegetation of snow-bound steppe region.

Koppen used *English Letter Symbols* to denote different climatic characteristics.

Major divisions:

A–Humid tropical climates

B–Dry climates

C–Warm temperate climates with mild winter

D–Cold temperate climates with severe winter

E–Polar climate

H–Highlands climate

Seasonal Distribution of Rainfall:

For this Koppen gave four subdivisions–

f–Wet all seasons

m–Monsoon type, short dry seasons

w–Dry winter

s–Dry summer

For latitude:

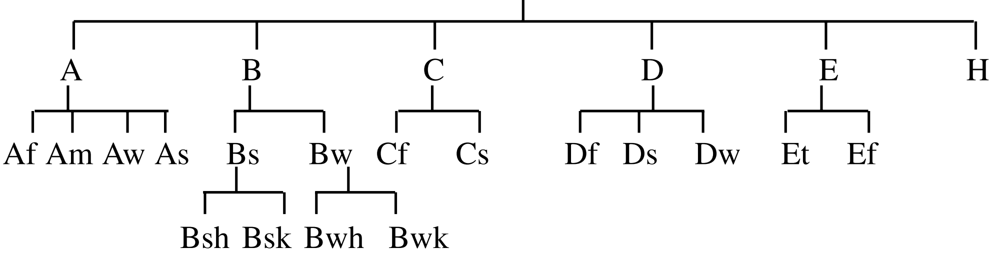
Koppen divided into low and high latitudes

H–Low latitudes

K–High latitudes

The main features of Köppen's climatic divisions are discussed below:

KÖPPEN'S CLIMATIC CLASSIFICATON



MAJOR TYPES	SUB TYPES	CHARACTERISTICS
A	Af	Tropical Rainfall mainly experienced over the Amazon Basin, Zaire Basin and South East Asia Characteristed by mean annual temperature of 27°C and anuual average rainfall of 250 cms, luxuriant vegetation.
	Aw	Tropical Savanna which is a tropical grassland with scattered deciduous trees.
	Am	Monsoon type characterised by alternate periods of rainfall and draught, seasonal reversal of winds.
	As	Tropical climate with dry summer found along the eastern coast of Tamilnadu and Orissa.
B	Bsh, Bsk	Semi-arid and Steppe climate, are experienced in the deep interiors of landmasses, these regions received little rainfall of 30 cms.
	Bwh	Low latitude desert climate like Sahara.
	Bwk	Mid latitude desert climate like Gobi.
C	Cf	Humid temperate climate, receives 100-140 cms of rainfall.
	Cs	Mediterranena climate with winter rainfall of 40-60 cms.
D	Df	Cool, East Coast climate between 45°-65° latitude.
	Ds	Taiga climate which is experienced over the belts from Alaska to Newfoundland and Norway to Kamchetka peninsula.
	Dw	Continental type climate which is experienced in deep interiors of the continents between Taiga and the mid latitude desert.
E	ET	Tundra climate which is experienced over coastal fringes of the Arctic Ocean. This climate is found exclusively in the northern hemisphere.
	Ef	Ice Cap, there are the areas permanently covered with snow, average temperature of the warmest month below 0°C. These conditions occur over the poles and the interiors of Greenland.
H	–	Higlands climate is found over the Rockies, Andes, Alps and the Himalayas. Here altitude play an important role.

CLIMATIC CLASSIFICATION AFTER KÖEPPEN

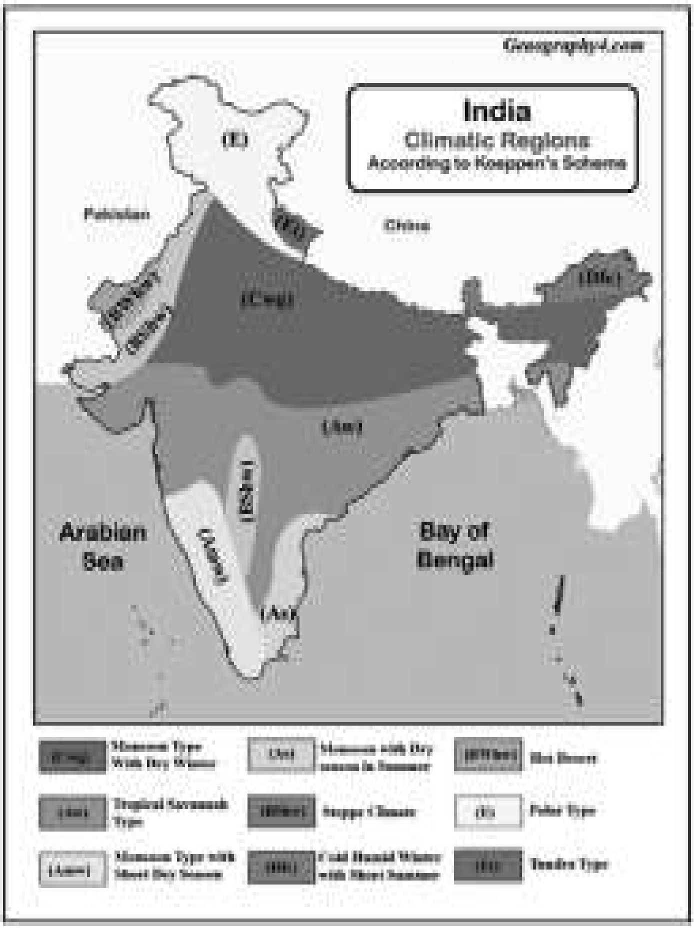


Fig. 8.2 Climate Classification of Koppen

Advantages:

1. Köppen has used temperature and precipitation as the basis of his classification which can easily be measured.
2. Köppen's scheme uses letter symbols to denote various climatic characteristics, which is practical and convenient.
3. Here specific quantitative techniques has been used not based on mere abstraction.
4. His climatic divisions coincide with vegetational divisions. This aspect is quite appealing to geographers.
5. Köppen's scheme can be adapted and taught at any level.

Limitation:

1. Other climatic elements such as wind pressure, cloundiness etc has not been considered by Köppen.
2. Köppen has not attempted to find out the causative factors of climatic characteristics.
3. Going by Köppen's classification, it is not possible to explain the existence of different vegetation types within the same climatic division.

8.4 Thornthwaite's Climatic Classification

Indroduction: C. W. Thornthwaite, an American climotologist presented his scheme of climatic classification in 1931 and 1948. His scheme is complex and empirical in nature.

8.2.1 Classification of 1931

Climatic classification of Thronthwaite is based on–

A. Effective Precipitation.
B. Thermal efficiency.
C. Seasonal distribution of rainfall.

He considered evaporation to be an important element and proposed five Humidity Provinces based on Precipitation Effectiveness (P/E index), six Temperature Provinces based on Thermal Efficiency (T/E index), which is expressed as the positive departure of mean monthly temperature from the freezing point.

Thornthwaite's Humidity Provinces:

The annual precipitation index in given as–

$$\text{P/E index (Annaul)} = \frac{\textbf{Total Rainfall}}{\textbf{Total Evaporation}}$$

The five Humidity provinces are given below–

Humidity Provinces	Vegetation Associated	P/E index
A – Wet	Tropical Rainforest	128+
B – Humid	Forest	64-27
C – Semi Humid	Tropical Grassland	32-63
D – Semi-Arid	Steppe	16-31
E – Arid	Desert	Below 16

Thornthwaite's Temperature Provinces:

Again the annual T/E index is taken as the sum of twelve individual monthly T/E index ratios, and the monthly T/E index ratio is given as–

$$\text{T/E index ratio (Monthly)} = \frac{\textbf{(T-32)}}{\textbf{4}}$$

Where, t = mean monthly temperature in degree farenhite.

Thus the six temperature provinces are as follows–

Humidity Provinces	T/E Index
A′ – Tropcial	128 & Above
B′ – Masothermal	64 –127
C′ – Microthemal	32–63
D′ – Taiga	16–31
E′ – Tundra	1–15
F′ – Frost	0

Further sub-divisions are also possible based on seasonal distribution of rainfall
r – rainfall in all seasons
s – summer deficient in rainfall
w – winter deficient in rainfall
d – dry in all seasons

Criticism:

1. The concepts of precipitation effectiveness and thermal effectiveness were used for the first time by Thornthwaite, but they make the delimitation of boundaries difficult.
2. The lack of climatic data, epecially on evaporation, is a serious handicap.

8.2.2. Classification of 1948

Thornthwaite's second classification is based on two variables:
a. Potential Evapotranspiration (PE)
b. Precipitation

The potential evapotranspiration in expressed as the amount of moisture that will be transferred to atmosphere by evaporation of solid and liquid water and by transpiration from living tissues, On the basis of it, he introduced the concept of Moisture Index:

Moisture Index	Humidity Province	Thermal Province
100 & above	Per Humid	Megathemal
20 to 100	Humid	Mesothermal
0 to 20	Moist Sub-humid	Microthermal
-33 to 0	Dry Sub-humid	Tundra
-67 to -34	Semi Arid	Dry Forst
-100 to -68	Arid	–

Criticism:

1. Because of inherent problem, mapping of Thornthwaite's divisions is not possible.
2. His scheme does not have a vegetational basis. Thus it is different from Köppen's scheme.
3. His scheme is more suitable for North America but it is not suitable for tropics.
4. This scheme is empirical as well as quantitative but does not consider causative factors.
5. His scheme involves a lot of calculations therefore it is difficult to apply.

8.2.3. Comparative analysis of Köppen's and Thornthwaite's scheme:

Similarities:

1. Both are based on empirical investigation and are genetic scheme.
2. Both have recognized climate-vegetation relationship.
3. Both have used letter symbols to represent climatic regions.

Differences:

1. While Köppen had considered vegetation to be direct indicator of of climate, Thornthwaite's has given indirect recognition to the vegetational aspects.
2. Köppen took into account the altitudinal aspect of climate by giving a seperate category of ''Highlands Climate''. Thornthwaite did not consider the altitudinal aspect.

8.5 Conclusion

Köppen and Thornthwaite have classified the world climate on the basis of some selected criteria as per their own choice. Köppen has used temperature and precipitation as the basis of his classification which can easily be measured. This was very simple and generalized classification and thus and taught at any level. While, the climatic classification scheme of Thornthwaite is complex and empirical in nature. Both have used letter symbols to represent climatic regions.

8.6 Summary

- The most popular and well accepted climatic classification of climate was made by Köppen in 1918.
- Köppen had considered vegetation to be direct indicator of of climate.
- Köppen has used temperature and precipitation as the basis of his classification.
- Thornthwaite had presented his climatic classification scheme in 1931 and 1948.
- Thornthwaite has given indirect recognition to the vegetational aspects.
- Thornthwaite considered evaporation to be an important element and proposed five Humidity Provinces based on Precipitation Effectiveness (P/E index), six Temperature Provinces based on Thermal Efficiency (T/E index).
- Both the classification are based on empirical investigation and are genetic scheme.
- Both the classification have recognized climate-vegetation relationship.

- Koppen and Thornthwaite - both have used letter symbols to represent climatic regions.

8.7 Key words

Köppen, Thornthwaite, PE index, TE index

8.8 Model Questions

Short answer type:

1. Write short note on TE Index.
2. What is PE Index?
3. Criticise Köppen's climatic classification.
4. What are the merits of Köppen's climatic classification?

Long answer type:

1. Classify climate of the world after Köppen highlighting its merits and demerits.
2. Critically discuss the Thornthwaite's climatic classification mentioning its merits and demerits.
3. Make a comparative analysis of the climatic classification of Koppen and Thornthwaite.

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❐ Differences and Brief Notes

9.1 Frontal Fog Vs. Advection Fog

9.2 Barotrophic wind Vs. Baroclinic wind

9.3 Lapse Rate-Normal Vs. Adiabatic Lapse rate

9.4 Adiabatic Lapse Rate

9.5 Warm Fronts Vs. Cold Fronts

9.6 Dry Adiabatic Lapse Rate Vs. Wet Adiabatic Lapse Rate

9.7 Tropical Cyclone Vs. Temperate Cyclone

9.8 Frontogenesis Vs. Frontolysis

9.9 Af Climate Vs. Aw Climate

9.10 Precipitation Effectiveness, Temperature Efficiency, Potential Evapo-transpiration

9.11 PE Index

9.12 Adiabatic Vs. Non-Adiabatic Process

9.13 Features of Frontogenesis

9.14 Features of Frontolysis

9.15 Ekman Spiral

9.16 Green house gases Vs. Pollutants

9.17 Local Winds

9.18 Katabatic Winds

9.19 El Nino Vs. La Nina

9.20 Southern Oscillation

9.21 Anticyclone-Origin and Characteristics

9.22 Anticyclone and Associated weather Phenomena

9.23 Types of Anticyclone

9.24 Stratosphere

9.25 Advection Fog Vs. Ground Fog

9.26 Impact of ENSO phenomena

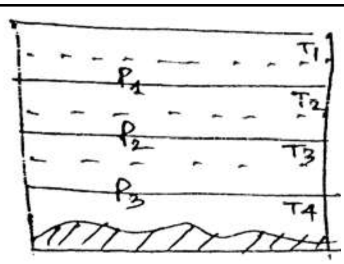
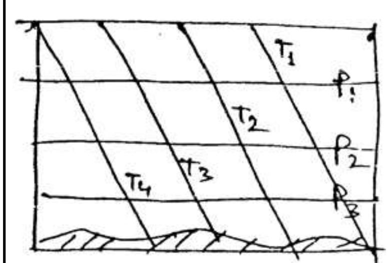
9.27 Ozone Formation

9.28 Atmospheric Window

9.1 Frontal Fog Vs. Advection Fog

Subject	**Frontal Fog**	**Advection Fog**
Situation	The fog developed due to development of front, is called frontal fog.	The fog developed due to the development of advection of warm and cold air/wind. is called Advection fog.
Distribution	This fog is mostly found in the temperate region.	This fog is mostly found in the tropical region and cold area.
Causes of development	This fog is developed due to collision of warm and cold air.	This fog is developed due to advection or touch related activities of warm and cold air.
Front	Front is observed in this type of fog.	Front is absent in this type of fog.
Duration	This frontal fog exist with long duration, more than advection fog.	The duration of time of advection fog is less than frontal fog.
Observed Time	This fog may observed in with the mid-latitude cyclone.	This fog may observed during morning time or winter climate.
Ground level	This fog may not be associated with ground level.	This fog is mostly associated with ground level.
Impact	This fog leave its inpact on the weather of mid latitude area.	This fog leave its impact on the weather in the tropical area and its amount is less than frontal fog.
Association	This fog is not associated with dry and wet adiabatic lapse rate.	Dry and wet adiabatic lapse rate are closely associated with this fog.
Development	This fog is developed only with the front develop due to the collision of warth and cold air.	This fog may also developed with the help or meeting of warm and cold ocean current.

9.2 Barotrophic wind Vs. Baroclinic wind

Subject	**Barotrophic wind**	**Baroclinic wind**
Definition	When the isotherms and isobars are parallel in a cross section, then wind blows paralled of that, this state of wind is called Barotrophic wind.	When the wind blows cross the parallely situated isotherms and isobars, this state of wind is called Baroclinic wind.
Nature	This is a stratification slate in which the constant slope and density slope parallely situated with each other.	This a stratification state when constant slope crossed the density slope.
Dependency	This state is largly dependent on the air pressure and density.	This state is mainly dependent on temperature.
Airmass	In this state, homogenous airmass exist.	In this state, the airmass became heterogeneous.
Condensation	Condensation occur due to extraction of latent heat of of condensed air.	Condensation is not able to occur in this state.
Isobar and Isotherm	Isobars and isotherms are paralled to each other.	Isobars and isotherms are crossed each other
Distribution	The level between the parallely distributed isobars and isotherms is less distributed.	The level between the cross wind is distributed about >100 km.
Diagram	 **Barotropic wind**	 **Baroclinic wind**

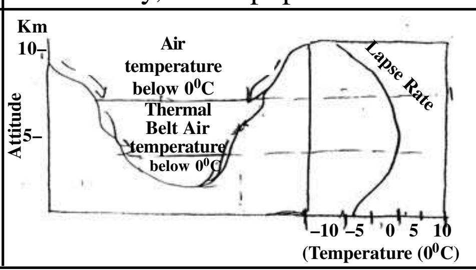
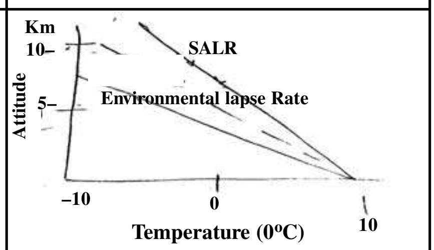
9.3 Lapse Rate

Introduction–Lapse rate is a rate of change in temperature observed which moving upward through the earth atmosphere.

It can be positive– When temperature decrease with altitude

It can be zero– When the temperateur is constant

It can be negative–When temperature increase with altitude (inversion of temperature).

	Normal Lapse rate	**Adiabatic Lapse rate**
Definition	It is also called environmental Lapse rate. It is a rate at which temperature decrease with elevation.	It involve changes due to rising and sinking of air.
Type	It done not have any type	-Dry adibatic lapse rate -Moist/Wet adibatic lapse rate
Heat	It is affected by radiation or heat.	Heat does not enter or leave this system.
Stabality	Actual stability of air is determind more as compair to adibatic lapse rate.	Actual stability of air is less determind as compair to normal lapse rate.
Air saturation	This rate is the rate when air saturation is put into account.	It is the lapse rate that is affected by saturation of the atmosphere.
Temperature	Temperature decreases when the rate is not affected.	Temperature decreases when air is either dry or moist.
Other name	Environment lapse rate.	Wet–Saturated lapse rate Dry–Non saturated lapse rate
Rate	6.5°C per km.	Wet: 4°C per km. Dry: 10°C per km. or 9.8°C. per km.
Zero Temperature	It drop to zero at uper boundary, of tropopause.	No such condition occur here.
Diagram		

9.4 Adiabatic Lapse Rate

It refers to the change in temperature with pressure. It involve rising and sinking of air. The air is moist when it is saturated by water vapour and dry when there is not much water vapour.

Types of Adiabatic Lapse rate:

(A) Dry Adiabatic Lapse rate–It's the rate of fall in temperature with altitude for a parcel of dry or unsaturated air which rise under adiabatic conditions.

- Unsaturated air has less than 100% relative humidity.

(Saturated air–The air that can't hold any more moisture. Its stomach is full with moistere. Unsaturated air–It's stomach is not full and it can accommodate some more moisture)

- It is mainly associated with stable condition.
- The dry adiabatic lapse rate for the Earth's atmosphere equals 8°C per kilometer.

(B) Wet Adiabatic Lapse rate–The rate of decrease of temperature of an ascending air beyond condensation level is lower due to addition of latent heat of condensation to the air.

- The wet adiabatic rate is 3°C–9°C per kilometer.
- It is mostly saturated air.
- Condensation occur due to saturation of water vapour.

9.5 Warm Front Vs. Cold Front

Subject	Warm Front	Cold Front
Definition	A warm front is defined as a gently sloping frontal surface in which there is active movement of warm air over cold air.	Cold front is that sloping frontal surface along which cold air becomes active and aggressive and involves the warm air territory and being denser remain at the ground.
Slope	Between 1 : 100 to 1 : 200	Varics from 1 : 50 to 1 : 100
Relative humidity	Humitidy increases here.	Humidity decreases here.

Weather	Heavy rainfall occur.	Drizzle rainfall occur.
Weather Forecaste	Clear weather followed by the warm front.	Clouded sky followed by the cold front.
Temperature	High temperature arround the warm front was found.	Low temperature along the cold front was found.

9.6 Dry Adiabatic Lapse Rate Vs. Wet Adiabatic Lapse Rate

The rate of change of temperature in an ascending or descending air mass through adiabatic process is called the **adiabetic lapse rate**.

The adiabetic lapse rate is of two types–

i) Dry adiabatic lapse rate

ii) Wet adiabatic lapse rate

Subject	**Dry adiabatic lapse rate**	**Wet adiabatic lapse rate**
1. Definition	When the ascending or descending air parcel is dry unsaturated, it's temperature changes at a constant rate. The dry adiabatic rate of change in temperature with height is referred to as the **dry adiabatic lapse rate**. **or** The temperature of unsaturated ascending air decreases with increasing height at rate of 10°C/km. This type of change of temperature of unsaturated ascending or descending air is called **dry adiabatic lapse rate**	The rate of decrease of temperature of an ascending air beyond condensation level is lowered due to addition of latent heat of condensation to the air. This is called **wet adiabatic lapse rate**.
2. Rate	Rate of 10°C/km	Rate of 3°C–9°C/km.
3. Nature of air	Mostly unsaturated air	Mostly saturated air
4. Condensation	Condensation occur mostly due to the lapse rate.	Condensation occur due to the saturation of water vapour.

9.7 Tropical Cyclone Vs. Temperate Cyclone

Subject	Tropical Cyclone	Temperate Cyclone
1. Location	Tropical cyclone occurs between 5° to 30° latitude within tropics.	They are found in temperate region between 35° and 65° latitude.
2. Size (diameter)	Their diameter ranges between 80 and 300 km.	Their diameter ranges between 800 and 1500 km.
3. Velocity of wind	Average wind velocity ranges from 120 to 200 km. per hour.	30–50 km/hour is the wind velocity range.
4. Movement	From east to west.	From west to east.
5. Influenced by	Trade wind move along it.	Westerlies move along it.
6. Size and shape	They are circular and symmetrical in shape.	They are elongated or oval in shape.
7. Time of observation	They originate mostly in late summer or autumn.	They mostly orignate in winter season.
8. Origin	They are thermal by origin.	They are of frontal by origin.
9. Formation	They form over both of land and sea and those ocean area where sea condition is favourable.	They are strictly oceanic phenomena and form only in surface temperature are at least 26°–27°C.
10. Energy	Tropical cyclones derive their energy from latent heat of condensation released within the clouds.	They derive their energy from airmass temperature contrsts.
11. Pressure	Low pressure gradient.	Steep pressure gradient.
12. Nature	They are very destructive in nature. They are accompained with violent wind and heavy rainall. They (cyclone) last for some hours.	They are less destructive and less violent. They bring rain and cloudy weather and last for a long period.

9.8 Frontogenesis Vs. Frontolysis

Subject	Frontogenesis	Frontolysis
1. Definition	The process of formation of front is known as frontogenesis.	The process of destruction of front is known as frontolysis.
2. Process	Genesis process.	Depletion process.
3. Occurance	First stage of temperate cyclone.	Last stage of temperate cyclone.
4. Duration	To proceed take more time.	To proceed take less time.
5. Nature	Creation of front.	Destruction of front.
6. Rainfall	Rainfall observe along frontogenesis.	No of rainfall is observed.
7. Occlussion	Occlusion occur.	No. occlusion occur.
8. Stage of formation	Frontogenesis create first.	Frontolysis formed later.
9. Types	There are two major types of front observed– a) warm front b) cold front	All the fronts are abolished.

9.9 Af climate Vs. Aw climate

Subject	Af climate	Aw climate
1. Climate	Equatorial climate	Savanna type of climate
2. Latitude	Found between 10^o north and south latitude.	It found from 10^o to 30^o north and south latitude.
3. Tempetatrue	Temperature is less than 27^{o}C (annual).	Monthly mean temperature is above 18^{o}C.
4. Rainfall	Annual precipitation is upto 250 cm 100 cm.	Annual precipitation is upto 100 cm.
5. Seasons	There is no dry seasons.	It include dry winter.

6. Character	-constant high temperature -equal day length -evently distributed heavy precipitation	-high sun seasons low sun dry period -less rainfall -It has dry climate.
7. Controlling factors	-The air masses -Rising air along trade winds	-Shiting influence by high sun and ITCZ -low sun shifting
8. Geographic distribution	-Amazon Basin -Congo river Basin -Brazil coast etc.	-Western Central America -North East India etc.

9.10 Precipitation Effectiveness

It refers to the amount of total precipitation which is available for the growth of vegetation. For obtaining this, Thornthwaite suggested to calculate precipitation effectiveness (P/E ratio) + precipitation effeciency index (P/E Index)

P/E Ratio = 11.5 (r/t – 10) 10/9t (for cach month)

(where r = mean monthly rainfall

t = mean monthly temperature.)

$$\text{P/E Index} = \frac{\text{Total rainfall}}{\text{Total evaporation}}$$

$$= \sum_{n-1}^{12} 11.5\ (r/t - 10)^{10/9t}$$

(where n = month.

r = mean monthly rainfall

t = mean manthly temperature.)

Thornthwaite proposed a P.E. ratio of a month and P.E. index which is the sum total of P-E ratio. On the bases of that he gave five humidity provinces–

Humidity Province		Vegetation Type	P/E index
A	Wet	Rainforest	128 and above
B	Humid	Forest	64-127
C	Semi-humid	Grassland	32-63
D	Semi-arid	Steepe	16–31
E	Arid	Desert	<16

Temperature Efficiency–It is the sum of 12 individual monthly T/E Index ratio

Thermal Efficiency Ratio (T.E ratio) =

$$\text{Thermal Efficiency Index (T/E Index)} = \sum_{n-1}^{12} \frac{(T-32)}{4}$$

(where, T = Mean monthly temperature)

Temperature Provinces–On the Basis of TE index six temperature provinces have been recognsied:

Temperature province		**T/E Index** $\frac{(T-32)}{4}$
A	Tropical	128 and above
B	Mesothermal	64–127
C	Microthermal	32–63
D	Taiga	16–31
E	Tundra	1–15
F	Frost	0

Protential Evapo–transpiration–It represent the amount of moisture transfered to atmosphere by evaporation + transpiration from living tissue

$$P/E = 1.6 \left(\frac{10t}{I}\right)^{a}$$

(where, I = Sum of months t = temperature, a = constant).

Moisture Index (MI) – If refers to the moisture deflected or surplus.

$$\text{Moisture Index} = \frac{(100^{S}-60^{D})}{PE}$$

(Where S = Monthly surplus of moisture

D = Monthly deficit of moisture)

Thermal Efficiecny Index, 1948–This is the potential evapotranspiration in cm.

Humidity Index, 1948–It is the annual water suplus in dry climate taken as percentage of annual PE.

9.11 PE Index

Definition–Precipitation efficiency was obtained by relating measurments of potential evaporation to temperature and precipitation.

Formula– 11.5 $(r/t-10)^{10/t}$(for each month)

(where r = mean monthly rainfall (inches)

t = mean monthly tempeerature (^{o}F).)

Features–

- It is calculated by the sum of 12 months ratios.
- It is the effectiveness of precipitation
- On the basis of P/E index five humidity provinces were difined.

Provience	Vegetation	P/E Index
A (Wet)	Rainforest	127+
B (Humid)	Forest	64-127
C (Sub-humid)	Grassland	32-63
D (Semi-arid)	Steppe	16-31
E (Arid)	Desert	< 16

$$\text{P/E Index (Annual)} = \frac{\text{Total Rainfall}}{\text{Total Evaporation}} = \sum_{n-1}^{12} 11.5\left(\frac{r}{t}-10\right)^{\frac{10t}{9}} \quad \text{(where, n = month)}$$

9.12 Adiabatic Vs. Non-adiabatic Process

Adiabatic: (1) When the air rises, it expands. Thus heat available per unit volume is reduced and therefore the temperature is also reduced.

(2) Temperture change which does not involve any subtraction of heat, and colling of air takes place only by ascent and expansion, is termed as ‘adiabatic change.’

(3) The vertical displacement of the air is the major cause of adiabatic and katabatic temperautre changes.

(4) Near the earth's surface, most process of change are non-adiabatic because horizontal movements after produce mixing of air and modify its characterstics.

(2) Non-Adiabatic

(1) Process include cooling by radiation, conduction or mixing with colden air. The air may be cooled due to loss of heat by radiation.

(2) In case there is direct radiation from moist air, the cooling produces fog or clouds subject to presence of hygroscopic nuclei in the air.

(3) Cooling by contact with a cold surface produces dew, frost or fog depending on other atmospheric conditions.

(4) But the effect of cooling produced by radiation, conduction and mixing is confined to a thin layer of atmosphere.

(5) The non-adiabetic processes of cooling produce only dew, fog or frost. They are incapable of producing a substaintial amount of precipitation.

9.13 Frontogenesis

Definition–The mechanism and process of front development, is known as Frontogenesis.

Features–

- T. Berjeron used the term Frotogenesis for the first time.
- It includes the process of regeneration.
- It is the creation of all together new fronts.
- It also mean the re-generation of decaying fronts already in existence.
- It is lively to occur when the wind blows in such a way that the isotherms became packed along the leading edge of the intruding air mass.
- During convergence, due to movement of air mass, frontogenesis occur.
- By frotogenesis– four types of fronts are generated, like–

  –Cold front

  –Warm front

  –Occluded front

  –Stationary front

9.14 Frontolysis

Definition–It means the destruction or dying of a front.

Features–

- It destroy fronts.
- Weaking or vanishing of existing fronts.
- This process is continued for sometime in order to existence and destroy fronts.
- Divergence of the wind is helpfull for frontolysis.
- It mostly occurs when fronts move into region on divergent air flow.
- It is mostly found in sub-tropical high pressure regions.
- When the air masses move away from each other, fronts may disipate.
- When temperature contrast between adjacent air masses diminises, this condition occur.

9.15 Ekman Spiral

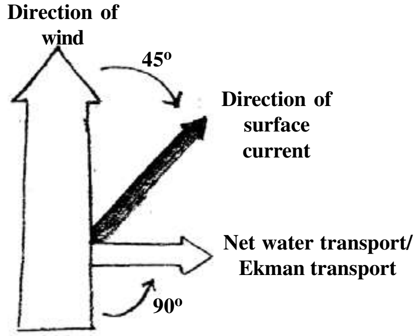
Definition–Ekman spiral is a structure of currents or winds near a horizontal boundary in which the flow and direction rotates as one moves away from the boundary.

Propounder: V. Walfrid Ekman (1902), a Scandinavian physicist, developed a mathematical model of defection of surface ocean currents relative to wind direction caused by **coriolis deflection**.

Characteristics:

1. According to Ekman, the surface water of the ocean, when set in motion by wind, is deflected to the right of the direction of the current-generating wind at almost 45^{o} angle in the norther hemisphere.
2. Surface water is deflected to the left of the wind direction in the sourthern hemisphere.
3. The speed of each successive lower layer of ocean water decreases in response to the downward decrease of frictional force of current generating wind.
4. The frictional force of wind becomes almost zero at the depth of 100 to 200 metres.
5. The winds sets the surface water of the ocean in motion through its friction with the surface of oceans caused by wind.

6. The resultant movement of surface water of the ocean does not follow the direction of wind but is deflected to right of the wind direction at the angle of 45^o.



7. Each successive lower layer of ocean water upto the depth of 100–200 meters moves forward.
8. Thus 'the Ekman spiral describes the speed and direction of flow of surface waters at various depths.'

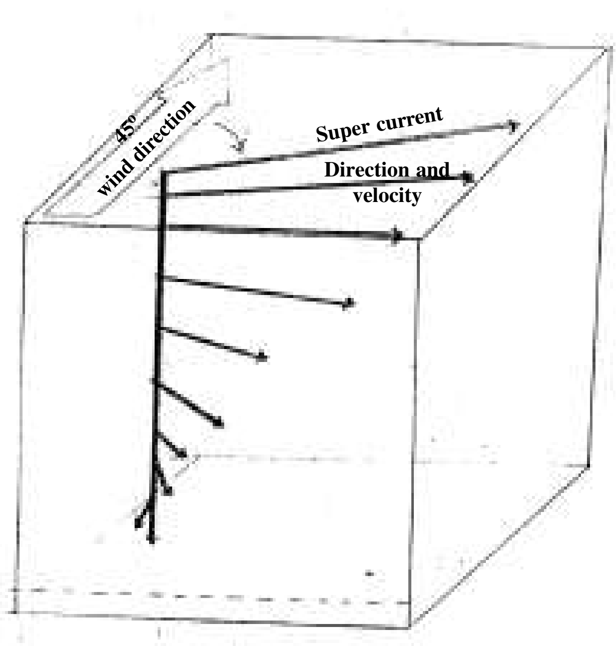


Figure : Ekman Spiral

9.16 Greenhouse gases vs. pollutants

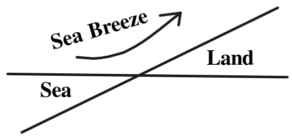
Greenhouse Gases	Pollutant
1. Those gases which are responsible for green house effect.	The elements which is responsible for environmental pollution.
2. Less effective on environment.	More effective on environment.
3. The responsible gases are CO_2, CO, N_2O, O_3, CFC, CH_4.	In most of the cases, the pollutants are CO_2, CO.
4. These are responsible for global warming.	These are causing environment pollution as well as degradation.
5. These are mainly associated with global warming and green house effect.	These are causing different environmental pollution as well as environmental degradation on a large scale.
6. The effect is limited.	These are widely spread and has a large scale impact on environment.

9.17 Local Wind

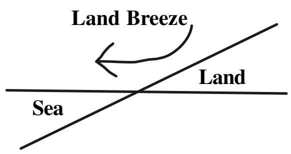
Indroduction–Meso scale winds are better known as local winds or regional winds. It can persist anywhere from several minutes to several days. It is mostly driven by temperature and pressure differences or by variation in topography. The main types of local winds are sea breezes and land breezes, Anabatic and katabatic winds. Due to difference in heating and cooling of earth surfaces can create several local and regonal winds.

Factors effecting local wind

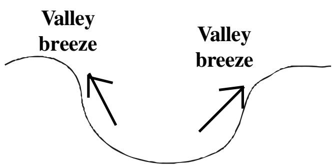
1) **Sea breeze–**During the day time land become hot as campared to sea, hence sea breeze flow from sea to land.



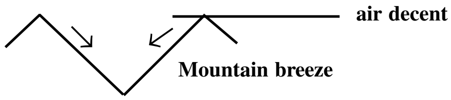
Land breeze–During the night land become cooler than sea. Hence land breeze flow from land to sea.



2. **Mountain breeze and valley breeze**–During the day, the slope get heated and air move upslope to still the resulting gap. The air from the valley blows up to the valley are called **valley breeze**. It is also known as **Anabatic wind**.



• **Mountain breeze**–During the night, slope gets cooled and dense air desent into valley as mountain wind or breeze.



The cool air of the high plateaus and ice fields draining into the valley is called **Katabatic wind**.

9.18 Katabatic Wind

It is a hot dry wind that blow down a mountain slope.

Explaination–When air over sloped terrain is cooled by conduction, it becames denser than near air and drains to lower level/when cool air is drain into the valley, then Katabatic wind generated.

Factors

1) The degree of cooling along the slope.
2) The roughness of the slope.
3) The steepness of the slope.

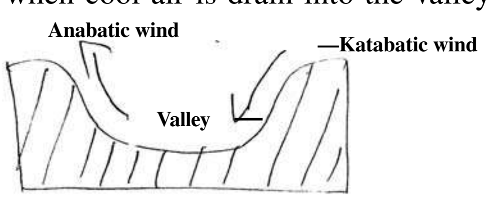


Figure: Katabatic wind

Characteristics:

1. It is technical name for a **drainage wind** and it rush down or it move down the slope.
2. Commonly found blowing out from the large and elevated ice sheet of Antarctica and Greenland.

9.19 El Nino vs. La Nina

Subject	El Nino	La Nina
Meaning	The little boy	The little girl
Interval	5-10 years	2-3 years
Ocean current	Warm	Cold
Location	Peru, Chile coast	Peru, Chile coast close to equator.
Temperature	Increase about 2-4^{o}C	Decrease about 4^{o}C
Impact	–global warming –change of wind movement and pressure –effect on plant and animal –southern oscillation –effect on monsoon –effect on south-east pacific climate	–cooling of climate –snowfall –rainfall and flood –creation of cyclone –increase of organism
Year seen:	2000, 2002, 2007	1995, 1998, 2005

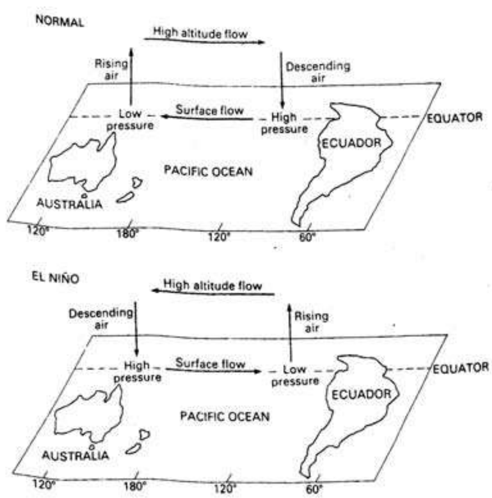


Figure: Pressure and circulation changes associated with El Nino

9.20 Southern Oscillation

It is a inter-annual fluctuation of atmospheric pressure over the tropical indo-pacific region.

It is an atmospheric compenent of a single large-scale coupled interaction called the El Nino.

It is a oscillation in air pressure between the tropical eastern and western before oceans water.

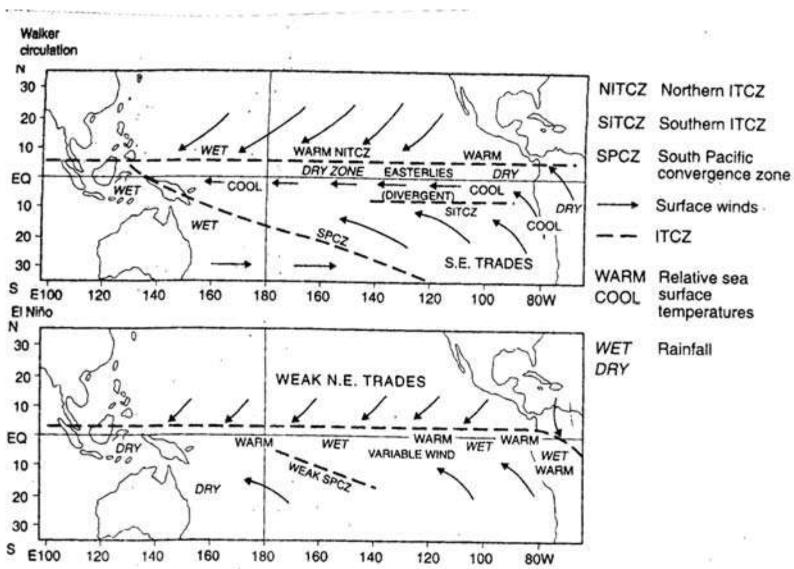


Figure: Circulation and precipitation associated with extreme phases of ENSO.

Measures of Southern Oscillation–It is measured by Southern Oscillation Index (SOI). It is a record of the monthly or seasonal fluctuation in the normalized surface air pressure.

Types of SOI Index–

Positive Southern Oscillation Index.

(a) Tahiti pressure is greater than port Darwin.

(b) High pressure of East pacific and low over Indian Ocean.

(c) Low rainfall over East Pacific and normal monsoon over Indian region.

Negative Southern Oscillation Index–

(a) Port Darwin pressure is greater than Tahiti.

(b) High pressure over Indian Ocean and low pressure of East pacific

(c) Bad or low rainfall over Indian region.

El Nino is associated with negative value of SOI.

9.21 Anticyclone

Introduction–The term anticyclone was introduced by Galten in 1861. It is a circulation of wind around a central region of high atmospheric pressure. It is clockwise in northern hemisphere and anti-clockwise in southern hemisphere.

Characteristics–

1. It is a weather phenomenon that is a large scale circulation of winds, around a central region of high atmospheric pressure.
2. It moves clockwise in northern hemisphere and anti-clockwise in southern hemisphere.
3. The strongest anticyclones occur over snow covered portions of Asia and North America in the winter season.
4. Gradient wind speed is greater for an anticyclone.
5. No clouds are present as they tends to evaporate.
6. There is no precipitation occur and tend to become dry.
7. They are larger upto 3000 km across.

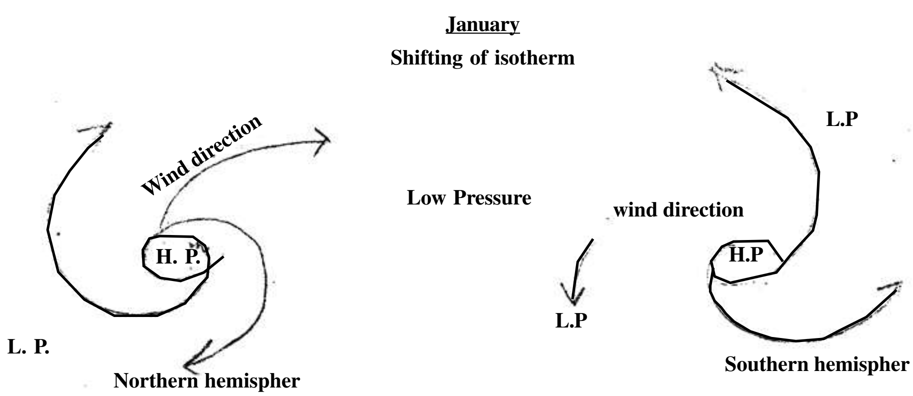


Figure : Anticyclone

H.P—High Pressure

L.P–Low Pressure

Origin–The origin of anticyclones lies in upper air circulation in the oscillating westerlies. The Rossby waves and subsidence induced by density of the air.

- As the air cools, its density increases and it sinks forming high pressure zone. This is how anticyclone originate in polar and continental area.
- The Movement of Rossby waves change the forces. The result is the wind speed is greater than the ridgers of Rossby weaves.
- They compensated by convergence and divergence near the ground lead to anticyclone. Thus divergence take peace when convergence aloft.
- As long as Rossby waves is stable pressure area is stable.

9.22 Anticyclones and Associated weather Phenamena

1) **Cold core anticyclones or cold anticyclones–**

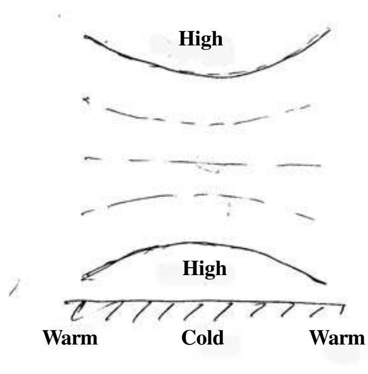
- The core is high, as they are called cold core and have low temperature in their centres.
- As sea level a cold-core high weakeness with elevation and may change into high level to low. The spacing of isobar at the centre is low.

Characteristic–Shallow anticyclone with circulation extend up to 23 km.

Development–The cold core anticyclone develop over Arctic and Antarctic region in winter.

Latitude–Cold core anticyclone form in high latitude.

Origin–Due to radiation, cooling of land surface and chilling of the overlying atmosphere.



Troposphere–It is cold and in tropopause it is low.

Stratosphere–It is warm in stratospher.

Intensity–It decrease with height.

On occasions cold–Core highs move into warmer region of low latitude where they turn into deep warm core anticycle.

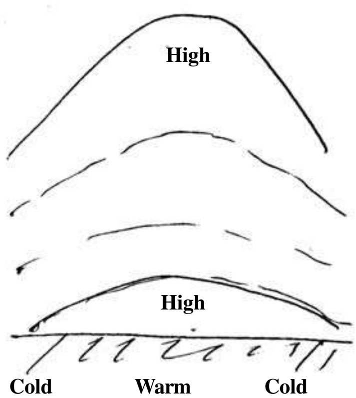
Warm core anticyclone or warm anticyclone

Temperature–High temperature observe in the centre. Temperature gradually decrease from centre to outward.

Isobar–The vertical spacing of isobar at the centre is relatively greater. At higher elevation, the isobar bulged out upward so, slope of isobar is steeper.

Development–The anticyclone develop in south-east state of United State of America and South California during summer.

Latitude–Warm core anticyclone form in low latitude.



Troposphere–It is warm in troposphere, therefore the temperature in tropopause is high.

Stratosphere–It is cold in stratosphere.

Intensity–Increase with height.

Origin–Convergence in upper tropospher.

Blocking anticyclones–This are warm anticyclonic cells that have broken away from the rossby waves, during high index and have establish themselves in higher latitude.

It affect the normal westerly flow at all levels by diverting than and also block the eastured passage of depresion.

The maximum frequency of blocking anticyclones occur over Alaska, Greenland, Australia, New Zealand etc.

It has enormous effect on weather and climate and responsible for producing anomalous months and seasons.

9.23 Types of Anticyclones

1. **Subtropical high–**Develope in subtropical region they are almost permanent high-pressure system positioned in subtropical high pressure belts. They are well develop over the oceans and have low pressure over continent.
2. **Polar Continental high–** These cold anticyclone from over continental surface in winter. The produced by radiational cooling of the earth is surface.
3. **High embedded between cyclones–**This are weather system which are found between individual cyclone. They produce clear and fine weather after more turbulent cyclonic weather.
4. **Polar out break–**This are the last member of cyclone family which may move even in tropical region.
5. These anticyclones moves equator ward and it slows down. They transformed into subtropical warm anticyclones.

9.24 Stratosphere

1. **Stratosphere**

It is the second most lower layer of atmosphere.

- **Extension**–12-50 km.
- **Features/Characteristics**:
    1. Lower portion of the layer is isothermal.
    2. Temperature increases according to elevation increasement.
    3. Upper part of this layer is known as stratopause.
    4. Cirrus cloud found here.
    5. No wheather phenomena is visible here.
    6. It is divided into two part, lower stratosphere and upper stratosphere.
    7. Thickness is highest at the poles.
    8. Temperature increases above this layer of atmosphere.
    9. Lower layer is toposphere.
       and upper layer is mesosphere.
    10. It's a calm layer.
    11. Jet planes are travel through this layer.

9.25 Advection Fog Vs. Ground Fog

Subject	Advection fog	Ground fog
1. Definition	It genrates when warm moist air moves horizontally accross cooler surface.	Fog formed by cooling of land after sunset and clear sky.
2. Duration	Can last for several days.	Generally last for short duration.
3. Intensity	Can range from thin to dense but dense condition cover larger area.	Varies with denser fog likely over open area or near water bodies.
4. Coverage	May be advected over large area.	It remains in ground of a place.
5. Depth	It varies with boundary layer but deeper than radiational fog.	It varies with depth of radiation inversion.
6. Time	It can form almost at any time of day.	It can form late right or early morning.
7. Wind	Occur with light or moderate low level wind. winds generally less than zero.	Boundary layer dynamic and adiatatic process in negligible and winds generally blows 5 km in speed.

9.26 Impact of ENSO

ENSO in El Nino and Southern Oscillation.

It has both good and bad impact on the biosphere including human being.

1. El Nino affect the location of jet stream which produce winter weather pattern.
2. In Peruvian portion of the Atacama Desert, it bring copius rainfall associated with voilence storm.
3. It is associated with coral bleaching.
4. It reduces the upwelling of cold, nutrient rich water that sustains large fish population.

5. Agriculture of Australia, Indenosia, Africa etc. is effected due to El Nino.
6. Human health hazard can be related to ENSO as it increases famine, water population diseases such as malaria, dengu, cholera etc.

Diagram

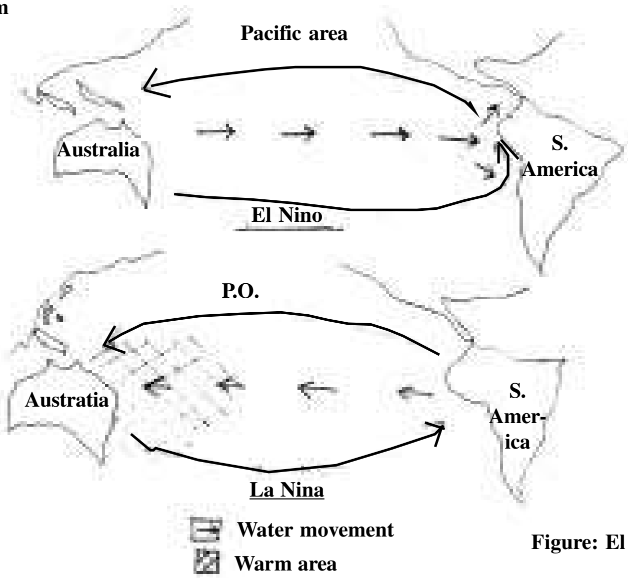


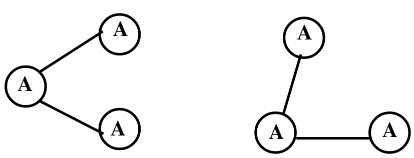
Figure: El Nino and La Nina.

9.27 Ozone Formation

Stratospheric Ozone is formed naturally by chemical reactions involving solar ultraviolet radiation and oxygen molecules which make up 21% of atmosphere.

Steps of formation

First stage–When short-wave length UV light from the sun hits a molecule of oxygen gas. Due to which the oxygen bond holding the atoms together break and create two oxygen atom.



Second stage– Each of these highly reaction atoms combines with an oxygen molecules to produce an ozone molecules. These reaction occur continually whenever solar ultraviolet radiation is present in the stratospher.

Some of the ozone are transported down to the troposphere. In Troposphere, ozone is produced by chemical reaction. It primarily involve hydrocarbon and nitrogen oxide gases as well as ozone itself and requir sunlight to complete.

9.28 Atmospheric Window

It is that portion of eletromagnetic spectrum that can be transmitted through the atmosphere without absorption. The region where carbondioxide and water vapour is minimum than its absorption. Basically, from where the electromagnetic radiation from space can penetrate the earth atmosphere, is called atmospheric window.

Importance

1. It allow specific wave length like gamma rays.
2. Water vapour, ozone, carbon dioxide in the atmosphere is absents. So specific bands of EM spectrum can freely pass.
3. It help in remote sensing by taking atvantage of visible spectrum and non visible light.

Climatology
Sample Questions

Long answer type question : [10 Marks]

1. Give an account of nature and composition of atmosphere.
2. Describe the layers of the atmosphere.
3. Explain the factors controlling Insolation.
4. Explain the heat budget of the atmosphere.
5. Explain the vertical distribution of temperature.
6. Explain different types of inversion of temperature.
7. Describe the horizontal distribution of temperature in January and July.
8. Discuss the factors affecting the distribution of temperature.
9. Discuss the causes and consequences of global warming.
10. Describe the causes and consequences of Green House Effect.
11. Explain the formation and depletion of Ozone in atmosphere,
12. Assess the importance of Ozone layer in the atmosphere. What is Ozone hole?
13. Discuss the forms of Condensation.
14. Explain the process of Condensation.
15. Elucidate the mechanism of rain drop formation in atmosphere.
16. Explain the theories of precipitation.
17. Discuss different forms of precipitation and types of rainfall.
18. Classify different air masses and account for their modification.
19. Explain the source regions of the major air masses forms during winter and summer season.
20. State the concept of Frontogenesis and Frontolysis. Classify and discuss fronts.
21. Briefly explain the concepts of lapse rate. State the stability and instability of atmosphere.
22. Explain the general pattern of distribution of planetary winds.
23. Give an account of the global pressure belts with diagram.
24. Discuss the relation between the global pressure belts and planetary winds.
25. Describe the tri-cellular (meridional) models of wind circulation.
26. Discuss the types and development of jet stream.
27. Explain the growth, origin and structure of tropical cyclone.
28. State the origin and development of the extra-tropical cyclone.
29. Distinguish between the tropical and extra-tropical cyclone.
30. Explain about the ENSO phenomena. Distinguish between El-Nine and La-Nina.
31. Discuss the salient features of Indian Monsoon.
32. Explain the monsoon circulation over the Indian subcontinent.
33. Explain the monsoon mechanism.
34. Explain how the mechanism of jet stream influences Indian monsoon.
35. Highlights the properties and importance of jet stream.
36. Classify climate of the world after Koppen highlighting its merits and demerits.
37. Critically discuss the Thornthwaite's climatic classification mentioning its merits and

demerits.

38. Make a comparative analysis of the climatic classification of Koppen and Thornthwaite.

Short answer type question: [5 Marks]

1. Albedo.
2. Characteristics of Troposphere/Stratosphere
3. Inversion of Temperature
4. Role of Green house gases
5. Evidences of global warming
6. Importance of Ozone/Ozonosphere
7. Solution of Ozone depletion.
8. Types of fog
9. Classification of clouds
10. Types of front
11. Characteristics of fronts
12. Conditions responsible for frontogenesis and frontolysis
13. Differentiate stability with instability of atmosphere.
14. Factors controlling general circulation of winds
15. Geostrophic wind
16. Coriolis force
17. Byes ballot law's
18. Geostrophic wind Vs. Gradient wind
19. Factors controlling pressure systems
20. Structure of tropical cyclone
21. Favourable conditions for tropical cyclone
22. Baroclinic wave theory and polar front theory of mid latitude cyclone
23. Features of mid latitude cyclone
24. Anti-cyclone
25. Cyclone Vs. anti-cyclone
26. Nor' wester
27. Warm front Vs. Cold front
28. Occluded front
29. Frontogenesis and Frontolysis
30. Regional distribution of tropical cyclone
31. Classification of tropical cyclone
32. Green House Gases
33. Ozone depletion
34. Effect of El-Nino
35. Effect of La-Nina
36. Human induced factors of global warming
37. Sunspot
38. Southern Oscillation Index (SOI)
39. Burst of monsoon

40. Retreating monsoon
41. Branches of Indian Monsoon
42. Influence of monsoon on Indian climate
43. Classical concept of monsoon

44. Differences and Brief Notes **[5 Marks]**
    1. Frontal Fog Vs. Advection Fog
    2. Barotrophic wind Vs. Baroclinic wind
    3. Lapse Rate-Normal Vs. Adiabatic Lapse rate
    4. Adiabatic Lapse Rate
    5. Warm Fronts Vs. Cold Fronts
    6. Dry Adiabatic Lapse Rate Vs. Wet Adiabatic Lapse Rate
    7. Tropical Cyclone Vs. Temperate Cyclone
    8. Frontogenesis Vs. Frontolysis
    9. Af Climate Vs. Aw Climate
    10. Precipitation Effectiveness, Temperature Efficiency, Potential Evapo-transpiration
    11. PE Index
    12. Adiabatic Vs. Non-Adiabatic Process
    13. Features of Frontogenesis
    14. Features of Frontolysis
    15. Ekman Spiral
    16. Green house gases Vs. Pollutants
    17. Local Winds
    18. Katabatic Winds
    19. El Nino Vs. La Nina
    20. Southern Oscillation
    21. Anticyclone-Origin and Characteristics
    22. Anticyclone and associated weather phenomena
    23. Types of Anticyclone
    24. Stratosphere
    25. Advection Fog Vs. Ground Fog
    26. Impact of ENSO phenomena
    27. Ozone Formation
    28. Atmospheric Window

Further Readings

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