Karnataka State Open University

Department Of Studies In Geography
Manasagangotri, Mysore - 570 006

M.Sc. GEOGRAPHY

Second Semester

CLIMATOLOGY

COURSE - 201 **BLOCK - 1,2,3 and 4**

ಕರಾಮುವಿ

ರಾಷ್ಟ್ರೀಯ
ಅಂತಾರಾಷ್ಟ್ರೀಯ
ಮಾನ್ಯತೆ

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ಉನ್ನತ ಶಿಕ್ಷಣ ಎಲ್ಲರಿಗೂ ಎಲ್ಲೆಡೆ

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COURSE- 201

CLIMATOLOGY

COURSE INTRODUCTION

BLOCK-1, 2, 3 and 4

Climate is the average condition of the atmosphere over a long period of time over larger area. The climate of a particular region is obtained from long period as repeated observation of the atmospheric conditions. i.e., 30 to 35 years. The scientific study of climate is known as "climatology". The study of climate is very important, climate affects the life and activities of man, the configuration of land and the topographical features and it is so comprehensive on its influence that no study of any world phenomena is possible without some basic knowledge of climate. The vegetation and animals also depend upon climate.

Man's need for shelter and clothing is also directly determined by the factors of climate.

First block climatology is divided in to unit 1, Insolation ; Unit 2, Distribution of temperature and their types such as vertical and horizontal, Unit 3, temperature and heat budget and Unit 4, pressure over the earth and pressure belts.

Second block pressure models divided into Unit 5, cell models, Hadley models, Unit 6, circulation of air-Palmen model, Unit 7 polar circulation of air and its causes, Unit 8, wind, causes and types-planetary wind.

Third block wind types and causes Unit 9, seasonal wind , Unit 10, local wind and its types, Unit 11, cyclones-temperate and tropical and Unit 12 Fronts and its location.

Fourth block cyclones divided into Unit 13, jet stream and anti-cyclones, Unit 14 climate classification- Koeppen's , Unit 15 Thornthwait's classification, Unit 16 Global warming and climate change, theories of climate change.

UNIT - 1: INSOLATION

Structure:

1.0. OBJECTIVES

After studying this unit, you will be able to ;

- Know the effects of solar radiation on the Earth system
- Identify the various factors affecting the distribution of solar insulation.
- Understand of many physical cycles and concepts associated with the Earth system.

1.1. INTRODUCTION

The earth receives only a minute fraction of energy received by the sun. This insignificant solar radiation provides more than 99.9 percent of the energy that heats the earth. This radiant energy controls our weather and climate. The incoming solar radiation that strikes the earth is equal to 23 billion horse power!!

The word 'Insolation' is nothing but the incoming solar radiation". The sun emits the radiant energy in the form of electromagnetic waves. The electro magnetic energy has wavelength and frequency, which are inversely related. The ultra violet and infrared rays effectively heat the earth. Infact the rays of the solar spectrum reaching the earth are converted after absorption by the earth surface from short wave to long wave radiant energy. This is known as heat. There are various factors responsible for the temporal and spatial distribution of these temperatures.

1.2 THE SOLAR CONSTANT

The amount of radiant energy is to be constant. The standard value of solar constant is 1.94 grams calories/ sq cms/ min. The solar constant is defined as the rate at which solar radiation is received on a surface perpendicular to the sunrays when the earth is at an average distance from the sun. There is slight variation in the solar constant, but it is negligible (2-3 percent)

The solar constant is an important value for current studies of global radiation balance & climate models. The problem that faces scientists studying Earth's radiation budget and climate is that while satellites can "accurately" measure solar irradiance and calculate a solar constant, is much more difficult to assess. When the solar constant is calculated there are four major problems.

- First, the calculation is made for the top of the atmosphere and not for the surface of the Earth.

- Second, the calculation assumes that the surface receiving the radiation is perpendicular to the radiation.
- Third, the calculation assumes that the surface receiving the radiation is at a mean Sun-Earth distance.
- Fourth, the calculation assumes that radiation emission from the Sun remains constant.

Trying to relate calculations made for the top of the atmosphere to the surface is a problem because up to 70% of incoming radiation can be blocked by the atmosphere and cloud cover. In attempts to create global energy budget models, scientists must estimate for the amount of energy actually reaching the surface. Assuming that the surface receiving the radiation is perpendicular to the incoming radiation is a problem because this is a rare occasion even at tropical latitudes due to the rotation of the Earth (time of day), tilt of the Earth's axis in relation to the incoming solar radiation (season), and the latitude and orientation of the surface. All of these factors change the angle of the surface receiving the radiation, which changes the intensity of the energy received.

1.3. DISTRIBUTION OF INSOLATION

There is an unequal distribution of solar insolation on the earth surface. That means at different latitudes different amount of solar insolation is received at different times of the year.

The following table reveals the diurnal solar radiation on a horizontal surface

Table: 1 Diurnal total amount of solar and sky radiation on a horizontal surface on a clear day (gram cal/sq cm)

North lat	Vernal Equinox	Summer Solstice	Autumnal Equinox	Winter Solstice
90	0	896	0	0
80	247	853	203	0
70	374	795	322	0
60	413	794	368	46
50	504	895	480	150
40	599	800	526	270
30	630	772	593	392
20	692	790	663	466
10	726	696	704	602
0	682	609	687	650

On these dates the sun, because of refraction, is visible on the horizon and adequate amount of solar radiation is received from the sky light. So the actual value of these zeros is more. The mean values of the zonal distribution of the incoming solar radiation received at the earth's surface of the northern hemisphere were calculated by Baur and Phillips. While making the calculations, they also took into account the amount of cloudiness and the turbidity factor.

In the mean values of incoming solar radiation received at the outer boundary of the atmosphere and the earth's surface in different latitude zones can be seen. A comparison of the mean values of insolation as shown in part A and B Latitudinal and seasonal variation in the amount of the table throws sufficient light on the of insolation received at the outer margin of the atmosphere, evidence that a certain percentage of the incoming solar radiation is lost by various factors such as the amount of cloudiness, reflection and atmospheric turbidity. The comparative values of both the parts of also indicate that at the time of summer solstice the highest values of insolation received at the outer boundary of the atmosphere occur at the poles.

However, at the surface the situation is otherwise. It is between latitudes 30° and 40° north, that on June 21 the maximum amount of insolation is received on the surface of the earth. Because of the presence of sub-tropical high-pressure belt there is the minimum amount of cloudiness in these latitudes. It is mainly due to the difference in cloudiness that the maximum amount of insolation at the time of vernal equinox is received in the latitudinal belt extending from latitudes 10° to 20° north. But at the time of autumnal equinox the maximum insolation belt shifts to 20°-30° North latitudinal belt. The conditions are almost the same in the southern hemisphere also. In fact, the total annual insolation is greatest at the equator, and there is a general decrease pole-ward. The total amount of insolation received at the equator is roughly about four times that received at either of the poles.

The zone of maximum possible insolation, as it were, is tied with the sun. In tropical regions the amount of insolation is not only constantly large, but also there is little seasonal variation. Since all places between the Tropic of Cancer and the Tropic of Capricorn experience overhead sun twice during the course of a year, there are naturally two maxima of insolation. In the belt lying between latitudes 23V2° and 66V2⁰ the periods of maximum and minimum insolation coincide with the summer and winter solstices respectively.

However, so far as the actual insolation received at the surface is concerned, there is a slight departure from a simple latitudinal pattern. Because of aridity and clear skies the maximum amount of incoming solar radiation is received at about latitude 20° north and south. It may be noted that it is simply on account of relatively clearer air at higher elevations that high mountain ranges and plateaus are always in receipt of a larger amount of insolation. Beyond the Arctic Circle, the sun is always seen in the sky on mid-summer days, but the altitude of the mid-day sun decreases steadily till it is 23¹/2° at the poles. However, the longer duration of the period of sunshine more than compensates the low noon-time elevation of the sun. That is why on its midsummer day the insolation received at the poles is greatest among all the latitudes.

It is between lat 30 ° -40° north on June 21, the maximum amount of insolation is received because of the sub tropical high-pressure belt; there is a maximum amount of cloudiness in these latitudes. However, at the time of autumnal equinox the maximum insolation belt shifts to 20°-30° north latitudes. The total amount of insolation is greater at the equator and decreases pole ward. The total amount of insolation at the equator is 4 times greater than poles.

The tropic of Cancer and tropic of Capricorn experience overhead sun twice during the year hence there will be two maxima of insolation

Table: 2 percentage of insolation received at the earth surface from the equator to poles

Latitude	0	10	20	30	40	50	60	70	80	90
Percent	100	99	95	88	79	68	57	47	43	42

At the equator, the amount of solar insolation received by the earth is about 100 percent and at the Polar Regions, it is only 42 percent.

1.4. FACTORS AFFECTING THE DISTRIBUTION OF INSOLATION

Actual amount of insolation received at a place is depending upon the following factors:

- Angle of incident
- Duration of sunshine
- Solar constant
- Distance between the sun and the earth.
- Transparency of the atmosphere

1.4. 1. Angle of incident

Vertical rays of the sun heat the maximum possible area, on the contrary, oblique rays have to traverse larger distances before the strike; the larger amount of energy will be lost due to the reflection, absorption, and scattering. At mid days, the intensity of the insolation is maximum, but in the morning and in the evening hours it is reduced because of the slanting of the rays.

1.4. 2. Duration of sunshine

Duration of sunlight hours determines the length of the day which also affects the solar radiation- longer period of sunshine ensures larger amount of insolation supply.

The latitudinal and monthly variations in the length of days have shown in the following table

Table: 3 MAXIMUM LENGTH OF DAY IN DIFFERENT LATITUDE

Latitude	Longest day/night	Latitude	Longest day/night
0	12 hours	63.4	20 hours
17	13 hours	66.5	24 hours
31	14 hours	67.4	1month
41	15 hours	69.8	2 months
49	16 hours	78.2	4 months
58.5	18 hours	90.0	6 months

The inclination of the earth axis, parallelism, rotation and revolution, all these factors combine together to bring about seasonal changes. At the equator, the length of the day and night is 12 hours and at the poles, it is 6 months.

Sept 21 and March 21the sun is overhead at the equator. On these two days all over the earth, the days and nights are equal. On these two days, the maximum amount of insolation is received at the equator and the amount decreases toward poles.

June 21 to Dec 22 nd length of the day in the southern hemisphere increases and in the northern hemisphere decreases.

On the contrary, at the winter solstice, the southern hemisphere has the longest day and the northern hemisphere has the longest nights.

1.4.3 The solar constant

As the energy emitted by the sun varies, the amount of insolation received at the surface is also changes.

1.4.4 Distance between the sun and the earth

The earth revolves around the sun is in elliptical orbit. Distance varies from season to season. The mean distance between the earth and the sun is about 149 million kms. Earth comes closer on January 3rd (about 147 million kms) this position is known as ***Perihelion.*** On July 4th earth will be further away about 152 million kms. This position is called ***Aphelion.*** With the result, there will be about 7 percent variation in the amount of solar insolation received between January and July.

1.4.5. Transparency of the atmosphere

Transparency of the atmosphere is an important control on the amount of insolation that the earth receives. Reflection from the dust, salt and dust particles in the air affect the incoming solar radiation. Reflection from the cloud tops depletes the amount of solar radiation. Gas particles, dust particles, water vapor also affect the incoming solar radiation through the process of reflection, scattering and absorption.

1.5. ATMOSPHERIC DEPLETION OF SOLAR RADIATION

The loss of solar energy while passing through atmospheric layer is called the atmospheric depletion. Longer the path traveled, the greater the amount of radiant energy depleted.

The heat energy is lost due to the

1) **Scattering**
2) **Diffusion**
3) **Absorption and**
4) **Reflection**

1.5.1. Scattering

The atmosphere is composed of molecule of air, water vapor, and dust particles. These molecules scatter the shorter the ultra violet rays at different directions. Ultra violet rays scatter more because of short wave length.

1.5.2. Diffusion

when the diameter of the particle is larger than the wavelength, scattering does not occur. With the result, the light defuses. This is called ***twilight***

1.5.3. Absorption

it is a process in which the incident radiation is retained and converted to some form of energy. Due to the absorption, there will be a loss of energy. When a gas molecule absorbs light waves, this energy is transformed in to inter molecular motion, whichcauses a rise in temperature. Nitrogen is a poor absorber; oxygen and ozone are the good absorbers. At the higher altitudes, oxygen absorbs most of the ultra violet rays.

The following table shows the albedo of various earth surface features.

Table 4: Albedo of various surfaces

Surface	Percent	Surface	Percent
Fresh snow	80-85	Forest	05-10
Old snow	50-60	Water	50-80
Sand	20-30	Thick cloud	70-80
Grass	20-25	Thin cloud	25-50
Dry earth	15-25	Earth and atmosphere	35
Wet earth	10		

1.5.4. Reflection

A part of the incident radiation falling on any earth surface reflected back. It is called reflection. Reflectivity is expressed in terms of percentage. It is called albedo or reflection coefficient. It differs from place to place and time to time depending upon the cloudiness and atmospheric impurities. The albedo for the earth as a whole also known as planetary albedo is only 35%. Clouds play an important role in reflecting incoming solar radiation. Earth's land sea surfaces accounts only 4 percent of the 35%. When the altitude of the sun is 47 degrees, the albedo varies from 3-5 percent. On the other hand, when the sun is near the horizon the albedo is about 50 to 80 percent.

1.6. LET US SUM UP

A number of factors can influence the intensity of the solar radiation received at the Earth's surface. We discovered that the Sun can vary in its output of radiation and that a variety of geometrical relationships between the Earth and the Sun have considerable effect on the intensity and duration of incoming solar radiation. As the solar radiation passes through the Earth's atmosphere the processes of scattering, absorption, and reflection can also reduce the intensity of the shortwave beam.

1.7. KEY WORDS

Solar insulation, solar constant, solar radiation.

1.8. QUESTIONS FOR SELF STUDY

1. What factors affect the amount of sunlight reaching the surface of the earth?
2. What is the maximum and minimum albedo? Why and where does it occur?
3. What effect would changes in the earth's average albedo have on the climate?
4. How does the pattern of incoming solar radiation change over the year for each of the hemispheres?
5. Give your understanding on the effect of the latitudinal imbalance in the Earth's radiation

1.9. FURTHER READINGS

1. **Bary R.G. & Chorley, R.J.** : "Atmosphere, Weather and Climate", Routledge, 1998.
2. **Critchfield H** : "General Climatology" Prentice-Hall, New York, 1975.
3. **Das P.K.** : The Monsoons, National Book Trust, New Delhi, 1968.
4. **Lal D.S** : "Physical Geography"Sharada Pustak Bhavan, Allahabad, 2009
5. **Lydolph, Paul, E.** : The Climate of the Earth, Rowman and Allanheld, Totowa, N.J., 1985.
6. **Mather J.R.** : Climatology, McGraw-Hill, New York, 1974.
7. **Patterson S.** : Introduction of Meteorology, McGraw-Hill Book Co., London, 1969.
8. **Stringer E.T.** : Foundation of Climatology, Surjeet Publications, Delhi, 1982.
9. **Trewartha G.T.** : An Introduction to Climate, International Studentsedition, McGraw Hill, New York, 1980.

UNIT - 2: HORIZONTAL AND VERTICAL DISTRIBUTION OF TEMPERATURE

Structure:

2.0 OBJECTIVES

After studying this unit, you will able to ;

- Provide better understanding of the distribution of temperature
- Identify an important element of our weather and climate.
- Know the climate in order to study the complex nature of climatic change.

2.1. INTRODUCTION

There are a number of factors that determine the horizontal distribution of temperature. There is a general decrease in temperature from the equator towards poles. The isotherms over certain part of the globe are closely spaced. While elsewhere they are widely spaced. There are other factors also affecting the distribution of the temperature like,

a) Differential heating of land and water

b) Effect of ocean currents

c) Mountain barriers.

The highest temperatures are found in the tropics and sub tropics which receive the largest amount of insolation all year round. On the contrary lowest average temperatures are recorded in the Polar regions.

Isotherms are the lines joining points of equal temperature. Global temperature patterns are shown with isothermal maps. Temperature maps are based on daily averages.

Isotherms while passing from the continents to oceans get distorted. The distortion is larger in the northern hemisphere due to the larger percentage of land surface. The coldest temperature in the winter and the highest temperature in the summer are found over continents. Since the temperature do not fluctuate as much over water as over land, the north south migration of isotherms is greater over continents than oceans, especially in the mid latitudes. The temperature gradient is very steep in the higher latitudes as well as along the eastern margins of the continents.

2.2. PROMINENT CONTROLS OF TEMPERATURE

Gross patterns of temperature are controlled largely by the following four factors:

Temperature responds sharply to altitudinal changes. Isotherms on world temperature maps have conspicuous east-west trend. If the earth had a uniform surface and did not rotate, isotherms probably would coincide exactly with parallels.

The fundamental cause of temperature variation world over is insolation, which is governed primarily by latitude. Summer temperatures are higher over the continents than over the oceans; the isotherms over the continents bend pole ward. Winter temperatures are lower over the continents than over the oceans; the isotherms over the continents bend equator ward. In both seasons isotherms make greater north-south shifts over land than over water. Regularity of isothermal pattern in the mid latitudes of the southern hemisphere is a manifestation of the fact that there is very little land. Isotherms in near-coastal areas of the oceans have prominent bends where warm or cool currents reinforce the land-water contrast. Cool currents deflect isotherms equator ward; warm currents deflect them pole ward. Cool currents produce the greatest isothermal bends in the warm season; warm currents in the cool season. Isotherms reflect the changing balance of insolation: moving northward from January to July and southward from July to January.

Isothermal shift is more pronounced in high latitudes than low latitudes and over continents than over the oceans. Temperature gradient is steeper in winter than in summer and over continents than oceans. The coldest places on Earth are over landmasses in high latitudes. For example Siberia, Canada, Greenland **in January** and Antarctica in **July**

The highest temperatures are found over the continents in subtropical latitudes where descending air maintains clear skies, not in equatorial regions where frequent cloudiness prevent highest temperatures.

For example, Northern Africa and southwestern Asia and North America in July, Australia, southern Africa, South America in January. Highest average annual temperatures are in equatorial regions because these regions experience so little winter cooling.

2.2.1. Average temperature range:

difference between the average temperatures of the warmest and coldest months are usually, but not always in July and January.

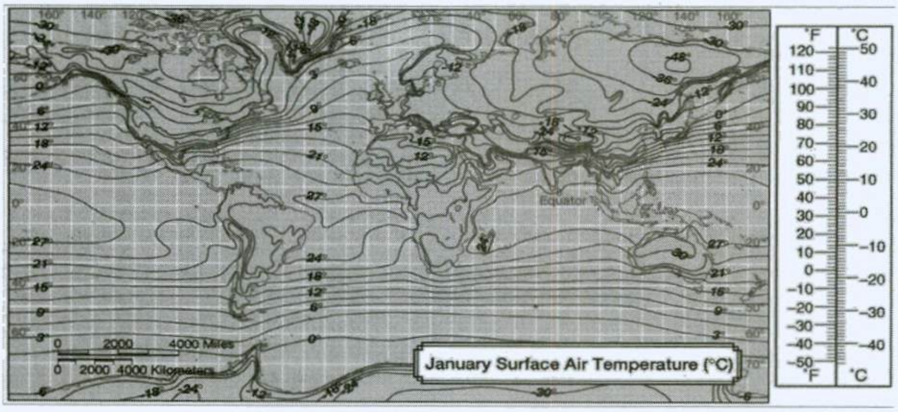
Largest annual temperature ranges occur in the interiors of high latitude continents. Annual temperature ranges in the tropics are very small

2.3. SEASONAL DISTRIBUTION OF TEMPERATURE

Since January and July represent the seasonal extremes, the horizontal distribution of temperature in these two months only is described.

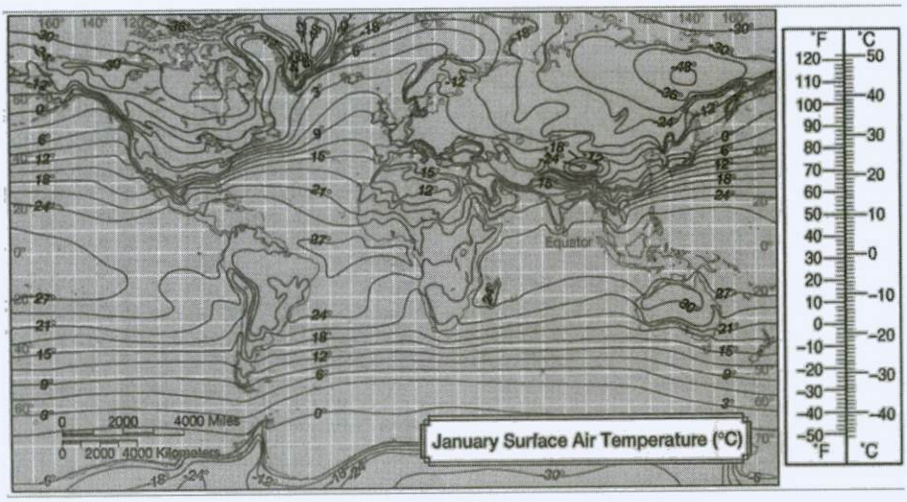
Distribution of temperature in January

Jan map



- Because of the presence of the more land surfaces in the Northern hemisphere the isotherms are more regularly and closely spaced.
- On the contrary, in the southern hemisphere (large water surface) the isotherms are relatively more symmetrical.
- The northern hemisphere has larger number of isothermal lines than in the southern hemisphere.
- Isotherms bend sharply in January towards the equator.
- In January the coldest place on the earth is found in the north eastern Siberia, and another coldest region lies in Green land.
- In the mid latitude the western costal regions of the continents are warmer because of the prevailing westerlies.
- In the Northern hemisphere the isotherms deflect more towards the pole, because of the warm current.
- There will be a larger contrast in temperature over continents and oceans in the NH

Distribution of temperature in July; July map



- Isotherms in July in NH are most irregular and zig zag. On the contrary, the isotherms in the SH are more regular and straight.
- High temperature is seen in N Africa through SW Asia to the North Western parts of US.
- In northern Hemisphere, the continents are much warmer than oceans.(cooler)
- There are less number of isotherms and they are widely spread in NH
- Isotherms over continents bend towards the North Pole and over oceans towards the equator.

2.4 ANNUAL RANGE OF TEMPERATURE

The difference between the warmest and the coldest monthly means is called the ATR.it varies from place to place. The following are the factors affect and control the range of temperature.

a) The latitudes

b) Height above the MSL

c) Ocean currents

d) Prevailing winds

e) Precipitation and cloudiness

f) Local relief

g) Distance from the sea.

2.4.1 Latitude

twice in a year the sun rays are vertical at the equator, thus the temperature is uniformly high in equatorial regions and **annual range of temperature** is negligible. But from the equator poleward there is a in temperature. It results in greater range of temperature. In Polar Regions the length of the day and night is 6 months, one should exp ect the highest range annual range of temperature. But due to the angle of incidence is low and most of the energy being reflected back, checks the rise in the temperature. But in mid latitudes where seasonal variation of temperature is greatest, the annual range of temperature is also greatest.

2.4.2 Height above the MSL

The **annual range of temperature** at a particular place is highly controlled by height. At high elevations the rarity of the air, large amount of precipitation and cloudiness combine together to lower down the average temperature. Thus, places situated at higher elevations have lower annual range of temperature.

2.4.3 Ocean currents

The warm ocean currents, prevailing winds help to raise the temperature of the adjoining regions. The effect of warm ocean currents is more pronounced in winter. Hence the annual range of temperature is relatively smaller.

2.4.4 Prevailing winds

Among all the factors that have controlling influence over the annual range of temperature the prevailing winds are the most important. Offshore winds bring about an increase in annual range of temperature of the adjacent land. Besides, the effect of ocean currents is largely determined by the prevailing winds. Hence the annual range of temperature is relatively low.

2.4.5 Precipitation and cloudiness

In those regions where the rains are more and the skies are covered with clouds, the summer temperatures are not allowed to fall much. Thus, the annual range of temperature is relatively low.

2.4.6 Local relief

Slope is one of the factors which affect the temperature of a place. Slopes facing the sun have higher temperature during summer months, and the slopes protected by the sun have lower temperature during winter. Thus, the local factors are also affects annual range of temperature.

2.4.7. Distance from the sea

water is heated or cooled in a longer period of time than land. Because of this characteristic of water, the coastal areas enjoy a moderate climate and the variations in temperature between warmest and coldest months are not very large. Increasing distance from the sea- coast, there is a corresponding increase in the seasonal variation of temperatures. Hence the annual range of temperature is very negligible.

2.5. VERTICAL DISTRIBUTION OF TEMPERATURE

As one moves from equator to poles, there is a steady decrease in temperatures are observed. In the same way there is a steady decrease in temperature with increasing elevation in the atmosphere. This decrease in temperature with increasing altitude is called vertical temperature gradient.

Various factors affecting the vertical temperature gradient interact in a complex manner. Energy transfers involve the latent heat of condensation, cooling of air by the process of radiation and heat transfer from the ground. High pressure systems descending of air which lead to warming of extensive layers of air results in the decrease of vertical temperature gradient. On the other hand low temperature systems give rise to ascending air currents increases the vertical temperature gradient. Moisture is said to be the additional factor which creates lot of complications in the vertical distribution of temperature.

2.6. LAPSE RATE

The vertical decrease in temperature is called the "Lapse rate". The lapse rate is not constant, but it varies with height, location and season. The vertical decrease in temperature continues to only up to the tropopause. Beyond which it stops. In tropical regions, where insolation is intense the lapse rate is generally high, up to 160 mts on most of the afternoons. The lapse rate may be steep or low depending upon the atmospheric conditions. Heating of the lower air is not due to the nearness of the earth surface, but at the lower level air is denser than the upper layer containing large quantity of water vapor and dust particles. On the contrary, the upper strata are dry fewer amounts of water vapor and CO2 are present. Upper air is more transparent, temperature is relatively low. Hence the temperature is low as we go away from the earth surface. Actual lapse rate and normal lapse rate is always different. Continents and oceans not only influence on the horizontal distribution, but also on the vertical distribution.

Under normal conditions the temperature decreases with altitude. But some times the temperature increases with the altitude. This phenomenon is known as temperature inversion.

During winter in Polar Regions layers of air close to the surface become so cold that up to a certain height the temperature increases with elevation. Out side the polar region, the inversion of temperature over continents is of common occurrence. But on oceans inversion of temperature occur in summer.

Another important feature of laps rate is that in tropical regions the decrease in temperature with elevation continues up to a height of 16 to 18 kms in the troposphere. In this zone the temperature at the outer boundary of the troposphere is reduced to -80° C, but in the Polar Regions the laps rate continues up to 6 kms. Beyond latitude 60°N and S the height of the troposphere is 10 kms in summer and 9 kms in winter. The height of the troposphere in higher latitudes is relatively less.

2.7 TEMPERATURE INVERSION

In the lower part of the atmosphere Up to the height of 8-10 kms from the earth surface the temperature normally decreases with increasing altitude (6.5°C per km). But some times under special circumstances it is reversed and the temperature instead of decreasing is found to increase with elevation. In other ward the temperature gradient is inverted. It is called inversion of temperature.

Temperature Inversion near the surface may be produced under the following conditions

- When there is a long clear winter nights-clear sky with high clouds, dry and calm air, the inversion of temperature occurs.
- When there is little wind movement near the ground or wind movement is too slow-little mixing of air, inversion takes place.
- In higher latitudes- snow covered areas- where solar radiation is reflected-loss of heat-air near the surface goes rapid cooling- temperature inversion develops.
- In polar regions temperature inversion is common- all the year round
- Snow covered land surfaces in temperate regions- witness temperature inversion at night in winter.
- Inversion layer in Polar Regions is thicker than middle latitudes.
- It is greater on the continent in winter- and on oceans in summer except in Arctic Ocean. During winter there is absence of temperature inversion.

Type of Inversion of temperature

- Radiation Inversion
- Subsidence Inversions
- Trade wind Inversion
- Frontal Inversion

2.7.1. Radiation Inversion:

The surface inversion produced by radiational cooling of lower air is called radiation inversion. Inversion layer develops at an altitude of about 90 mts. Since the land surface radiates more heat than the air, ground is cooled more rapidly than the air at a great height during night time with the result, the coldest air lies at the ground and is overlaid by warm air. The layer of air in close proximity to the earth's surface is cooled by the process of radiation and condensation more quickly than the upper layer of the air. Thus, at a certain height (90mts) the temperature increases with altitude. It continues up to 300 mts.

2.7.2. Subsidence Inversions:

Subsidence Inversions take place in valleys and mountains. When the air blows over the hills, it is heated as it is compressed into the side of the hills when that warm air comes over the top; it is warmer than the cooler air of the valley. Also, increasing the inversion, as the air comes over the top of the hill, it causes the air in the valley to be compressed, heating the cooler, and valley air from the top down. It is known as Subsidence Inversions.

2.7.3. Trade-wind inversion:

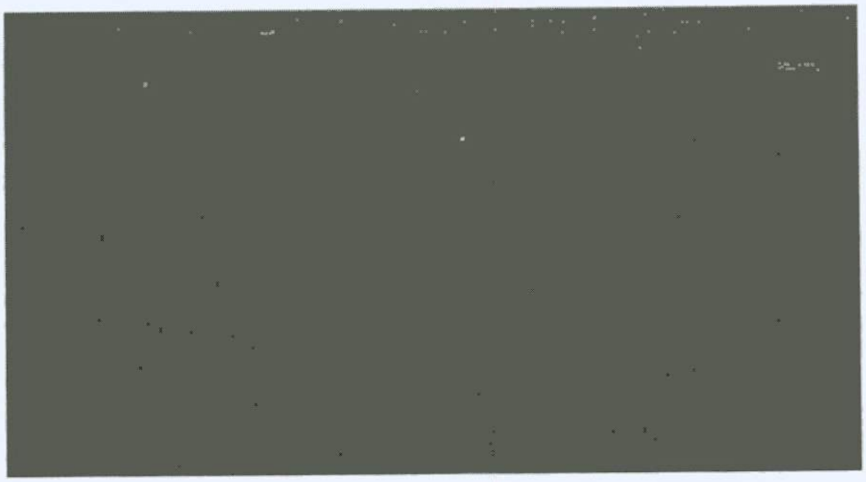
The temperature inversion usually present in the trade-wind streams over the eastern portions of the tropical oceans. In the equatorial zone and over the western portions of the trade-wind belt, the inversion does not exist as a mean condition, although it appears in certain weather patterns. The strength of the inversion varies enormously, occasionally being more than 10°C over 1 km, but sometimes being absent altogether, especially in the Northern Hemisphere. The inversion is generally strongest when the height of its base is lowest, and vice versa. The thickness of the inversion layer varies from only a few meters to more than 1000 meters and an average thickness of about 400 m.

2.7.4. Frontal Inversions

Frontal Inversions are inversions caused by a shallow "cold front" blowing in under warmer air. In other words, sometimes a bunch of cold air, called an air mass, will get blown by the wind from one place to another, warmer place, and will get blown underneath the warm air, causing an inversion. This is known as frontal inversion.

2.8. EFFECTS OF INVERSIONS

One of the most harmful effects of inversions is that they trap the pollution close to the ground, trapping the smog. In places like Los Angeles and Salt Lake City, this is a real problem because of all the emissions from vehicles, power plants, and other factories or heat sources add to the atmosphere. Besides, inversions also trap sound waves. Because of this, the loud sounds coming from airplanes while taking off will seem louder as the sound waves refract off the inversion layer and back down to the ground. But sound waves aren't the only thing that gets refracted by weather inversions, light can be bent by the inconsistency of the temperature.



2.9. LET US SUM UP

Sun is a primary source of heat but it is not the rays of the sun which directly heat the air. A considerable portion of heat and light is absorbed by atmosphere but the increase of temperature is small due to the great mass of air. The earth emits infra-red rays after receiving the heat energy from the sun. Consequently the air absorbs a larger proportion of heat radiated out from the earth. Normally the temperature goes on declining as we proceed higher up from the sea level. But under special circumstances, there is an increase in temperature with an increase in elevation. This state of affairs is known as temperature inversion. The isotherms near the Equator bend pole-wards over the land, equator-wards over the sea, towards the poles the bends are in the opposite direction. The horizontal distribution of temperature depends on insolation, High pressure systems descending of air which lead to warming of extensive layers of air results in the decrease of vertical temperature gradient. On the other hand low temperature systems give rise to ascending air currents increases the vertical temperature gradient.

2.10. KEY WORDS

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

2.11. QUESTIONS FOR SELF STUDY

1. Explain the factors affecting the distribution of temperature
2. Explain the reasons for the seasonal variation of temperature
3. What is temperature inversion? Explain why inversion of temperature takes place.
4. Discuss the type of inversion of temperature
5. Discuss the impact of temperature inversions on climate.

2.12. FURTHER READINGS

1. **Barry R.G. & Chorley R.J.** : "Atmosphere, Weather and Climate", Routledge, 1998.
2. **Critchfield H** : "General Climatology" Prentice-Hall, New York, 1975.
3. **Das P.K.** : The Monsoons, National Book Trust, New Delhi, 1968.
4. **Lal D.S** : "Physical Geography"Sharada Pustak Bhavan, Allahabad, 2009
5. **Lydolph Paul E** : The Climate of the Earth, Rowman and Allanheld, Totowa, N.J., 1985.
6. **Mather J.R** : Climatology, McGraw-Hill, New York, 1974.
7. **Patterson S** : Introduction of Meteorology, McGraw-Hill Book Co., London, 1969.
8. **Stringer E.T.** : Foundation of Climatology, Surjeet Publications, Delhi,1982.
9. **Trewartha G.T** : An Introduction to Climate, International Students edition, McGraw Hill, New York, 1980.

UNIT-3 :   HEAT BUDGET

Structure:

3.0 OBJECTIVES

After studying this unit, you will be able to ;

- Identify the continuously receiving electro magnetic
- To know the Energy from the Sun reaching the Earth drives almost every known physical and biological cycle in the Earth system.
- To know the solar radiation calculations and examining radiation measurements,
- Better understanding of many physical cycles and concepts associated with the Earth system.

3.1 INTRODUCTION

Absorption and re-emission of radiation at the earth's surface is only one part of an intricate web of heat transfer in the earth's planetary domain. Equally important are selective absorption and emission of radiation from molecules in the atmosphere. If the earth did not have an atmosphere, surface temperatures would be too cold to sustain life. If too many gases which absorb and emit infrared radiation were present in the atmosphere, surface temperatures would be to the earth's surface, atmosphere, and clouds emit radiation in the infrared band and near-infrared band. Outgoing infrared (IR) radiation from the earth's surface (also called terrestrial radiation) is selectively absorbed by certain molecules, particularly water vapor and carbon dioxide. Gases which absorb IR radiation are termed collectively as "greenhouse gases". Water vapor and carbon dioxide emit infrared radiation. Infrared radiation from greenhouse gases in the atmosphere is emitted in all directions, including back to the earth's surface. It is this re-emission to the earth's surface that maintains a higher temperature on our planet than what would be possible without the atmosphere. Condensed water is also an efficient absorber and emitter of IR radiation. Thus, clouds act in a manner similar to greenhouse gases.

Satellite infrared imagery detects infrared emission from clouds and the When averaged over a year, the incoming energy in both the earth and its atmosphere equals the outgoing energy.

If we consider the entire Earth-atmosphere system, then the amount of radiation entering the system must equal to the amount leaving, or the system would continually heat or cool. Not all of this energy is radiative energy; some is sensible and latent heat. If we consider the atmosphere alone, we find that the atmosphere experiences radioactive cooling. The atmosphere is kept from a net cooling by the addition of energy by latent and sensible heating.

The atmosphere has a warming effect on Earth's surface - the "atmospheric greenhouse effect". If Earth had no atmosphere, the globally averaged surface temperature would be -18 degrees Celsius. Because Earth does have an atmosphere, the average surface temperature actually is 15 degrees Celsius.

The atmosphere acts as a greenhouse because of gases that selectively allow solar radiation to pass through but absorb and then re-emit terrestrial radiation. These gases are collectively called "greenhouse gases" and include water vapor, carbon dioxide, ozone, molecular oxygen, methane and nitrous oxide. These gases are selective as to which wavelengths they will absorb. For example, ozone absorbs shortwave ultraviolet radiation whereas water vapor absorbs infrared radiation more readily.

3.2. THE HEAT BUDGET

It has been clear that the earth has been continuously receiving solar energy in the form of short wave radiation, where it is converted in to heat by the process of absorption. Similarly, through long wave terrestrial radiation the earth sends the same amount of energy back to space. There exists a balance between them. In the absence of such a balance, the earth would be getting progressively warmer or colder. This balance between the amount of insolation received from the sun and out going terrestrial radiation is known as the earth's heat budget.

3.3. INCOMING ENERGY

The total flux of energy entering the Earth's atmosphere is estimated at 99.97% which is equal to174 petawatts or 340 W/m2

- **Solar radiation** (99.97%)
- This is equal to the product of the solar constant, about 1,366 watts per square metre, and the area of the Earth's disc as seen from the Sun, about 1.28 × 10^{14} square metres, averaged over the Earth's surface, which is four times larger.
- **Geothermal energy** (0.025%)
- This is produced by stored heat and heat produced by radioactive decay leaking out of the Earth's interior.
- **Tidal energy** (0.002%)
- This is produced by the interaction of the Earth's mass with the gravitational fields of other bodies such as the Moon and Sun.
- waste heat from fossil fuel consumption (about 0.007%).

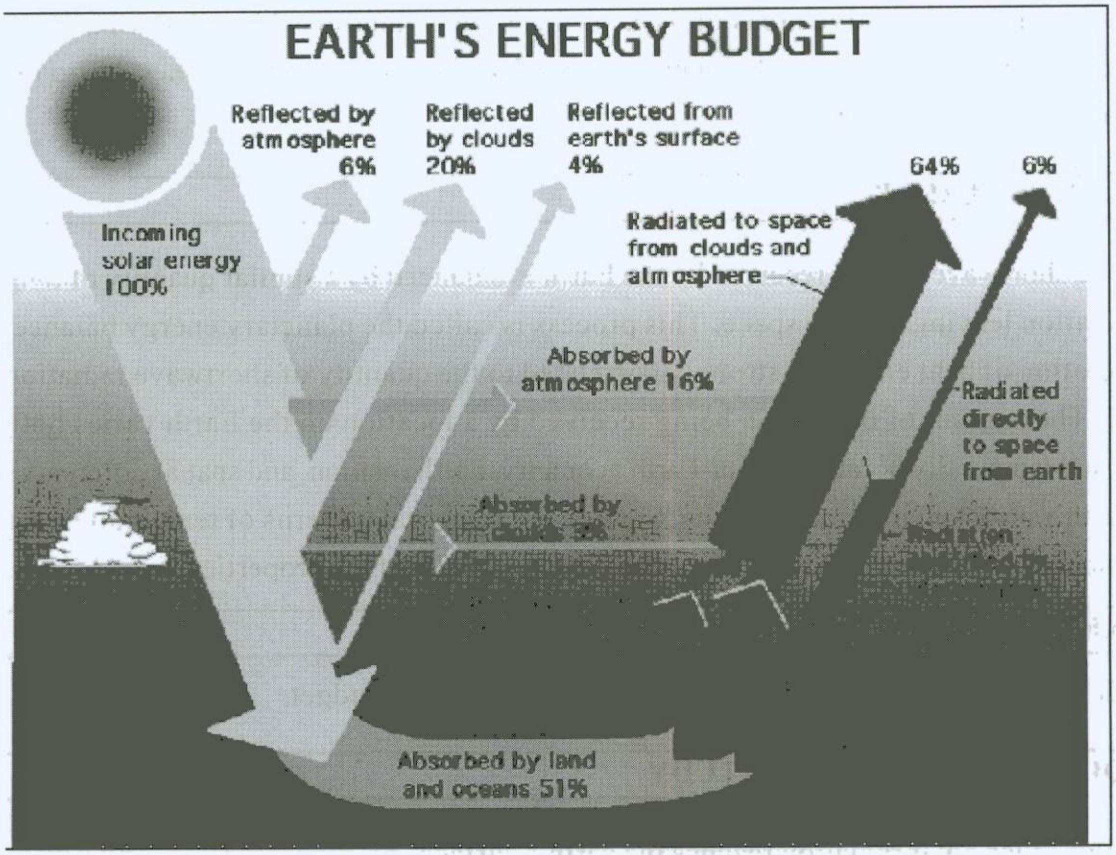
There are other minor sources of energy that are usually ignored in these calculations: accretion of interplanetary dust and solar wind, light from distant stars, the thermal radiation of space.

3.4 OUTGOING ENERGY

The average albedo (reflectivity) of the Earth is about 0.3, which means that 30% of the incident solar energy is reflected into space, while 70% is absorbed by the Earth and **reradiated** as infrared. The planet's albedo varies from month to month, but 0.3 is the average figure. It also varies very strongly spatially: polar ice sheets have a high albedo, low at oceans. The contributions from geothermal and tidal power sources are so small that they are omitted from the following calculations.

So 30% of the incident energy is **reflected**, consisting of:

- 6% reflected from the atmosphere
- 20% reflected from clouds
- 4% reflected from the ground (including land, water and ice) Earth's long wave thermal radiation intensity, from clouds, atmosphere and ground The remaining 70% of the incident energy is **absorbed**:
- 51% absorbed by land and water, then emerging in the following ways:
- 23% transferred back into the atmosphere as latent heat by the evaporation of water, called latent heat flux
- 7% transferred back into the atmosphere by heated rising air, called Sensible heat flux
- 6% radiated directly into space
- 15% transferred into the atmosphere by radiation, then reradiated into space
- 19% absorbed by the atmosphere and clouds, including:
- 16% reradiated into space
- 3% transferred to clouds, from where it is radiated back into space When the Earth is at thermal equilibrium, the same 70% that is absorbed is **reradiated**:
- 64% by the clouds and atmosphere
- 6% by the ground



In this way, the total incoming solar radiation is balanced by an equal amount of out going radiation.

3.5 GLOBAL TEMPERATURE VARIATIONS

The latitudes between 37 degrees North and 37 degrees South is called the heat surplus zone. This is the case because places in this region get the most amount of heat energy per unit area. Places in the heat deficit zones (such as the north and south poles) receive the same amount of energy however it has to be spread over a much larger area.

Height above sea level can also influence temperature. As the height above sea level increases, the temperature decreases. The technical term for this is the "environmental lapse rate", which refers to an average temperature drop of 6.5 degrees Celsius per 1000m above sea level. Most greenhouse gases are close to the earth's surface as this is where a lot of the heat is absorbed, while oceans tend to have a moderating effect on temperature (this is why cities right next to the coastline tend to stay a bit warmer at night, as the ocean allows the area to retain its warmth).

Urban areas with large areas of dark surfaces can sometimes be called urban heat islands, as they generally have higher temperatures than natural vegetation zones due to the higher rate of heat absorption.

3.6 LET US SUM UP

The shortwave energy received by the Earth is balanced by a similar quantity of long wave radiation leaving back to space. This process is called the planetary energy balance. The generation of heat energy is strongly correlated to the quantity of shortwave radiation received. The amount of insolation being received by a location on the Earth varies both spatially and temporally because of Sun-Earth geometry, Earth rotation, and spatial differences in the Earth's atmospheric transparency. Spatial and temporal patterns of temperature are also influenced by factors like altitude, ocean currents, and surface properties.

3.7 KEY WORDS

Hear balance of the earth, Heart budget, earth's energy budget.

3.8 QUESTIONS FOR SELF STUDY

1. How much solar radiation reaches the earth's surface. ?
3. What is the role of green house gases on the distribution of temperature?
4. How can the heat budget change?
5. Why there is an imbalance in heat budget in 37 degree N and S latitudes?
6. Give your understanding of "heat budget"

3.9 FURTHER READINGS

Climatology

1. Barry R.G. & Chorley R.J.: "Atmosphere, Weather and Climate", Routledge, 1998.

2. Critchfield H : "General Climatology" Prentice-Hall, New York, 1975.

3. Das P.K. : The Monsoons, National Book Trust, New Delhi, 1968.

4. Lal D.S : "Physical Geography"Sharada Pustak Bhavan, Allahabad, 2009

5. Lydolph, Paul, E. : The Climate of the Earth, Rowman and Allanheld, Totowa, N.J., 1985.

6. Mather, J.R. : Climatology, McGraw-Hill, New York, 1974.

7. Patterson, S. : Introduction of Meteorology, McGraw-Hill Book Co., London, 1969.

8. Stringer, E.T. : Foundation of Climatology, Surjeet Publications, Delhi, 1982.

9. Trewartha, G.T. : An Introduction to Climate, International Students edition, McGraw Hill, New York, 1980.

UNIT-4 : HORIZONTAL AND VERTICAL DISTRIBUTION OF PRESSURE AND PRESSURE BELTS STRUCTURE

Structure:

4.0 OBJECTIVES

After studying this unit, you will be able to

- Identify the most important elements of weather is pressure which is governed by the distribution of temperature.
- Explain the Air pressure and winds are invisible elements which influences other weather elements in a significant way.
- Know the distribution of pressure and pressure belt systems as they are most important in day today life and weather forecasting.

4.1 INTRODUCTION

Air pressure and winds are invisible elements which influences other weather elements in a significant way. Variations in air pressure from place to place are responsible for the movement of winds which serves as a means of transporting heat and moisture from one region to another. They also bring about changes in day today weather conditions. Besides, air pressure is all the more important in weather forecasting. Regional variation in pressure is produced by temperature. According to Triwartha, they are crucial to all life form- as it controls temperature and precipitation.

4.2 AIR PRESSURE

Like any other material object, air has weight. The mass of column of air above a given point determines the atmospheric pressure at that point. Air has a mixture of several gasses. The behavior of air pressure is depending on the behavior of gasses. The gas is kept in a closed container, the motion is restricted. The gas molecules always tend to hit the wall. Similarly land sea surface below and above by the force of gravity does not allow to escape. The amount of pressure exerted by air at a particular point is determined by two factors- temperature and density. If there is a change in temperature there will be a corresponding change in the pressure also.

The following equation, called "the gas law" describes the relationship between pressure, temperature and density.

- **Pressure=density X temperature X constant**

So, according to the gas law, an increase in either in density or temperature will cause an increase in pressure provided the other variable (temperature and density) remains constant.

The atmospheric pressure at sea level will be 1034 grams per sq cms. This amount of pressure is exerted by the atmosphere at sea level on all animals and objects. Man does not feel the weight of the atmosphere because the air inside him exerts an equal amount of outward pressure, balancing the inward pressure of atmosphere. But some times there will be physiological disturbances when one goes to the higher altitude.

4.3 MEASUREMENT OF AIR PRESSURE

The atmospheric pressure is measured most accurately with the help of mercurial barometer. Evangelista Torricelli, a student of Galileo developed the barometer.

The standard sea level pressure is given as 1013 mb at a temperature of 15 degree C and at latitude of 45 degree. This pressure is equivalent to 29.92 inches or 760 mm.

The mb is a force equal to 1,000 dynes per sq cm and a dyne is a unit of force app. weight of a milligram (mg)

4.4 PRESSURE RECORDING INSTRUMENTS

Besides mercurial barometer, there are other types of pressure recording instruments such as Aneroid barometer-altimeter-micro barometer which is very sensitive (even nuclear explosion). Standard pressure at sea level is 1013.25 mb, pressure changes from day today and time to time. In 1893, July 14, Siberia was recorded the highest pressure (1075.2 mb). The lowest of 877 mb was recorded at Mariana Islands.

4.5 PRESSURE GRADIENT

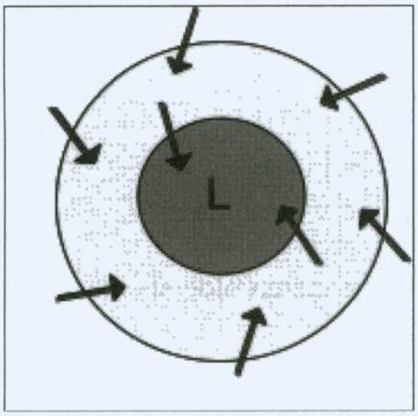
The decrease of pressure between two points along a line perpendicular to the isobars divided by the distance between the points is called the pressure gradient. In other words the pressure gradient is the rate of change of pressure per unit horizontal distances. Infact, it is the direction in which the change is most rapid. The rate and direction of change in air pressure is also known as barometric slope. It is expressed in mille bars per 100 kms. or per degree of latitude. A decrease of 34 mb in a horizontal distance of 24 km or a fall of 10 mb in 160 km signifies a steep pressure gradient. Close isobars represent steep pressure gradient and vise versa.

4.6 LOW PRESSURE SYSTEMS: CYCLONES

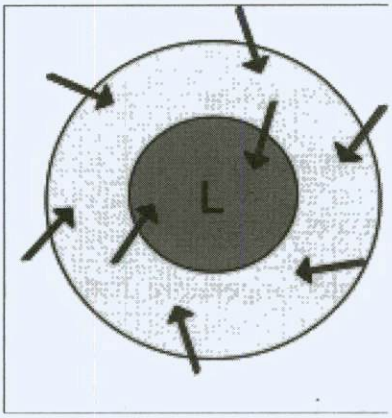
When the isobars are circular or elliptical in shape and the pressure is lowest at the center such a pressure system is called low or cyclones. A line of low pressure is called trough. Lowest pressure at the center, the wind from out side converges towards it.

According to Farrell's law the wind in the northern hemisphere are deflected towards right. So it is anti clock wise in the northern hemisphere. On the contrary it is clock in the southern hemisphere.

NORTHERN HEMISPHERE



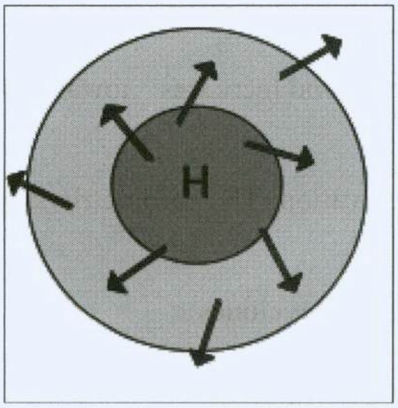
SOUTHERN HEMISPHERE



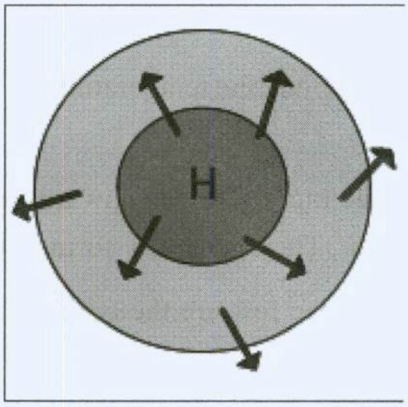
4.7 HIGH PRESSURE SYSTEM: ANTICYCLONE

In this system the High pressure is at the centre surrounded by low pressures. Centers of high pressure are called 'high' or anti cyclones. Therefore, in a 'high' the wind blow spiraling toward the outer margin. In an anti cyclone the direction of flow is clock wise in the northern hemisphere and anti clock wise in the southern hemisphere

NORTHERN HEMISPHERE



SOUTHERN HEMISPHERE



When the isobars are elliptical rather than circular, the system is called a ridge or a wedge of high pressure. Like cyclones the anti cyclones are also differ from one another in respect of their size, shape and character. Anti cyclones are larger than cyclones. The isobars are usually symmetrical (ac) and almost circular.

4.8 VERTICAL STRUCTURE OF CYCLONES AND ANTI CYCLONES

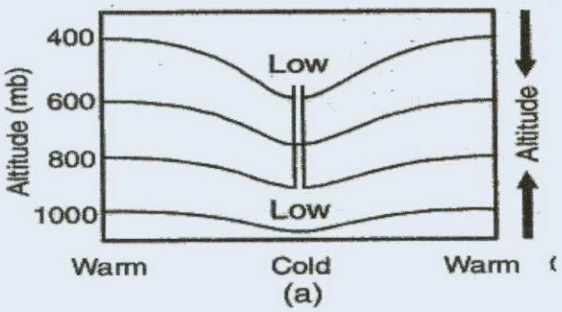
- Vertical distribution of a cyclone or anti cyclone depends on the temperature within it.

- **Cyclone and anti cyclones are classified as follows:**
  - Cold core cyclones
  - Warm core cyclone
  - Cold core anti cyclone
  - Warm core anti cyclone

The pressure and temperature distribution systems help the meteorologists in weather forecasting.

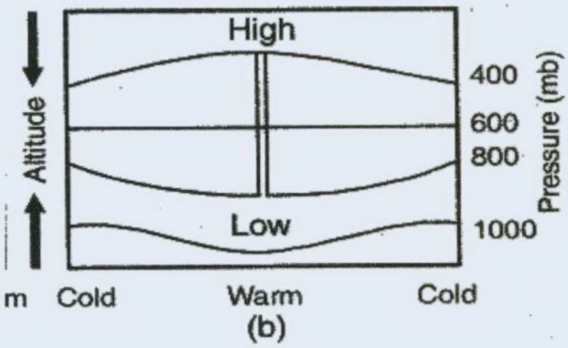
The following figures represent the cross sections of a cyclone and anti cyclones and their structures.

4.8.1 Cold core cyclones



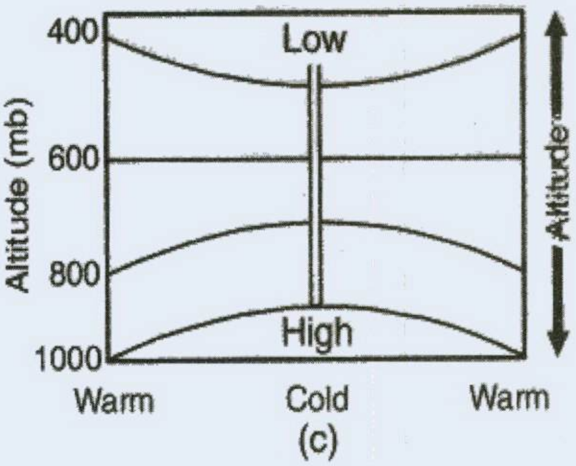
- In this type of cyclone the temperature is lowest at the center and increases towards the outer margin.
- Air registers the rapid changes upwards with increasing elevation. The barometric slope becomes steeper. They generally form in the upper layer.
- Icelandian, Aleutian low are the typical examples of cold-core cyclones

4.8.2. Warm core cyclon



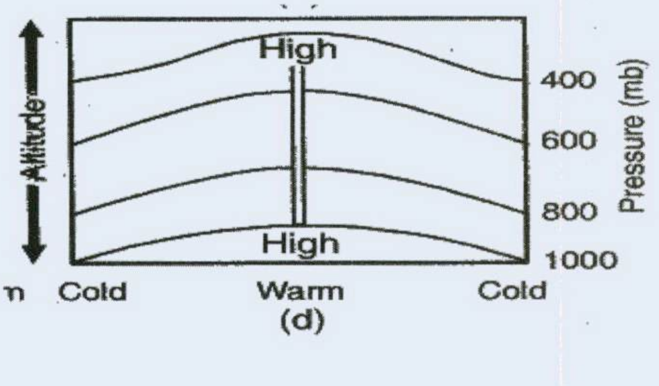
- Temperature is highest at the center and decreases towards the outer margins at the lower level. At the lower level the temperature is low and increases at the outer margins. Temperature increases with the altitude. Low turns in to high but decreases at the outer margins
- It originates at the desert regions- California, Arizona are the best examples of warm-core cyclones.

4.8.3 Cold core anti cyclone



- Cold core anticyclones have the "Low" at the center and up to certain height the temperature increases and at the top there exist the low temperature. But at the lower level the temperature is high at the center, decreases towards the outer margins.
- At the top, the temperature will be low at the center and increases towards the outer margins They originate on the arctic and Antarctic regions in winter.
- When they move towards the lower latitude they become warm core anticyclones.

4.8.4. Warm core anti cyclone



Highest temperature is observed at the center. Temperature gradually decreases from the center towards outer margins. Vertical temperature increases with altitude. Anticyclone of tropical regions generally of this type. Eastern US, south California-during summer are the good examples.

4.9 HORIZONTAL DISTRIBUTION OF PRESSURE

Horizontal distribution of pressure is shown by means of isobars. Isobars are lines drawn through points of equal pressure. Factors which contribute the distribution of temperature govern the distribution of pressure as well. There is a close relationship between pressure and temperature, since there is a great variation in the amount of insolation received at different places, there is a corresponding variation in the temperature also.

4.10 DISTRIBUTION OF PRESSURE PATTERN

Air rising near the equator moves towards poles in the upper atmosphere turned aside. The result is that not all the air rising from equator goes to the poles. They settle down in subtropical regions. Their subsiding air currents create subtropical high pressure between 25 and 35 deg N&S latitudes.

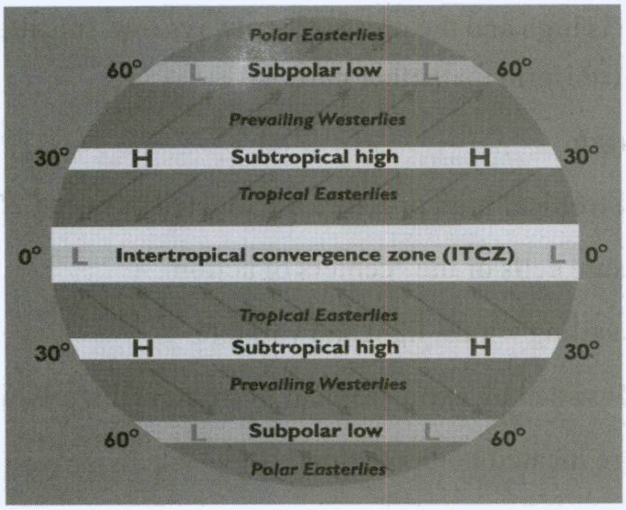
There are two factors to be considered:

Rising air currents move away from the equatorial region, they release latent heat keeps them warm. But radiational cooling results in their increased density in the upper atmosphere. Coriolis force gets stronger, the polar ward winds are deflected nearly W to E near 25°N and S lat. Because the subsiding air currents are relatively drier the weather in this zone remains dry. Because subsiding air current are relatively drier, and the relative humidity of the descending air is further reduced by the effect of adiabatic heating. That's why all the deserts of the world are situated in the sub tropical high belts.

Pole ward of the sub tropical HIGH pressure belts in both the hemisphere are large and when they move towards 50-65 ° latitude, they become subtropical LOW pressure belts. This region where cold polar winds and warmer west winds clash called POLAR FRONT.

4.11. THE PRESSURE BELTS

- **There are seven alternating low and high pressure belts**



1. Equatorial low pressure belt
2. Subtropical high (N Hemisphere)
3. Subtropical high (S Hemisphere)
4. Sub Polar Low (N Hemisphere)
5. Sub Polar Low (S Hemisphere)
6. Polar high (N Hemisphere)
7. Polar high (S Hemisphere)

4.11.1 Equatorial low pressure belt

- This belt lies between 5°N and 5 °S lat.
- The average pressure in this belt is less than 1013 mb
- Since the max insolation is available in the equatorial region, the intensity of heating is more at the lower layers
- The heated air expands becomes lighter and rises upward. These convectional currents are set up in the atmosphere through out the year.
- In the equatorial low pressure belt the air is warmer and moist.
- This is the zone of convergence. The winds are lighter and variable and calm. That's why it is called doldrums

- During July the low pressure belt extends up to 20°N lat in the January it migrates to the south of the equator.
- The temperature is high and the pressure is always low. It is thermally produced. The pressure is more uniform than other parts.

4.11. 2. Subtropical high

- The areas of sub tropical high pressure are located between 25-35°N&S lat.
- These high pressure cells or the "centers of action"
- There are no prevailing winds, light and variable
- These belts are Invaded by extra-tropical or tropical disturbances
- All the deserts are located in this region.
- These high pressure belts are also called as " horse latitudes"

4.11. 3. Sub Polar Low

- Sub polar belts are located between 60-70°N&S lat.
- Vast expanse of ocean in the SH
- Vast expanse of land in the NH (cold and dry)
- Pressures over these land masses are increased.
- During winter, there is a great contrast between temperatures of the oceans and continents.
- In summer the temperature contrast between the continents and oceans is much reduced,

4.11. 4. Polar high

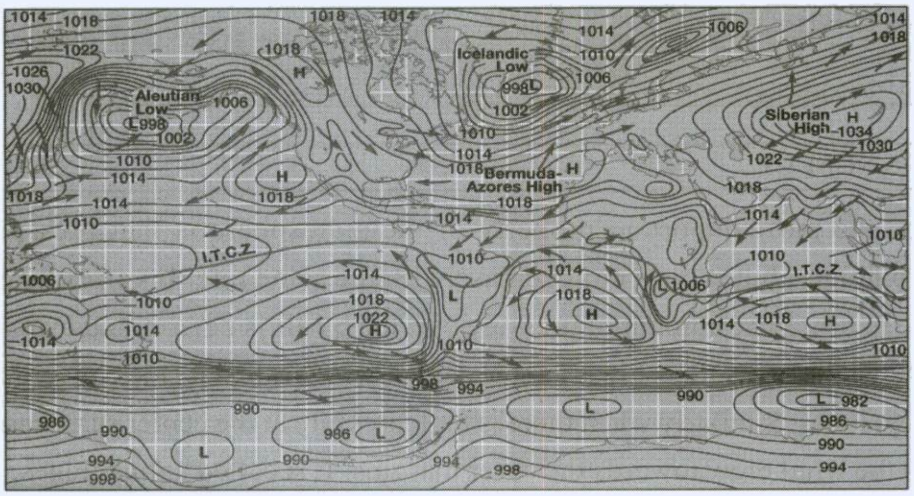
- Pressures at the poles are constantly high through out the year.
- In NH the high pressure areas is not centered at the pole but near the Green land and Canada
- In the southern hemisphere – Antarctica is the high pressure belt
- Thermal factors are more important than dynamic factor

Seasonal variations in the pressure patterns in January Fig.1

- Seasonal variations in the general patterns of surface pressure are represented in the following figures. Fig.1 represents the pressure distribution in general

- Because of the apparent movement of the sun towards the tropic of Capricorn the equatorial low pressure is displaced to the south of the equator
- January being one of the summer months in the southern hemisphere, the continents of Australia, Africa, South America are relatively warmer and their exist low pressure belts
- The sub-tropical belt of the high pressure in the northern hemisphere is located well to the north. The high pressure exists over North America and Eurasia. Siberia becomes the coldest regions on the earth with highest pressure.
- During summer the subtropical belt lies at 30-40 souths, over Pacific, Atlantic and Indian Oceans.
- There are two low pressure cells found over the north Atlantic and North Pacific oceans. There are Islandic low and Aleutian low respectively.

Fig. 1 DISTRIBUTION PATTERN OF PRESSURE IN JANUARY

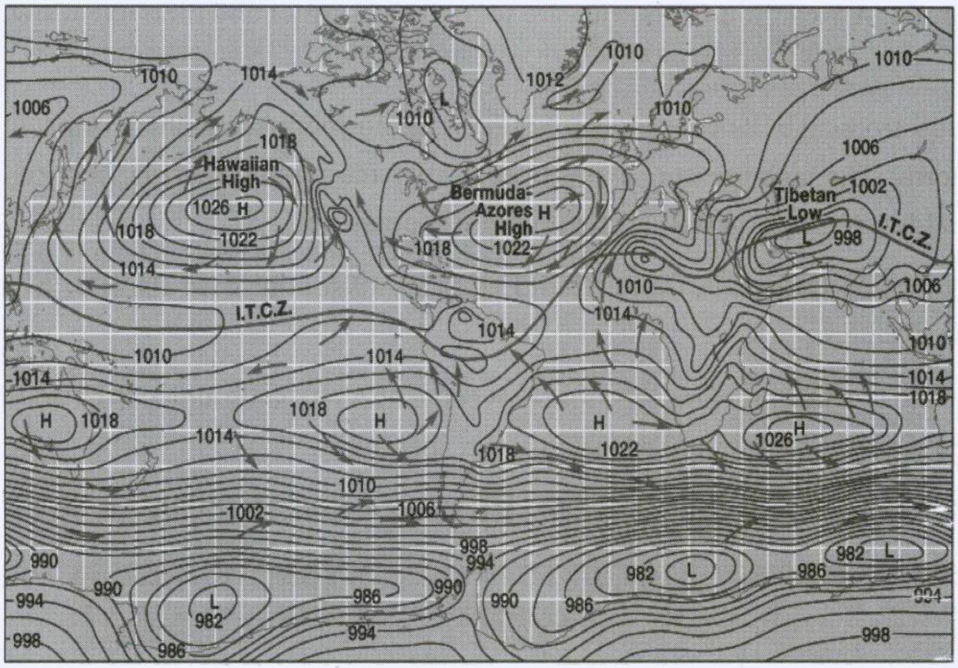


Distribution pattern in July Fig.2

This is the period of summer in the northern hemisphere. Because of the apparent movement of the sun towards the Tropic of Cancer, all pressure belts shift towards the north. Therefore the equatorial trough of low pressure also is located well to the north of equator, especially over the warm land areas of the northern hemisphere. The heat lows are conspicuous over the South west U.S. and over India, Asia Minor and North Africa.

In Northern hemisphere, the well developed high pressure cells found over the north Atlantic north Pacific oceans. There is a high pressure cell established over the continent of Australia. But in the northern hemisphere the sub polar and equatorial low pressure belts merge over the continents. However the sub-polar low pressure belt persists a small degree over the oceans.

Fig.2 DISTRIBUTION PATTERN OF PRESSURE IN JULY



4.12. LET US SUM UP

Perhaps the most important property of the atmosphere is that pressure always decreases with height, but it does not decrease with the same rate. It varies from place to place and time to time. The amount of pressure exerted by air is determined by temperature and density. When the pressure is lowest at the center, wind from out side converges towards it. It is called cyclones. Similarly when there is high pressure at the center surrounded by low pressure areas the wind blow towards the outer margins. It is called anticyclones. There is a vertical variation in the distribution of temperature amongst these cyclones. There is a latitudinal variation in pressure also. The pressure at the poles is constantly high where as in the equatorial regions there exists the low pressure belt.

4.13. KEY WORDS

Vertical and horizontal distribution of pressure, pressure belts

4.14. QUESTIONS FOR SELF STUDY

1. What is pressure gradient? Explain how they are helpful in weather forecasting.
2. Bring out the difference between cyclones and anticyclones with a diagram

3. Write a note on the classification of cyclones.
4. Explain the seasonal variation of pressure patterns over the globe in January
5. Discuss various types of winds and explain how they are important in modifying the climate of a region.

4.15. FURTHER READINGS

1. Barry R.G. & Chorley R.J. : "Atmosphere, Weather and Climate", Routledge, 1998

2. Critchfield H : "General Climatology" Prentice-Hall, New York, 1975.

3. Das P.K : The Monsoons, National Book Trust, New Delhi, 1968.

4. Lal D.S : "Physical Geography"Sharada Pustak Bhavan, Allahabad, 2009

5. Lydolph Paul E : The Climate of the Earth, Rowman and Allanheld, Totowa, N.J., 1985.

6. Mather J.R. : Climatology, McGraw-Hill, New York, 1974.

7. Patterson S : Introduction of Meteorology, McGraw-Hill Book Co., London, 1969.

8. Stringer E.T : Foundation of Climatology, Surjeet Publications, Delhi, 1982.

9. Trewartha G.T. : An Introduction to Climate, International Students edition, McGraw Hill, New York, 1980.

UNIT-5 : CELL MODELS: HADLEY MODELS

Structure :

5.0. OBJECTIVES

After studying this unit, you will be able to ;

- Understanding of the general circulation of the atmosphere and climate
- Learn about the global-scale motion system on Earth and how it divides the planet into different zones.
- Know that the atmospheric general circulation and climate have undergone very large fluctuations.

5.1. INTRODUCTION

Atmospheric Circulation

One way to accomplish the transfer of heat from the equator to the poles would be to have a single circulation cell that was upward in the tropics, poleward aloft, downward at the poles, and equatorward at the surface. This is the single-cell circulation model first proposed by Hadley in the 1700's. Since the earth rotates, the axis is tilted, and there is more land mass in the northern hemisphere than in the southern hemisphere, the actual global pattern is much more complicated. Instead of a single-cell circulation the global circulation model consists of three cells for both N and S hemispheres. These three cells are the tropical cell (also called a Hadley cell), the midlatitude cell and the polar cell.

Global Atmospheric Circulation

The sun heats the entire Earth, but there is an uneven distribution of heat across the Earth's surface: equatorial and tropical regions receive far more solar energy than the midlatitudes and Polar Regions.

The radiation received by the tropics is more than they can emit, while the Polar regions emit more radiation than they receive. If there were no heat transferred between the tropics and the Polar Regions, the tropics would get hotter and hotter, while the poles would get colder and colder. This latitudinal heat imbalance is what drives the circulation of the atmosphere and oceans: the heat energy is redistributed from warmer to colder areas by means of atmospheric air circulation.

It is in fact varying amount of insolation received at the earth's surface brings about the differential heating of the earth. The temperature differences thus produced accounts for the density differences that drive the atmosphere in 3D motion on global scale. Required amount of energy to maintain the global circulation comes from the sea through the process of evaporation. The general circulation of atmosphere depends on many factors some of which are external to the earth. For example, the distribution pattern of temperature, pressure and resultant winds depends basically on the distribution of insolation. This is in turn depending upon the insolation. Tropical regions receive large amount of insolation than temperate and colder regions of the higher latitude. Thus there is a latitudinal imbalance of heat budget. Wind tries to balance out the uneven distribution of temperature. Wind also carries water vapor from water to land surfaces.

Wind movement in the atmosphere may be classified in to 3 categories: Primary circulation, Secondary circulation, Tertiary circulation. Primary wind circulation includes planetary wind systems which are related to general arrangements of pressure belts. Trade winds, westerlies and polar easterlies are the Primary circulations. Secondary circulations consist of cyclones, anti cyclones, monsoons and air masses. Tertiary circulations include all local winds, produced by local causes which affect the weather and climate of a particular area.

5.2. THERMAL CIRCULATION ON A ROTATING EARTH

The coriolis force deflects any mass of moving air to the right in the northern hemisphere and to the left in the southern hemisphere. Therefore any air which starts to move directly southward from the polar regions towards the low latitudes as a north wind would become a north-east wind. Similarly in the southern hemisphere wind becomes south-easterly in direction. There are seven alternating belts of high & low pressure belts, but the general circulation is divided in to three distinct zones in each hemisphere. In these belts the atmospheric motion are almost parallel to the circles of latitudes. The winds in these latitudinal belts blow either from east to west or from east to west. Therefore the general circulation pattern is rather zonal than meridional in character.

The following wind belts are found on each hemisphere.

1) Doldrums
2) Trade wind belts
3) Prevailing westerlies
4) Polar easterlies

1) Doldrums

Doldrums are the equatorial belt of calm and variable winds lying over the equator of low pressure between 5° N and 5 ° S latitudes. It lies between two trade winds (NE &SE)

There is no strong pressure gradient, the wind is light and variable. In the late afternoon, there is strong convection which brings about heavy thundershowers. Since this zone is in the meeting place of the two trade winds, it is also called as "inter tropical convergence zone" (ITCZ)

2) Trade wind belt

On both side of the equatorial trough of low pressure lie the trade wind belts extending roughly from 5 to 30 ° of latitude. Here surface wind flow is equator ward. – and the flow in upper troposphere is –polar ward. The trade wind originates because of the pressure gradients from the Subtropical high to equatorial low pressure. In the northern hemisphere prevailing winds are NORTH EASTERLY and are called North East trade winds. In the southern hemisphere the prevailing winds moving equator ward are SOUTH EASTERLY and are termed as south east trade winds. The zone of trade winds is also called the HADLEY CELL. The energy to drive this cell is to come from the latent heat released during the formation of cumulonimbus clouds in the equatorial region. The pole ward movement of winds in the upper troposphere subsides in a zone between 20°-35° latitude. It becomes cold and heavy. The coriolis force becomes stronger with increasing distance from the equator. By the time it reaches the latitude of 20°-35° it would have released much of its moisture in the equatorial region itself in the form of precipitation. This is why all the tropical deserts of the world are located in this zone. This zone of descending air is particularly known as the HOURSE LATITUDE

3) Prevailing Westerlies

The belt of prevailing westerlies lies between 30 ° -60° N & S latitudes. These are the winds move from the pole ward margins of subtropical high pressure belts. The winds that move towards higher latitudes are deflected and become south westerly and the north westerly in the northern and southern hemisphere respectively. The prevailing westerlies of the mid latitudes are relatively more variable than the trade winds both in direction and intensity. In the northern hemisphere due to the presence of high mountains and plateaus the westerly flow is obscured. But in the southern hemisphere where there is preponderance of water, the westerlies are stronger, retaining their character.

Westerlies blow through out the year, but stronger in cold seasons particularly in the North Atlantic and north Pacific. This is because of the steep pressure gradient from the Aleutian and Icelandic low pressure areas towards the extremely cold continental interiors during winter.

4) Polar easterlies

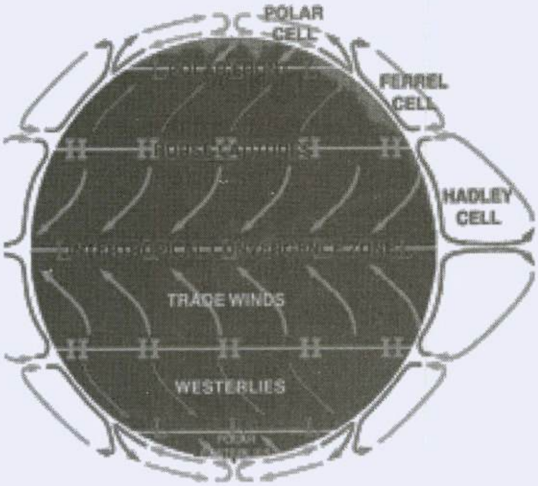
The polar easterlies the winds are those winds that move out of the polar high towards sub polar low pressure belt. There are no regular winds blowing from the north Polar Regions. The winds in Polar Regions are largely controlled by the local weather disturbances. In southern hemisphere polar easterlies are more coherent and well defined. We know a very little about the atmospheric motion in higher latitudes. Our knowledge is only and hardly extends beyond 70 ° - 75 ° N and 60 °S latitudes because of the lack of information,

5.3. ATMOSPHERIC CIRCULATION

Atmospheric circulation is the large-scale movement of air, and the means by which thermal energy is distributed on the surface of the Earth.

The large-scale structure of the atmospheric circulation varies from year to year, but the basic climatological structure remains fairly constant. Individual weather systems - mid-latitude depressions or tropical convective cells - occur "randomly", and it is accepted that weather cannot be predicted beyond a fairly short limit: perhaps a month in theory, or (currently) about ten days in practice. Nonetheless, as the climate is the average of these systems and patterns - where and when they tend to occur again and again -, it is stable over longer periods of time.

As a rule, the "cells" of Earth's atmosphere shift polewards in warmer climates, but remain largely constant even due to continental drift; they are, fundamentally, a property of the Earth's size, rotation rate, heating and atmospheric depth, all of which change little. Tectonic uplift can significantly alter major elements of it, however - for example the jet stream -, and plate tectonics shift ocean currents. In the extremely hot climates of the Mesozoic, indications of a third desert belt at the Equator has been found; it was perhaps caused by convection. But even then, the overall latitudinal pattern of Earth's climate was not much different from the one today.



5.4. LATITUDINAL CIRCULATION FEATURE

The wind belts girdling the planet are organized into three cells: the Hadley cell, the Ferrel cell, and the Polar cell. Contrary to the impression given in the simplified diagram, the vast bulk of the vertical motion occurs in the Hadley cell; the explanations of the other two cells are complex. Note that there is one discrete Hadley cell that may split, shift and merge in a complicated process over time. Low and high pressures on earth's surface are balanced by opposite relative pressures in the upper troposphere.

5.5. LONGITUDINAL CIRCULATION FEATURES

While the Hadley, Ferrel, and Polar cells are major factors in global heat transport, they do not act alone. Disparities in temperature also drive a set of longitudinal circulation cells, and the overall atmospheric motion is known as the zonal overturning circulation.

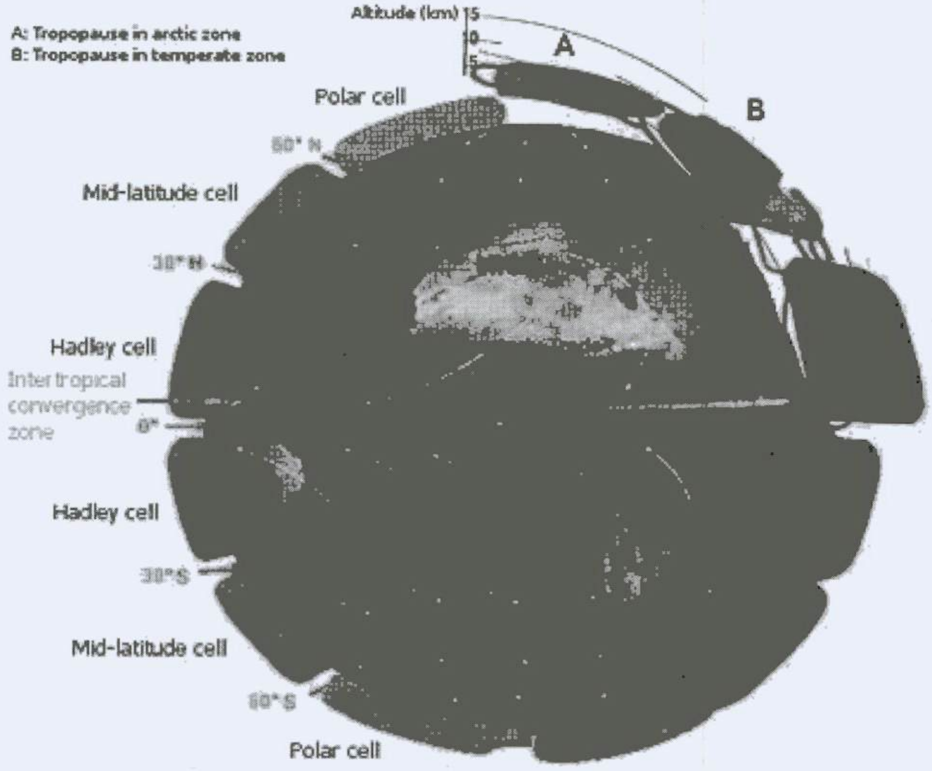
Latitudinal circulation is the consequence of the fact that incident solar radiation per unit area is highest at the heat equator, and decreases as the latitude increases, reaching its minimum at the poles. Longitudinal circulation, on the other hand, comes about because water has a higher specific heat capacity than land and thereby absorbs and releases more heat, but the temperature changes less than land. Even at mesoscales (a horizontal range of 5 to several hundred kilometers), this effect is noticeable; it is what brings the sea breeze, air cooled by the water, ashore in the day, and carries the land breeze, air cooled by contact with the ground, out to sea during the night.

On a larger scale, this effect ceases to be diurnal (daily), and instead is seasonal or even decadal in its effects. Warm air rises over the equatorial, continental, and western Pacific Ocean regions, flows eastward or westward, depending on its location, when it reaches the tropopause, and subsides in the Atlantic and Indian Oceans, and in the eastern Pacific. The Pacific Ocean cell plays a particularly important role in Earth's weather. This entirely ocean-based cell comes about as the result of a marked difference in the surface temperatures of the western and eastern Pacific. Under ordinary circumstances, the western Pacific waters are warm and the eastern waters are cool. The process begins when strong convective activity over equatorial East Asia and subsiding cool air off South America's west coast creates a wind pattern which pushes Pacific water westward and piles it up in the western Pacific. (Water levels in the western Pacific are about 60 cm higher than in the eastern Pacific, a difference due entirely to the force of moving air.)

5.6. HADLEY CELL

The Hadley cell is an atmospheric circulation pattern in the tropics that produces winds called the tropical easterlies and the trade winds. In the Hadley cell, air rises up into the atmosphere at or near the equator, flows toward the poles above the surface of the Earth, returns to the Earth's surface in the subtropics, and flows back towards the equator.

This flow of air occurs because the Sun heats air at the Earth's surface near the equator. The warm air rises, creating a band of pressure at the equator. Once the rising air reaches the top of the troposphere at approximately 10-15 kilometers above the Earth's surface, the air flows toward the north and south poles. The Hadley cell eventually returns air to the surface of the Earth in the subtropics, near 30 degrees north or south latitude.



The air near the surface flows toward the equator into the low pressure area replacing the rising air. This area of low pressure and converging winds (air flowing together) is called the Intertropical Convergence Zone (ITCZ). These winds are turned toward the west by the Coriolis effect and become the trade winds or the tropical easterlies.

The air that returns back to the surface of the Earth in the subtropics produces a band of high pressure called the subtropical high. Once the air reaches the surface, some air flows toward the equator from the subtropical high to the lower pressure in the ITCZ to become part of the trade winds.

The Hadley cell mechanism is well understood. The atmospheric circulation pattern that George Hadley described to provide an explanation for the trade winds matches observations very well. It is a closed circulation loop, which begins at the equator with warm, moist air lifted aloft in equatorial low pressure areas (the Intertropical Convergence Zone, ITCZ) to the tropopause and carried poleward. At about 30°N/S latitude, it descends in a high pressure area. Some of the descending air travels equatorially along the surface, closing the loop of the Hadley cell and creating the Trade Winds.

5.7 POLAR CELL

The Polar cell is likewise a simple system. Though cool and dry relative to equatorial air, air masses at the 60th parallel are still sufficiently warm and moist to undergo convection and drive a thermal loop. Air circulates within the troposphere; limited vertically by the tropopause at about 8 km. Warm air rises at lower latitudes and moves poleward through the upper troposphere at both the north and south poles. When the air reaches the polar areas, it has cooled considerably, and descends as a cold, dry high pressure area, moving away from the pole along the surface but twisting westward as a result of the Coriolis effect to produce the Polar easterlies.

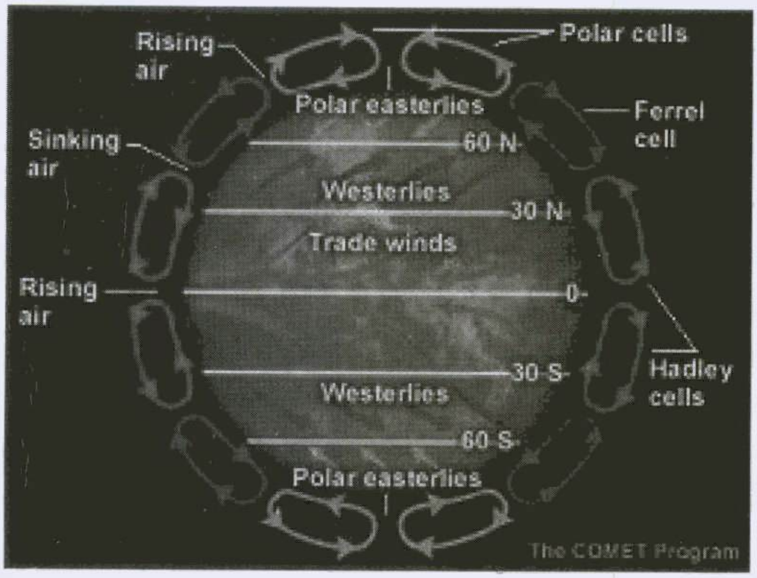
The outflow from the cell creates harmonic waves in the atmosphere known as Rossby waves. These ultra-long waves play an important role in determining the path of the jet stream, which travels within the transitional zone between the tropopause and the Ferrel cell. By acting as a heat sink, the Polar cell also balances the Hadley cell in the Earth's energy equation.

It can be argued that the Polar cell is the primary weather maker for regions above the middle northern latitudes. While Canadians and Europeans may have to deal with occasional heavy summer storms, there is nothing like a winter visit from a Siberian high to give one a true appreciation of real cold. In fact, it is the polar high which is responsible for generating the coldest temperature recorded on Earth: -89.2°C at Vostok Station in 1983 in Antarctica.

The Hadley cell and the Polar cell are similar in that they are thermally direct; in other words, they exist as a direct consequence of surface temperatures; their thermal characteristics override the effects of weather in their domain. The sheer volume of energy the Hadley cell transports, and the depth of the heat sink that is the Polar cell, ensures that the effects of transient weather phenomena are not only not felt by the system as a whole, but — except under unusual circumstances — are not even permitted to form. The endless chain of passing highs and lows which is part of everyday life for mid-latitude dwellers is unknown above the

60th and below the 30th parallels. There are some notable exceptions to this rule. In Europe, unstable weather extends to at least 70° north.

These atmospheric features are also stable, so even though they may strengthen or weaken regionally or over time, they do not vanish entirely.



5.8. FERREL CELL

Ferrel cell, model of the mid-latitude segment of the Earth's wind circulation, proposed by William Ferrel (1856). In the Ferrel cell, air flows poleward and eastward near the surface and equatorward and westward at higher altitudes; this movement is the reverse of the airflow in the Hadley cell. Ferrel's model was the first to account for the westerly winds between latitudes 35° and 60° in both hemispheres. The Ferrel cell, however, is still not a good representation of reality because it requires that the upper-level mid-latitude winds flow westward; actually the eastward-flowing surface winds become stronger with height and reach their maximum velocities around the 10-kilometre level in the jet streams.

The Ferrel cell, theorized by William Ferrel (1817-1891), is a secondary circulation feature, dependent for its existence upon the Hadley cell and the Polar cell. It behaves much as an atmospheric ball bearing between the Hadley cell and the Polar cell, and comes about as a result of the eddy circulations (the high and low pressure areas) of the mid-latitudes. For this reason it is sometimes known as the "zone of mixing." At its southern extent (in the Northern hemisphere), it overrides the Hadley cell, and at its northern extent, it overrides the

Polar cell. Just as the Trade Winds can be found below the Hadley cell, the Westerlies can be found beneath the Ferrel cell. Thus, strong high pressure areas which divert the prevailing westerlies, such as a Siberian high (which could be considered an extension of the Arctic high), could be said to override the Ferrel cell, making it discontinuous.

While the Hadley and Polar cells are truly closed loops, the Ferrel cell is not, and the telling point is in the Westerlies, which are more formally known as "the Prevailing Westerlies." While the Trade Winds and the Polar Easterlies have nothing over which to prevail, their parent circulation cells having taken care of any competition they might have to face, the Westerlies are at the mercy of passing weather systems. While upper-level winds are essentially westerly, surface winds can vary sharply and abruptly in direction. A low moving polewards or a high moving equator wards maintains or even accelerates a westerly flow; the local passage of a cold front may change that in a matter of minutes, and frequently does. A strong high moving polewards may bring easterly winds for days.

The base of the Ferrel cell is characterized by the movement of air masses, and the location of these air masses is influenced in part by the location of the jet stream, which acts as a collector for the air carried aloft by surface lows (a look at a weather map will show that surface lows follow the jet stream). The overall movement of surface air is from the 30th latitude to the 60th. However, the upper flow of the Ferrel cell is not well defined. This is in part because it is intermediary between the Hadley and Polar cells, with neither a strong heat source nor a strong cold sink to drive convection and, in part, because of the effects on the upper atmosphere of surface eddies, which act as destabilizing influences.

5.9 WALKER CIRCULATION

The Walker circulation is an ocean-based system of air circulation that influences weather on the Earth. The Walker circulation is the result of a difference in surface pressure and temperature over the western and eastern tropical Pacific Ocean. Normally, the tropical western Pacific is warm and wet with a low pressure system and the cool and dry eastern Pacific lie under a high pressure system. This creates a pressure gradient from east to west and causes surface air to move east to west, from high pressure in the eastern Pacific to low pressure in the western Pacific. Higher up in the atmosphere, west-to-east winds complete the circulation.

The warm waters of the western Pacific Ocean in East Asia heat the air above it and supply it with moisture. On average, the air rises, forms clouds, and then flows to the east across the Pacific, losing moisture to rainfall. The air then sinks off the west coast of South

America and returns to the west along the surface of the ocean, back to the western Pacific Ocean. The Walker circulation contributes to normal weather conditions in the tropical Pacific Ocean: warm, wet weather in the western Pacific and cool, dry weather in the eastern Pacific.

5.10 EL NINO - SOUTHERN OSCILLATION

The Walker circulation reverses every few years, as part of a phenomenon called the El Niño-Southern Oscillation (ENSO). When the Walker circulation weakens, the winds also weaken and the warm water of the western Pacific spreads to the east. These conditions are called El Niño. During times when the Walker circulation is particularly strong, called La Niña, the winds are stronger across the Pacific. These strong winds cause cooler ocean temperatures because of upwelling in the eastern Pacific. El Niño and La Niña impact the weather in North and South America, Australia, and Southeast Africa, and can cause flooding, droughts, and increases or decreases in hurricane activity.

5.11 LET US SUM UP

At about the time that Coriolis published his studies on rotating bodies, scientists were beginning to realize that Hadley's single convection cell model was too simple. Atmospheric pressure and wind measurements taken at many locations around the planet did not fit the predictions made by the Hadley model.

Some important modifications in the Hadley model were suggested in the 1850s, therefore, by the American meteorologist William Ferrell. Ferrell had, of course, much more data about wind_patterns than had been available to Hadley. On the basis of these data, Ferrell proposed a three-cell model for atmospheric circulation.

Ferrell's model begins where Hadley's began, with the upward flow of air over the equator and its continued flow toward the poles along the upper atmosphere. At approximately 30° latitude, however, Ferrell hypothesized that this air had become sufficiently cooled so that it began to descend to the earth's surface. Once at surface level, some of this air would then flow back toward the equator, as in the Hadley model. Today this large convection_current over the third of the globe above and below the equator is called a Hadley cell.

Ferrell had agreed with Hadley about the movement of air above the poles. That is, cool air would descend from higher altitudes and flow toward the equator along the earth's surface. At about 60° latitude, however, this flow of polar air would collide with air flowing toward it from the 30° latitude outflow.

The accumulation of air resulting from this collision along latitude 60° would produce a region of high pressure that could be relieved, Ferrell said, by massive updrafts that would carry air high into the atmosphere. There the air would split into two streams, one flowing toward the equator and descending to the earth's surface once more at about 30° latitude. This downward flow would complete a second convection cell covering the mid-latitudes and now known as the Ferrell cell. The second stream above 30° latitude would flow toward the poles and complete the third, or polar, cell.

One can hardly expect a model of the atmosphere developed nearly 150 years ago to be completely valid today. We know a great deal more about the atmosphere and have much more data than Ferrell knew or had. Still, his hypothesis is still valuable because it provides some general outlines about the nature of atmospheric circulation. It also explains a number of well-known circulation phenomena.

5.12. KEY WORDS:

General circulation of the atmosphere, The three cell models, Hadely cell.

5.13. QUESTIONS FOR SELF STUDY

1. Describe the applications and limitations of the tri-cellular model
2. What is EL Nino and explain its impact on the climate of monsoon regions.
3. Explain the latitudinal and longitudinal circulation of atmospheric motion of wind systems
4. General circulation pattern of atmospheric circulation is rather zonal than Meridian in character- discuss

5.14. FURTHER READINGS

1. Barry R.G. & Chorley, R.J. : "Atmosphere, Weather and Climate", Routledge, 1998.
2. Critchfield H : "General Climatology" Prentice-Hall, New York, 1975.
3. Das P.K. : The Monsoons, National Book Trust, New Delhi, 1968.
4. Lal D.S : "Physical Geography"Sharada Pustak Bhavan,Allahabad, 2009
5. Lydolph Paul, E. : The Climate of the Earth, Rowman and Allanheld, Totowa, N.J., 1985.

6. Mather, J.R. : Climatology, McGraw-Hill, New York, 1974.
7. Patterson, S. : Introduction of Meteorology, McGraw-Hill Book Co., London, 1969.
8. Stringer, E.T. : Foundation of Climatology, Surjeet Publications, Delhi, 1982.
9. Trewartha, G.T. : An Introduction to Climate, International Students edition, McGraw Hill, New York, 1980.
10.http://science.jrank.org/pages/602/AtmosphericCirculation.html#ixzz1v6lNdQ4w

UNIT-6 PALMEN MODELS

Structure:

6.0. OBJECTIVES

After studying this unit, you will be able to ;

- Understand to the general circulation of the atmosphere.
- Analyse Hadley, Ferrel and Polar cells.

6.1. INTRODUCTION

Erik Herbert Palmén (August 31, 1898, Vaasa, Finland - March 19, 1985) was Finnish meteorologist. He worked at the University of Chicago in the Chicago school of meteorology on cyclones and weather fronts with Vilhelm Bjerknes. He contributed to the explanation of the dynamics of the jet stream and the analysis of data collected by radiosondes; his preprocessed and quality checked datasets were widely used by other researchers. Palmen was a multisided researcher who published articles in meteorology, geophysics and oceanography. The 1969 book by Palmen and Chester W. Newton, "Atmospheric Circulation Systems: Their Structure and Interpretation", is still used as lecture material in the universities around the world.

Palmen was the director of Finnish Institute of Marine Research, a professor in Helsinki University and a member of the Finnish Academy of Arts and Letters. Palmen received the Buys-Ballot Medaille of Royal Dutch Academy in 1964. Then, when enough computing power was available and the first steps of numerical weather prediction were taken, the value of work done by the Chicago School 10-20 years earlier was really appreciated.

6.2. GENERAL CIRCULATION OF THE ATMOSPHERE

'The general circulation' is the term given to the way in which the atmosphere circulates air that carries with it moisture and heat. Day-to-day changes are not significant in the general circulation, which takes account of the long-term average motion of air. However, because the circulation is usually different in different seasons it is also possible to define different average circulations for each season. The most important question to try to answer is, 'Why does the air in the atmosphere move at all?' Is the motion random or is there a reason for it? If there were no atmosphere, as for example on Mercury, then the parts of the Earth that are most exposed to the Sun would be hottest and those that get least sunlight would be coldest.

Because the Earth is almost spherical and, over the course of a year, the average position of the Sun is over the Equator, we would expect equatorial regions to receive most sunlight and be the warmest. Near the poles the Sun is never overhead, and here the Sun's rays are spread over a wider area and the heating effect is less. This is what we observe. However, if the atmosphere, and also the oceans, were not circulating, equatorial regions would be far too hot to support life as we know it, and polar regions would be much colder than they are now. The atmosphere takes the enormous input of heat around the tropics and tends to redistribute it to the cooler parts of the planet. In the process the cooler air is brought to the tropics to be heated. The oceans also play a major role in this circulation. The effect of the general circulation is to remove largetemperaturedifferencesThe largest differences in temperature are between the equatorial regions and the poles. These differences between different latitudes are much larger than differences between longitudes. It is conventional; therefore, to describe the general circulation in terms of what happens at different latitudes and to ignore, to some extent, the variations which occur at any particular latitude around the world.

Some of the earliest attempts to describe the general circulation of the atmosphere were undertaken in the days of sailing ships when it was vitally important to know the direction and strength of the prevailing wind in different regions of the globe. One of the simplest models of the circulation, although it is incorrect, highlights several important points. If air is heated in the tropics it will become more buoyant and will rise. Cooling air in polar regions will sink as it becomes denser. A circulation could be established if the cool air from the poles were to flow equator wards near the Earth's surface while the warm air from the tropics flowed pole wards at high levels (Fig. 1a). This circulation would satisfy the requirement of transferring heat from the equator to other parts of the planet. If such a circulation existed what would be the wind pattern observed at the Earth's surface? If we ignore the fact that the Earth is rotating, the flow at the Earth's surface would be from the poles to the Equator. However, the Earth is rotating and the effect of that rotation is that for observers on the Earth there appears to be a component of the wind at right angles to the direction of motion. In the northern hemisphere this means that a wind from the North Pole blowing southward would appear to be deflected towards the west. The prevailing wind would be a north-easterly. In the southern hemisphere the prevailing wind would be a south-easterly. Such a uniform distribution of winds is not observed. However, the wind pattern postulated above is close to what is observed in the trade wind regions between about 30° north and south of the equator. This part of the circulation is known as the Hadley cell, after George Hadley, an English meteorologist who first proposed it in 1735.

The theoretical circulation described above, with a single cell in each hemisphere, was later replaced by a three-cell explanation which included a Hadley cell in the tropics with a similar cell in polar regions and a cell circulating in the opposite direction in mid-latitudes (30° to 65°). This had the advantage that it explained the prevailing wind pattern at the surface quite well. However, it became clear later, when observations of the upper atmosphere were carried out, that winds at upper levels were not correctly described in the mid-latitude region. A full explanation of the way in which heat is transferred in mid-latitudes was not produced until the twentieth century. It was then realized that the depressions and anticyclones that predominate in this region can be described as almost horizontal waves. These waves transport warm air towards the poles on the eastern side of depressions and transport cold air towards the Equator on the western side of depressions. In fact, the waves are not exactly horizontal, for the poleward-moving warm air is also rising slowly while the equatorward-moving cold air is sinking (Fig. 1c).

We can now consider in detail what happens in the two main parts of the circulation. These are the Hadley cells, which cover about half the Earth's surface, and the mid-latitude waves, which cover more than 40 per cent of the surface. The Hadley cells have rising air near the Equator and sinking air near 30° north and south. There is one cell in the northern hemisphere and another in the southern hemisphere. In the spring and autumn each of these cells is approximately symmetrical. During the summer in one hemisphere, and in the winter in the other, the Sun is not directly above the Equator and heating is greater in the tropics in the summer hemisphere. The boundary between the two Hadley cells then moves into the summer hemisphere and the Hadley cell in that hemisphere is stronger. This boundary is characterized by rising air which is converging near the surface from a north-easterly direction to the north and a south-easterly direction to the south. As the air rises at this boundary, it cools and clouds form as water condenses. The broken band of clouds that is seen on satellite images in this area is called the ITCZ (Inter-Tropical Convergence Zone) (Fig. 2). Very heavy rainfall is produced at the ITCZ because water vapour has been transported into this region from the tropical belts to the north and south. The relatively dry air at upper levels in the Hadley cell moves away from the ITCZ, and also eastward owing to the Earth's rotation. The air subsides in the region about 20 to 30 degrees north and south of the ITCZ. Because subsiding air is becoming warmer and more stable, clouds do not form in this region, which is sometimes called the subtropical anticyclone belt. The subsidence of the air in this subtropical region is very slow in comparison with the rapidly rising air in the ITCZ. Clear skies in this region mean that more sunshine can reach the surface than over the cloudy

ITCZ, and the highest temperatures at the surface are usually observed in this area. These high temperatures also enhance the evaporation of water from the ocean surface, and this moisture-laden air is carried towards the ITCZ in the low-level flow of the Hadley circulation.

The mid-latitude circulation takes warm air from low levels in the subtropics and transports it almost horizontally poleward. The warm air is carried poleward between depressions and anticyclones on the eastern flank of the depressions. As it moves it rises slowly at a rate of about a kilometre upwards for every 200 or 300 km horizontally. This slow rising motion cools the air, and condensation occurs to produce clouds and precipitation over large areas. On the other flank of the depressions cold air is moving from high levels at high latitudes and slowly subsiding as it is carried towards the subtropics.

The general circulation succeeds in transporting heat from the warmest parts of the Earth to the cooler parts. In so doing it also transports moisture from places where evaporation is dominant to places where precipitation is greatest. There are also significant components to the general circulation, such as monsoons, that occur on smaller scales than the phenomena described here.

Our atmospheric system is incredibly complex, but we do have models that can help us to explain it. Generally, air moves from high to low pressure areas on the globe. On a non rotating globe with no other factors, this would mean that air molecules would move from the area with the greatest amount of energy, the Tropics (also the hottest area) to both of the Poles, the areas with the least energy and coldest areas. Cold air would move in the opposite direction. This occurs as the atmosphere seeks to balance out the uneven distribution of energy received from the sun.

Unfortunately, our Earth is far more complex than this, and in reality there is a tri-cellular model of atmospheric circulation that is itself IMPERFECT! The tri-cellular model is a 2 dimensional model that give us a general understanding of how our atmosphere functions. It is a global scale model that is based entirely upon the fact that there are recognizable insolation differences between the Equator and the Poles. The insolation budget of our planet determine that because of the tilt of the earth and the way that it orbits around the sun, the Poles receive an overall deficit of insolation over a year and there is a surplus at the equator . This puts or whole atmospheric system out of balance and the tri-cellular model of atmospheric circulation tries to equalize those differences.

It starts in the Doldrums, an area of intense low pressure found at the equator where the intense heating (be convection) of the earth's surface forces air to rise through the Troposphere. This area is known as the Inter Tropical Convergence zone (ITCZ). As this air rises it cools and condenses forming a belt of clouds. Some of this air migrates northwards in the upper Troposphere to equalize out the temperature and insolation differences of our globe. As this air migrates north it cools relative to the air around it, becomes denser and sinks to the Earth's surface at around 30°N and S of the Equator, creating a band of high pressure. Some of this air migrates (because of Pressure gradient force) back to the low pressure area at the equator to complete the first cell of the system, the Hadley cell. Some of the air continues towards the poles to continue equalizing the temperature differences. When this air reaches 60°N and S it reaches cold polar air that is migrating south. This is our second convergence zone where 2 surface air streams meet. This causes the warmer, less dense tropical air to rise through the atmosphere again creating an area of low surface pressure. It is this zone where we find the mid-latitude weather systems that blight British weather. Some of this air migrates back towards the Equator where it eventually sinks at 30°N and S to form the middle cell of the model, the Ferrell cell. The rest of the air migrates to the pole, where it cools and sinks creating high pressure in the Polar Regions and completing a weak polar cell. Near the Tropopause at 30°N and S and 60 °N and S we find the high speed jet stream winds.

6.3. THE TRI-CELLULAR MERIDIONAL CIRCULATION: THE PALMED MODEL

The three-cell model of the northern hemisphere meridional circulation (also called the tri-cellular meridional circulation). This model was prepared by Palmen in 1951, when more complete upper air data were made available during and after the World War II.

The model makes it clear that there are two possible ways of transporting heat and momentum; (a) by circulation in the vertical plane' as depicted in the model showing three distinct meridional cells in the northern hemisphere, and (b) by horizontal circulations.

The following meridional circulation cells have been discussed separately:

(1) Tropical cell (also called Hadley cell).

(2) Polar front cell (also called Ferrel cell).

(3) Polar or sub-polar cell.

6.3.1. Tropical cell

The tropical cell, which is the dominant feature of the tri-cellular circulation model, is also called Hadley cell after G. Hadley who put forward his own explanation in 1735 for the existence of these thermally directed cells in each hemisphere. It is through this cell that the pole-ward heat transport in tropical and middle latitudes is accomplished. The tropical jet stream is located at 200 mb pressure-height level towards the pole-ward margin.

The tropical cell is considered to be the main source of angular momentum in the atmosphere. This circulation cell is located between the equators and roughly 30° latitudes.Since it resembles the convective model used by Hadley for the entire earth, the term Hadley cell is applied to it.

In the equatorial zone the warm ascending air currents release latent heat, when cumulonimbus clouds with great vertical heights form. Latent heat released during the formation of such clouds provides the required energy to drive the tropical cell. The rising air from thermally-driven tropical cell moves pole-ward in the upper troposphere. The pole-ward outflow of air in this cell is called the 'antitrades'. These air-currents found elevations of 8,000 to 12,000 meters near the equator begin to descend in a zone between 20 and 25 degrees latitude. The so-called antitrades are not affected by the surface friction.

While moving from low to higher latitudes, these upper tropospheric winds are subject to progressively increasing Coriolis force as a result of which they are deflected and become geostrophic westerlies. As more upper-air data were made available it was discovered that the antitrade wind systems are neither regular nor continuous. Presently there is a lot of confusion regarding the tropical circulation at higher levels. Undoubtedly, there are large differences with longitude, and strong seasonal variations. However, the continuity of antitrades is found over the eastern parts of the oceans. This is truer in the southern hemisphere and during the colder part of the year. Over the continental land masses the antitrades are characterized by interrupted movements.

The subtropical jet streams at about 12,000 m height takes the form of high-velocity westerly winds. This jet stream in the northern hemisphere is limited to the winter season. On the contrary, in the southern hemisphere the jet stream at 200 millibar level persists throughout the year over 25 to 30 degree south latitude.

The northern hemisphere winter jet stream is replaced by the Tropical Easterly Jet during the summer months over the continents of Asia and Africa at about 10° north latitude. In brief, it can be stated that there is a considerable amount of deviation from the traditional picture of a continuous antitrade circulation in the tropical cell. It would be pertinent to point out that the subsidence zone of the pole-ward moving upper flow in the tropical cell is the site of the world's tropical deserts. Near the centre of this zone of subsiding air, where the winds are light and variable, the region is popularly known as the horse latitudes. From the equator-ward margin of the horse latitudes the surface flow towards the equator is known as the trade winds: north-easterly trades in the northern hemisphere and southeasterly trades in the southern hemisphere.

In this way, the horizontal flow near the surface completes the cellular pattern of tropical circulation. Remember that the trade winds from both the hemispheres converge at the equatorial trough of low pressure or intertropical convergence zone (ICT). This region is called the doldrums. As regards the factors responsible for the maintenance of circulation of this cell, thermal as well as dynamic theories have been put forward. According to the thermal explanations latitudinal temperature difference between the tropics and the higher latitudes is the main driving force.

Dynamic theories of the Hadley cell, on the other hand, relate the existence of this circulation cell to the self-reinforcing nature of wind movements. According to the dynamic theories, instability of the equatorial air masses is one of the main causes of the Hadlay cell circulation. However, both the groups of theories may be considered to be complementary.

6.3.2. Polar front cell

The polar front cell is also called the Ferrel cell. This mid-latitude cell is thermally indirect. In the tri-cellular meridional circulation model, the circulation pattern between 30 and 60 degrees latitude is just the reverse of that found in the tropical cell.

In this mid- latitude cell the surface air flow is directed towards the pole, and because of the Coriolis force the winds blow almost from west to east.

The prevailing westerlies, the name given to surface winds in this zone, are disrupted frequently by the migratory extra tropical cyclones and anticyclones.

It is noteworthy that a general westerly flow exists in the upper troposphere in the mid- latitudes. If we take into account the conservation of angular momentum, then the upper-air flow in this indirect cell should be easterly. But according to Rossby, who modified the three-cell model, the westerly momentum is transferred to middle latitudes from the upper branches of the cells in high and low latitudes. The upper-air westerlies play a very significant role in the transfer of both air and energy. The cause of the upper-air westerlies in the polar front cell is said to be the pole-ward decrease of temperature. In winter when the meridional temperature gradient is steepest, the upper-air westerlies are most intense.

According to Trewartha, the middle and upper-troposphere westerlies are characterized by long waves and jet streams. Troughs and ridges in the upper westerlies are formed by long waves.

It may be pointed out that in the upper westerlies of the temperate zone dominated by long waves; the transfer of heat is affected by the sporadic thrusts of cold polar air towards low latitudes and the warm tropical air towards the pole. In this cell warm air is seen ascending the polar front and breaking through near the tropopause. The most important feature of this cell is that the polar front is more continuous and prominent in the middle troposphere.

Major heat exchange takes place at the surface and aloft. As shown in the aforesaid figure, there is subsidence of air in the horse-latitudes from the tropical as well as polar front cells.

In the subtropical high-pressure belt the tropical air moves towards higher latitudes in the western sector of the high pressure cells, while the air from middle cell moves into the tropical region in their eastern part. It is noteworthy that in maintaining the terrestrial heat balance the middle latitude circulation cell plays the most significant role.

6.3.3. Polar or Sub-polar cell

Pole-ward of the polar front cell, the third circulation cell over the polar and sub-polar regions is almost obliterated. Roughly this cell is located between 60 latitude and the poles.

Despite the fact that the polar anticyclones are not permanent features, subsidence near the poles produces a surface flow that, while moving towards the equator, comes under the Coriolis force and becomes polar easterly in each hemisphere. The cold polar easterlies in their equator-ward movement clash with the warmer westerlies of the temperate regions. The zone of contact between these airflows of contrasting nature is called the polar front, which has been discussed elsewhere in the book.

The third cell is characterized by considerable horizontal turbulent mixing at all levels. Here heat transport is accomplished by the waves in the westerlies.

6.4. APPLICATIONS AND LIMITATIONS OF THE MODEL

This model has many applications and limitations. The model fails to accommodate other major transfers of energy, such as the El Nino and La Nina models of circulation from West to east or Vice Versa across The Pacific Ocean. It also fails to acknowledge the presence and impact of Geomorphological features such as the Himalaya which complexly disrupt the movement of jet streams and surface level winds within the Hadley cell on a yearly basis.

However, it does offer people a starting point for understanding atmospheric circulation, and does allow for some level of prediction of the weather that affects billions of people around the globe. The understanding of high level jet streams within the model is also of use to pilots and balloon enthusiasts!

6.5. THE ROLE OF OCEAN CURRENTS

The second major way that heat is redistributed around our planet is by oceanic circulation or ocean currents. These are hugely important and our understanding of then is increasing with time. The globes ocean currents are interlinked into a global system, which is commonly known as the Thermohaline conveyor. The word can be broken down, "Thermo" relates to temperature, whilst "haline" relates to salinity differences. Basically, warm less salty water travels at the surface of our oceans driven by surface winds that blow over the top of those oceans. This water cools as it travels north and south from the Equator and increases in salinity as the salt is left behind during evaporation of the warm water. This water is now cooler and salt laden, sinks and returns to the equator as another method of balancing out the Earth's heat budget. This mechanism is hugely important for the people of Western Europe, as a warm ocean current called the Gulf Stream brings warm ocean waters which warm Western Europe well beyond what it should be given its latitude. Consider this, Newcastle in the UK is on similar latitude as MOSCOW – but the Gulf Stream and the moderating impact of the seas and oceans around the British Isles massively impact the temperatures.

6.6. LET US SUM UP

To sum up, in the tropical regions the exchange of heat and momentum is accomplished by direct circulations. According to Riehl, the above mentioned exchange in the tropical circulations is a direct meridional one. But the seasonal variations do not allow the components to be identified easily. Byers give example of the northern hemisphere trade winds. Over the oceans the trade winds transport air towards the equator. But over the continents the monsoon circulation transports air towards the north during the warmer part of the year. During the winter months the dry offshore winds transfer air from land to sea. The direction is meridional in this case also. In the middle to high latitudes, according to Byers, the transfer of mean potential energy to mean kinetic energy is affected through the energy of extra tropical cyclones and anticyclones.

6.7. KEYWORDS

Tricellular meridional circulation of atmosphere, Palmen model, General circulation of atmosphere

6.8. QUESTIONS FOR SELF STUDY

1. Discuss the mechanism and significance of tricellular meridional circulation of atmosphere proposed by Palmen
2. Give an account of General circulation of the atmosphere
3. Discuss the application and limitation of Palmen model of general circulation of the atmosphere
4. Write a short note on the role of ocean currents on the redistribution of temperatures at the global level.

6.9. FURTHER READINGS

1. Barry R.G. & Chorley, R.J. : "Atmosphere, Weather and Climate", Routledge, 1998.
2. Critchfield H : "General Climatology" Prentice-Hall, New York, 1975.
3. Das P.K. : The Monsoons, National Book Trust, New Delhi, 1968.
4. Lal D.S : "Physical Geography"Sharada PustakBhavan,Allahabad, 2009
5. Lydolph Paul, E. : The Climate of the Earth, Rowman and Allanheld, Totowa, N.J., 1985.
6. Mather J.R. : Climatology, McGraw-Hill, New York, 1974.
7. Patterson S. : Introduction of Meteorology, McGraw-Hill Book Co., London, 1969.
8. Stringer E.T. : Foundation of Climatology, Surjeet Publications, Delhi, 1982.
9. Trewartha G.T. : An Introduction to Climate, International Students Edition, McGraw Hill, New York, 1980

UNIT - 7 : POLAR CIRCULATION OF AIR

7.0. OBJECTIVES

After studying this unit, you will be able to ;

- Know unequal surface heating
- Understanding the atmosphere and its consequences on weather phenomenon.
- Know the regional changes in wind, temperature, precipitation, moisture and other climatic variables

7.1. INTRODUCTION

This unit examines how unequal surface heating and the rotation of the earth generate global circulation systems in the atmosphere and its consequences on weather phenomenon. Atmospheric circulation is one of the key factors driving regional changes in wind, temperature, precipitation, moisture and other climatic variables.

7.1.1. Global Atmospheric Circulation

Energy from the Sun heats the entire Earth, but this heat is unevenly distributed across the Earth's surface. Equatorial and tropical regions receive far more solar energy than the mid latitudes and the Polar Regions. The tropics receive more heat radiation than they emit, while the polar regions emit more heat radiation than they receive. If no heat was transferred from the tropics to the Polar Regions, the tropics would get hotter and hotter while the poles would get colder and colder. This latitudinal heat imbalance drives the circulation of the atmosphere and oceans. Around 60% of the heat energy is redistributed around the planet by the atmospheric circulation and around 40% is redistributed by the ocean currents.

One way to transfer heat from the equator to the poles would be to have a single circulation cell where air moved from the tropics to the poles and back. This single-cell circulation model was first proposed by Hadley in the 1700's. Since the Earth rotates, its axis is tilted and there is more land in the Northern Hemisphere than in the Southern Hemisphere, the actual global air circulation pattern is much more complicated. Instead of a single-cell circulation, the global model consists of three circulation cells in each hemisphere. These three cells are known as the tropical cell (also called the Hadley cell), the midlatitude cell and the polar cell.

The weight of air and the force of gravity pulling air towards the earth create air pressure. Air pressure is greatest at the earth's surface and decreases with altitude. Differences in pressure cause air to move horizontally. This air in motion is called wind. Winds move from areas of high pressure to areas of low pressure.

Pressure differences between two places create pressure gradients and the resulting pressure gradient force causes air to move from high pressure areas to low pressure areas. Land and sea breezes are examples of winds caused by pressure differences that result from temperature differences over land and water surfaces. Wind direction is measured by a wind vane and wind speed is measured by an anemometer.

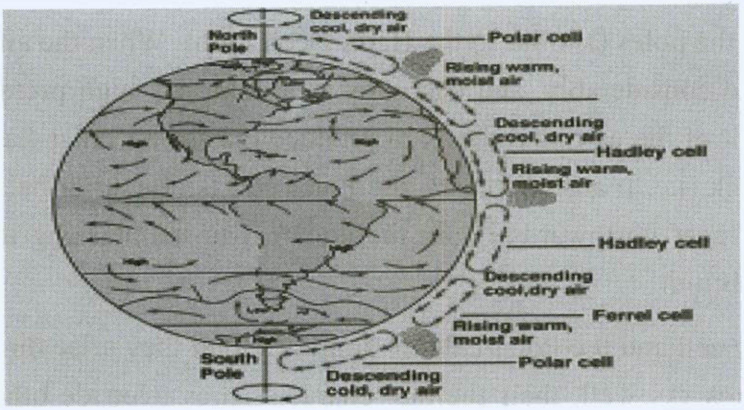
The Coriolis effect is due to the earth's rotation and causes objects in motion to appear to be deflected off course. This apparent deflection is to the right in the northern hemisphere and to the left in the southern hemisphere. The effect is absent at the equator and increases as you move toward the poles. The third force affecting the direction of wind is that of friction.

Air flow spirals into a low-pressure center and rises while the air descends and flows out of a high-pressure center. The inspiral at a low-pressure center is counterclockwise in the northern hemisphere and clockwise in the southern hemisphere. The outspiral at a high-pressure center is clockwise in the northern hemisphere and counterclockwise in the southern hemisphere.

Cyclones (low pressure centers) are associated with cloudy or rainy weather. Anticyclones (high pressure centers) are associated with clear, dry weather. At the equator, heating causes air to rise creating an area of low pressure called the intertropical convergence zone (ITC). At 30° latitude, air descends creating areas of high pressure in the subtropical high-pressure belt. Air moves out of these high pressure areas toward the equator creating the trade winds. Winds also move toward the midlatitudes creating the westerlies. The monsoon is a seasonally reversing wind pattern that brings heavy rains onto the Asian subcontinent in summer and hot, dry conditions in the winter. Winds at an altitude of 5 to 7 km above the earth's surface are influenced by pressure gradient force and Coriolis force but not by the force of friction. These are the geostrophic winds that flow parallel to isobars.

Rossby waves are large undulations in the flow of the upper air Westerlies along the zone of contact between cold and warm air. They allow warm air to penetrate northward and coldairtopenetrate southwar Jet streams are

7.2. ATMOSPHERIC CIRCULATION



Diagrammatic representation of the earth's atmospheric circulation cells as well as broad directions of surface winds

Atmospheric circulation is one of the key factors driving regional changes in wind, temperature, precipitation, moisture and other climatic variables. This large-scale movement of air is the means by which heat is distributed across the Earth's surface, particularly northward from the equator towards the poles. Without atmospheric circulation, average winter temperatures at the poles would be around -100°C rather than -30 °C as at present.

The large-scale structure of the atmospheric circulation varies slightly from year to year but the basic pattern remains fairly constant. Individual weather systems, however, occur "randomly" and it is accepted that weather cannot be predicted beyond a fairly short timeframe.

7.3. CIRCULATION "CELLS" IN THE TWO HEMISPHERES

Earth's weather results from the interactions of three large circulation cells in each hemisphere. The wind belts and the high altitude jet streams surrounding the planet are driven by three convection cells: the Hadley, Polar and Ferrel "cells".

The Hadley cell mechanism is a closed heat loop, where warm, moist air rises around the equator to the upper reaches of the troposphere (the atmospheric layer which stretches from the ground to the stratosphere) and thereafter moves toward the poles. At about 30° north (and south) of the equator, the air descends in a cooler high pressure area and then returns to the equatorial regions. The Hadley cell is made up of multiple mini-cells within the equatorial zone which merge and separate randomly over time but contribute to the general circulation within the larger cell framework.

The Polar cell is a similarly simple system. Though cool and dry relative to equatorial air, air masses at the 60th parallel are still sufficiently warm and moist to drive a thermal loop between there and the poles (similar to the Hadley cell loop). When the air reaches the polar areas, it has cooled considerably, and descends as a cold, dry high pressure area, twisting eastward as a result of the earth's rotation to produce the strong Polar Easterlies winds. By acting as a heat sink (i.e. it absorbs heat), the Polar cell is crucial to balancing the Hadley cell's transport of heat northwards (from the equator) in maintaining the Earth's overall temperature equilibrium.

The Hadley cell and the Polar cell are similar in that they arise directly as a result of surface temperatures. As well, their thermal characteristics override other weather effects within the cells. The passing highs and lows which form part of daily life for mid-latitude dwellers are unknown above the 60th and below the 30th parallels.

The Ferrel cell is a secondary circulation system, acting as a counterbalance between the Hadley and Polar cells. While the Hadley and Polar cells are truly closed predictable loops, the Ferrel cell is not. Localized weather systems can overcome the general trend for the winds to run from west to east.

7.4. DIFFERENCES BETWEEN THE POLAR CELLS

The considerable differences between the two Polar Regions mean that there are differences in the way atmospheric circulation operates at each pole (though still in a broadly similar way). For example, the presence of extensive land and mountains around the Arctic Ocean makes for considerably more disrupted weather patterns than in the Antarctic where the vast Southern Ocean and its circumpolar current buffers the polar continent. The air of the Northern polar cell therefore mixes much more with its adjacent Ferrel cell - this in part contributes to the phenomenon of an "ozone hole" being much less pronounced in the Arctic than in the Antarctic.

7.5. LONGITUDINAL CIRCULATION FEATURES

While the Hadley, Ferrel, and Polar cells are the major drivers of global heat transport, they do not act alone. Disparities in temperature also drive a set of long-term longitudinal circulation cells, and the overall atmospheric motion is known as the zonal overturning circulation.

Latitudinal circulation is a consequence of the fact that energy from the sun per square unit is highest at the heat equator, and decreases as the latitude increases, reaching its minimum at the poles. Longitudinal circulation, on the other hand, comes about because water absorbs and releases heat more readily than land.

7.6. POLAR-MIDLATITUDE CIRCULATION (JET STREAM AND THE POLAR FRONT)

As we move poleward of the mid-latitude westerlies, the Hadley cell fuelled by equatorial low pressure is replaced by a mirror-image engine of polar high pressure. These polar highs are the center of cold, calm, descending air masses which move toward the equator on the surface. This polar air meets the subtropical air coming north from the subtropical highs along the polar front—a variable meeting ground at 30 degrees to 60 degrees latitude defined by the often violent confrontation between two contrasting air masses: one cold and dry and the other hot and wet. The result is a steady stream of cyclonic subpolar lows, the source of most of the "storms" and significant weather events in mid-latitude locations such as North America and Europe.

The last piece of the puzzle is the jet stream, the high-altitude companion of the surface cyclones and westerlies located along the polar front. The jet stream is a geostrophic river of air flowing at close to 200 miles per hour, 25-45 thousand feet above the ground, near the tropospause. It is typically 100-300 miles wide and 3000-7000 feet thick. Actually, all of the upper level air poleward of the subtropics is flowing as westerly wind, and the jet stream is simply a generalized acknowledgement that the flow is faster and more concentrated at certain locations. There actually are several branches of the jet streams, including a polar jet at 25k to 35k feet, 30 to 70 degrees latitude and a subtropical jet at 30k to 45k feet, 20 to 50 degrees latitude.

Further complicating the jet stream's geography is its highly variable, meandering path of oscillating Rossby waves, which number 3 to 6 around the circuit of the globe at any given time. The jet stream is very significant to mid-latitude weather, because it:

- governs the latitudinal reach of polar outbreaks and eddies
- steersubpolarcyclones
- provides a storm-enhancing chimney at areas of upper-level divergence on the lee side of low-pressure troughs.

7.7. POLAR FRONT

In meteorology, the **polar front** is the boundary between the polar cell and the Ferrel cell in each hemisphere. At this boundary a sharp gradient in temperature occurs between these two air masses, each at very different temperatures.

The polar front arises as a result of cold polar air meeting warm tropical air. It is a stationary front as the air masses are not moving against each other. Off the coast of eastern North America, especially in winter, there is a sharp temperature gradient between the snow-covered land and the warm offshore currents.

The polar front theory says that mid-latitude cyclones form on boundaries between warm and cold air. In winter, the polar front shifts towards the Equator, whereas high pressure systems can dominate more in the summer.

7.8. POLAR CELL

The polar cells are located over both the north and South Pole, and circulation in these cells is driven primarily by the dome of extremely cold high pressure air that resides over both poles, especially in winter. Air diverging aloft and outward off the top of the subpolar lows gets transported pole-ward across the top of the troposphere. This high altitude air gets super-cooled and then descends into the super dense subsiding air masses of the polar highs. These polar anticyclones are virtual deserts for lack of moisture, but it is so cold that what little precipitation falls does not always melt. Then this cold air reaches the surface and diverges outward from the central region of high pressure, and this divergence from the polar highs is clockwise in the northern hemisphere (counter-clockwise in the southern hemisphere), giving rise to the polar easterlies, the most bitter cold surface winds on Earth. The big climate consequences of the polar cells are the polar "deserts", the polar easterlies, and the polar front which is the boundary where polar and tropical air masses collide in deep, rising mid-latitude storm systems (lows) where some of the nastiest weather in the world occurs. The position of the polar front is anything but stationary, of course, its part of the fluid atmosphere and the thing moves in a highly dynamic fashion. Locating, mapping, and predicting the future movement of the polar front (and all lesser fronts) is one of the great objectives of modern meteorology.

7.9. LET US SUM UP

Intensely cold, dense air sinks at the poles, and then blows as surface winds towards the Equator. At about 60ºN and 60 ºS, the cold polar air is warmed in contact with the earth's surface. This warmed air rises and returns polewards, carrying heat energy. This circular motion is called the POLAR CELL. The Hadley Cell is driven by differences in heat energy at the Equator. As the air in the Hadley Cell falls at about 30ºN and 30ºS, it pulls the air beside it down as well, due to friction. The Polar Cell is driven by differences in heat energy. Cold polar air falls and spreads towards the Equator. As the air in the Polar Cell rises at about

60°N and 60°S, it pulls the air beside it up as well, due to friction. Unlike the Hadley and Polar Cells, the Ferrel Cell is not driven by differences in heat energy. The Ferrel Cell is caused by friction where air is in contact with the other two cells. The Hadley Cell drags air down at about 30°N and S. The Polar Cell causes an uplift at about 60°N and S. Where air carrying energy from the Equator in the Hadley Cell comes into contact with air in the Ferrel Cell, there is a transfer of heat energy into the Ferrel Cell. There is a similar transfer of heat energy from the Ferrel Cell to the Polar Cell. In this way, heat energy is transferred from the Equator, where there is a surplus of energy, to the poles where there is a deficit. In the Polar cell cold air from Polar Regions flows to mid-latitudes as polar easterly winds

7.10. KEY WORDS

Polar cells, atmospheric circulation, polar front cell

7.11. QUESTIONS FOR SELF STUDY

1. Explain in detail the polar cell and describe how it maintains equilibrium in terms of temperature and pressure.
2. Describe and explain how heat energy is transferred from the zones of surplus to zones of deficit.
3. Describe and explain the pressure belts associated with these cells.
4. Describe, in detail, what happens as a result of insolation at the Equator.

7.12. FURTHER READINGS

1. Barry R.G. & Chorley R.J. : "Atmosphere, Weather and Climate", Routledge, 1998.

2. Critchfield H : "General Climatology" Prentice-Hall, New York, 1975.

3. Das P.K. : The Monsoons, National Book Trust, New Delhi, 1968.

4. Lal D.S : "Physical Geography"Sharada Pustak Bhavan, Allahabad, 2009

5. Lydolph Paul E. : The Climate of the Earth, Rowman and Allanheld, Totowa, N.J., 1985.

6. Mather J.R. : Climatology, McGraw-Hill, New York, 1974.

7. Patterson S. : Introduction of Meteorology, McGraw-Hill Book Co., London, 1969.

8. Stringer E.T. : Foundation of Climatology, Surjeet Publications, Delhi, 1982.

9. Trewartha G.T. : An Introduction to Climate, International Studentsedition, McGraw Hill, New York, 1980.

UNIT-8 : PLANETARY WINDS

Structure:

8.0 OBJECTIVES

After studying this unit, you will be able to ;

- Provide better understanding of wind systems and pressure belts.
- Know the different types of wind and its pattern

8.1. INTRODUCTION

The horizontal movement of air along the earth's surface is called a Wind. The vertical movement of the air is known as an air current. Winds and air current together comprise a system of circulation in the atmosphere. The movement and the speed of wind are affected by three main factors:

- Pressure gradient
- Rotation of the Earth
- Friction of the Earth.

8.1.1. Pressure Gradient

We know that a wind always blows from a region of high-pressure to a region of low-pressure. Steeper the pressure gradient, higher is the speed or force of the blowing wind. Slower the pressure gradient, slower is the force of the blowing wind.

8.1.2. Rotation of the Earth

If the Earth did not rotate upon its axis, winds would follow the direction of the pressure gradient. But the rotation produces another force other than the pressure force. It is called the 'Coriolis force'. This tends to turn the flow of air by changing its direction from its original straight path. The wind starts deflecting more and more to its right from its original path in the northern hemisphere. In the southern hemisphere it starts deflecting more and more to its left from its original path. Thus a wind blowing from north becomes north-easterly in the northern hemisphere. A wind blowing from south becomes south-easterly in the southern hemisphere. The effect of the Coriolis force on wind is stated in Ferrel's law as follows:

"Any object or fluid, moving horizontally in the Northern Hemisphere, tends to be deflected to the right of its path of motion regardless of the compass direction of the path. In the Southern' Hemisphere, a similar deflection is towards the left of the path of motion." The deflection is the least at the equator and the greatest at the poles.

8.1.3. Friction of the Earth

The friction along the Earth's surface decreases both the angular deflection and velocity of the wind. It is very little over vast free surface of oceans and is considerable over the mountains and the heavily forested areas.

8.2. WHAT CAUSES WIND

Going by the simplest possible definition, wind is the flow of gases from one place to another. This is just a basic definition though, and there is a lot more to know about this natural phenomenon - its formation being one of them.

Basically, there are different types of winds grouped on the basis of numerous underlying factors. While the definition of wind on planet Earth would be the bulk movement of air, the same in outer space would either be movement of gases and charged particles ejected from the Sun into the space (solar wind) or atmospheric escape of gases from the planets into the outer space (planetary winds). The fact about occurrence of wind in outer space may come as a surprise to many, but that is just one of the numerous facts about it which not many people are aware of. Exploring this natural phenomenon to trace simple facts like how it is caused or its patterns in different regions, can be fun in itself. More importantly, you don't need to be a stalwart of the field for that; just the basics of geography is more than enough.

8.3. WHAT CAUSES WIND ON THE EARTH?

Basically, wind is formed as a result of the movement of air from the high pressure area to the low pressure area. The most important factor when it comes to wind formation is atmospheric pressure. Differences in atmospheric pressure result in formation of high pressure and low pressure areas on the planet which are studied with great interest in prediction of weather. Once these pressure areas are formed air starts moving from high pressure region to low pressure region. On the basis of its strength, wind is classified into several types - ranging from a simple breeze to devastating thunderstorms.

8.4. WINDPATTERNS

Even though wind flows from the high pressure region to a low pressure region, it doesn't directly move from one area to another. The two major factors which contribute to the global wind pattern are rotation and differential heating of the planet. As a result of the Earth's rotation, the wind is deflected when it moves from a high pressure area to a low pressure area. This deflection is attributed to the Coriolis force, which deflects the wind towards right in the northern hemisphere and left in the southern hemisphere. Secondly, incoming solar radiations are not uniform. While the equatorial region gets more of direct sunlight, the condition towards the poles is exactly opposite. This results in differences in the atmospheric circulation of air, and influences the global pattern of wind.

8.5. OTHER FACTORS WHICH INFLUENCE THE WIND

There also exists other factors which contribute to the velocity of the wind, one of the prime determinants of the different types of wind. Atmospheric pressure gradient is determined by the distance between high pressure and low pressure area. Lesser the pressure gradient, stronger is the wind formed. Similarly, the speed of wind blowing at high altitude is always faster than that of wind blowing closer to the surface of the planet. This can be attributed to the fact that the wind moving near the surface is subjected to friction with the various man-made and geological structures on the planet. Similarly, the speed of wind over the ocean is more than it is over the land surface, as the number of obstructions which hamper the movement of wind are less over the water body.

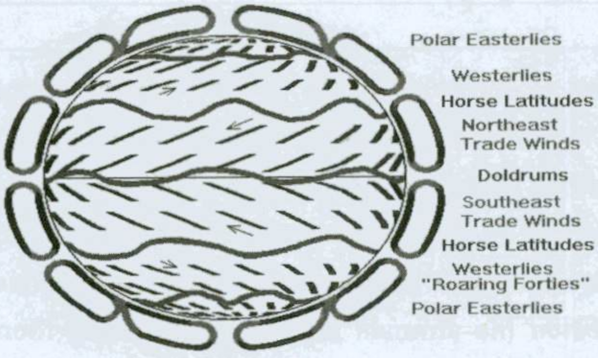
Wind has always been resourceful for human beings, with numerous uses which can be traced back to the ancient times. While the early civilizations used this force of nature to facilitate transportation, today it is being used to generate power. In fact, wind energy, i.e. the energy created by harnessing wind, is considered to be one of the most environment friendly sources of energy and pitched as one of the best alternative for fossil fuels.

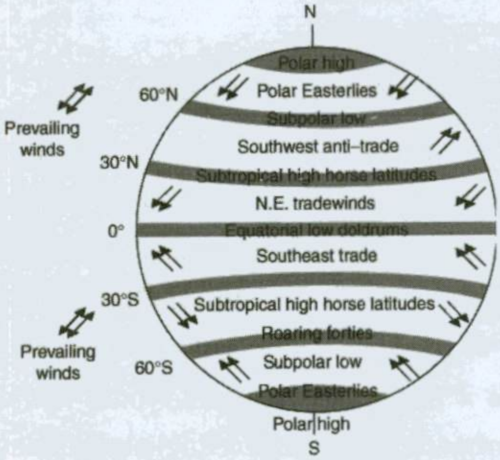
8.6 TYPES OF WINDS

On the earth's surface, certain winds blow constantly in a particular direction throughout the year. These are known as the 'Prevailing Winds'. They are also called the Permanent or the Planetary Winds. Certain winds blow in one direction in one season and in the opposite direction in another. They are known as Periodic Winds. Then, there are Local Winds in different parts of the world.

8.7 PLANETARY WINDS

Planetary wind belts are related to the general circulation of the atmosphere. In this circulation there are three cells of vertical circulation. At the equator the air rises with heating and in the upper atmosphere begins to flow toward the north. At about 30 degrees north latitude it sinks and flows back toward the equator forming the easterlies in the band from 30 N to the equator. This cell is the Hadley circulation. Between 30 N and about 60 N there is a similar circulation but in a reverse mode. It flows at the surface from 30 N to 60 N where it rises along the Polar front and returns aloft by flowing southward where it sinks at 30N. This cell is called the Ferrel cell. This is the belt of the westerlies. Finally, north of 60 N there is the Polar cell which in the upper atmosphere flows toward the Pole where it sinks and flows southward near the surface forming the polar easterlies. Where the Ferrell and Hadley cells sink at 30 N we have the Horse latitudes an area of generally high pressure. This same pattern is repeated in the southern hemisphere.





8.8. THE POLAR EASTERLIES

The polar easterlies are located at the poles next to the westerlies. They are formed as cold air at the poles sinks and begin to move towards the equators. However, as they meet warmer air from the westerlies, they create a polar front located at 60 degrees north and south which is an area of low pressure that often results in storms. The polar easterlies are winds that are intensely freezing and dry, due to its location at such high latitudes. This contributes to the polar climate, which is characterized basically by icy winds of high temperatures, where the polar cold easterlies cold wind meets the warm wind from the westerlies, a region of mild and moist winds that bring about precipitation fronts from. This is known as a temperate climate which is founding areas at the mid latitudes.

8.9. WESTERLIES

The **Westerlies**, **anti-trades**, or **Prevailing Westerlies**, are prevailing winds in the middle latitudes between 30 and 60 degrees latitude, blowing from the high pressure area in the horse latitudes towards the poles. These prevailing winds blow from the west to the east, and steer extra tropical cyclones in this general manner. The winds are predominantly from the southwest in the Northern Hemisphere and from the northwest in the Southern Hemisphere.

The Westerlies are strongest in the winter hemisphere and times when the pressure is lower over the poles, while they are weakest in the summer hemisphere and when pressures are higher over the poles. The Westerlies are particularly strong, especially in the southern hemisphere, where there is less land in the middle latitudes to cause the flow pattern to amplify, or become more north-south oriented, which slows the Westerlies down. The Westerlies play an important role in carrying the warm, equatorial waters and winds to the western coasts of continents, especially in the southern hemisphere because of its vast oceanic expanse.

8.10. HORSE LATITUDES

Between about 30° to 35° north and 30° to 35° south of the equator lies the region known as the horse latitudes or the subtropical high. This region of subsiding dry air and high pressure results in weak winds. Tradition states that sailors gave the region of the subtropical high the name "horse latitudes" because ships relying on wind power stalled; fearful of running out of food and water, sailors threw their horses and cattle overboard to save on provisions. (It's a puzzle why sailors would not have eaten the animals instead of throwing them overboard.) The Oxford English Dictionary claims the origin of the term "uncertain."

Major deserts of the world, such as the Sahara and the Great Australian Desert, lie under the high pressure of the horse latitudes.

The region is also known as the Calms of Cancer in the northern hemisphere and the Calms of Capricorn in the southern hemisphere.

8.11. TRADE WINDS

Blowing from the subtropical highs or horse latitudes toward the low pressure of the ITCZ are the trade winds. Named from their ability to quickly propel trading ships across the ocean, the trade winds between about 30° latitude and the equator are steady and blow about 11 to 13 miles per hour. In the Northern Hemisphere, the trade winds blow from the northeast and are known as the Northeast Trade Winds; in the Southern Hemisphere, the winds blow from the southeast and are called the Southeast Trade Winds.

8.12. DOLDRUMS

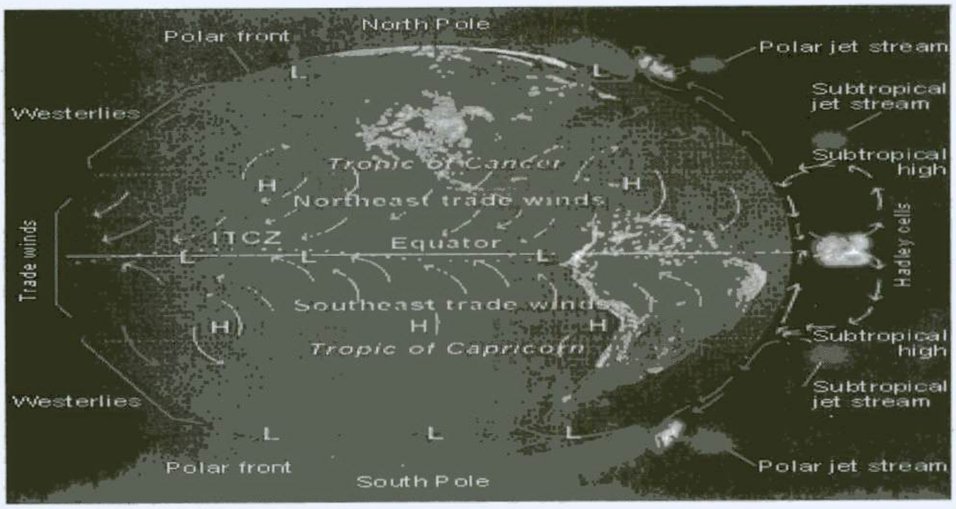
Sailors noticed the stillness of the rising (and not blowing) air near the equator and gave the region the depressing name "doldrums." The doldrums, usually located between 5° north and 5° south of the equator, are also known as the Intertropical Convergence Zone or

ITCZ for short. The trade winds converge in the region of the ITCZ, producing convectional storms that produce some of the world's heaviest precipitation regions.

The ITCZ moves north and south of the equator depending on the season and solar energy received. The location of the ITCZ can vary as much as 40° to 45° of latitude north or south of the equator based on the pattern of land and ocean. The Intertropical Convergence Zone is also known as the Equatorial Convergence Zone or Intertropical Front.

8.13. GLOBAL LOWS AND HIGHS

Across the globe, there are several important consistently low and high pressure areas. They are as follows:



8.13.1. The Equatorial Low Pressure Trough

This area is in the Earth's equatorial region (0°-10° North and South) and is composed of warm, light, ascending and converging air. Because the converging air is wet and full of excess energy it expands and cools as it rises, creating the clouds and heavy rainfall that are prominent throughout the area. This low pressure zone trough also forms the ITCZ and trade winds.

8.13.2 Subtropical High-Pressure Cells

Located between 20° N/S and 35°N/S this is a zone of hot, dry air that forms as the warm air descending from the tropics becomes hotter. Because hot air can hold more water vapor, it is relativelv dry. The heavy rain along the equator also removes most of the excess moisture. The dominant winds in the Subtropical high are called westerlies.

8.13.3 Sub polar Low-Pressure Cells

This area is at 60° N/S latitude and features cool, wet weather. The Sub polar low is caused by the meeting of cold air masses from higher latitudes and warmer air masses from lower latitudes. In the northern hemisphere, their meeting forms the polar front which produces the low pressure cyclonic storms responsible for precipitation in the Pacific Northwest and Europe. In the southern hemisphere, severe storms develop along these fronts and cause high winds and snowfall in Antarctica.

8.13.4 Polar High-Pressure Cells

These are located at 90° N/S and are extremely cold and dry. With these systems, winds move away from the poles in an anticyclone which descends and diverges to form the polar easterlies. They are weak however because there is little energy available in the poles to make the systems strong. The Antarctic high is stronger though because it is able to form over the cold landmass instead of the warmer sea.

By studying these highs and lows, scientists are better able to understand the Earth's circulation patterns and predict weather for use in daily life, navigation, shipping, and other important activities, making air pressure an important component to meteorology and other atmospheric science.

8.14 LET US SUM UP

The planetary wind system of the world accompanies the presence of the High and Low-Pressure Belts. We know that winds tend to blow from the high-pressure centers to the low-pressure centers. The effect of the earth's rotation (Coriolis force) tends to deflect the direction of these winds. The deflection in the direction of these winds takes place according to Ferrel's Law. Two sets of surface winds, the Trades and the Westerlies are the main planetary winds of the world.

8.15 KEY WORDS

Planetary winds, Prevailing winds, wind patterns.

8.16 QUESTIONS FOR SELF STUDY

1. Explain planetary winds systems with a neat diagram
2. How do planetary wind belts affect the climate of a land mass in the mid- latitudes?

3. What planetary wind pattern is present in many areas of little rainfall?
4. Discuss various pressure belts and explain how they are responsible for the general Circulation of air in the atmosphere
5. Explain the relationship between the formation of pressure belts and planetary winds

8.17 FURTHER READINGS

1. Barry, R.G. & Chorley, R.J. : “Atmosphere, Weather and Climate”, Routledge, 1998.
2. Critchfield, H : “General Climatology” Prentice-Hall, New York, 1975.
3. Das, P.K : The Monsoons, National Book Trust, New Delhi, 1968.
4. Lal D.S : “Physical Geography”Sharada Pustak Bhavan, Allahabad, 2009
5. Lydolph, Paul, E. : The Climate of the Earth, Rowman and Allanheld, Totowa, N.J., 1985.
6. Mather, J.R. : Climatology, McGraw-Hill, New York, 1974.
7. Patterson, S. : Introduction of Meteorology, McGraw-Hill Book Co., London, 1969.
8. Stringer, E.T. : Foundation of Climatology, Surjeet Publications, Delhi, 1982.
9. Trewartha, G.T. : An Introduction to Climate, International Students edition, McGraw Hill, New York, 1980.

UNIT-9 : SEASONAL AND LOCAL WINDS

Structure:

9.0 OBJECTIVES

After studying this unit, you will be able to ;

- Identify the sesonal and Local winds
- Explain The causeas of Local and sesonal wind

9.1 INTRODUCTION

A wind in low-latitude climates that seasonally changes direction between winter and summer is called a monsoon, and is a typical example of seasonal winds. Monsoons usually blow from the land in winter (called the dry phase, because it carries cool, dry air), and to the land in summer (called the wet phase, because it carries warm, moist air), causing a drastic change in the precipitation and temperature patterns of the area.

The word "monsoon" originates from the Arabic *mauzim,* meaning season. It was first used to depict the winds in the Arabian Sea, but later it was extended for seasonally changing wind systems all over the world. The main reason for monsoons is the difference in the heating of land and water surfaces, which results in land-ocean pressure differences. On a small scale, heat is transferred by land-sea breezes, to maintain the energy balance between land and water. On a larger scale, in winter when the air over the continents is colder than over the oceans, a large, high-pressure area builds up over Siberia, resulting in air motion over the Indian Ocean and South China, causing dry, clear skies for East and South Asia. This is the winter monsoon. The opposite of this happens in summer; the air over the continents is much warmer than over the ocean, leading to moisture-carrying wind moving from the ocean towards the continent. When the humid air unites with relatively drier west airflow and crosses over mountains, it raises reaches its saturation point, and thunderstorms and heavy showers develop. This is the summer monsoon in Southwest Asia—wind blowing from the ocean to the continent with wet, rainy weather patterns.

Although the most pronounced monsoon system is in eastern and southern Asia, monsoons can also be observed in West Africa, Australia, or the Pacific Ocean. Even in the southwestern United States, a smaller scale monsoonal circulation system exists . The North American Monsoon is a regional-scale circulation over southwest North America between July and September, bringing dramatic increases in rainfall in a normally arid region of Arizona, New Mexico, and northwestern Mexico. It is a monsoonal circulation because of its similarities to the original Southwest Asian monsoon—the west or northwest winds turn more south or southeast, bringing moisture from the Pacific Ocean, Gulf of California and Gulf of Mexico.

As the moist air moves in, it is lifted up due to the mountains, which, combined with daytime heating from the Sun, causes thunderstorms.

The monsoon is an important feature of atmospheric circulation, because large areas in the tropics and subtropics are under the influence of monsoons, bringing humid air from over the oceans to produce rain over the land. In highly populated areas (e.g., Asia or India), this precipitation is essential for agriculture and food crop production. Sometimes a strong monsoon circulation can also bring flooding. Or, if the monsoon is late in a certain year, it can cause droughts.

9.2 GLOBAL MONSOON AFRICA

The monsoon of western Sub-Saharan Africa is the result of the seasonal shifts of the Intertropical Convergence Zone and the great seasonal temperature and humidity differences between the Sahara and the equatorial Atlantic Ocean. It migrates northward from the equatorial Atlantic in February, reaches western Africa on June 22, then moves back to the south by October. The dry, northeasterly trade winds, and their more extreme form, the harmattan, are interrupted by the northern shift in the ITCZ and resultant southerly, rain-bearing winds during the summer. The semiarid Sahel and Sudan depend upon this pattern for most of their precipitation.

9.3 NORTH AMERICA

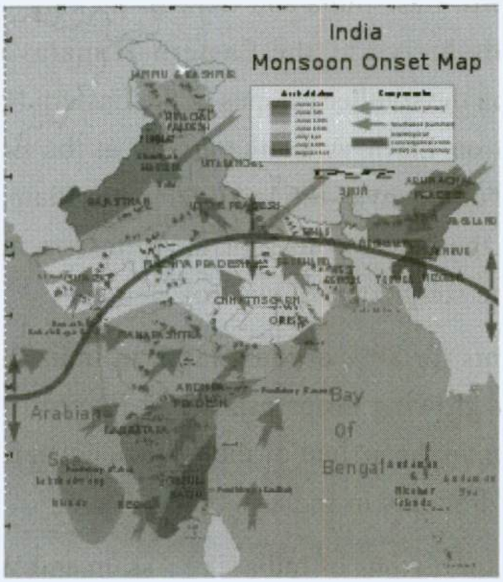
The **North American monsoon (NAM)** occurs from late June or early July into September, originating over Mexico and spreading into the southwest United States by mid-July. It affects Mexico along the Sierra Madre Occidental as well as Arizona, New Mexico, Nevada, Utah, Colorado, West Texas and California. It pushes as far west as the Peninsular Ranges and Transverse Ranges of Southern California, but rarely reaches the coastal strip of USA.

9.4 ASIA

The Asian monsoons may be classified into a few sub-systems, such as the South Asian Monsoon which affects the Indian subcontinent and surrounding regions, and the East Asian Monsoon which affects southern China, Korea and parts of Japan.

9.5. SOUTH ASIAN MONSOON

9.5.1. Southwest monsoon



The southwestern summer monsoons occur from June through September. The Thar Desert and adjoining areas of the northern and central Indian subcontinent heats up considerably during the hot summers, which causes a low pressure area over the northern and central Indian subcontinent. To fill this void, the moisture-laden winds from the Indian Ocean rush in to the subcontinent. These winds, rich in moisture, are drawn towards the Himalayas, creating winds blowing storm clouds towards the subcontinent. The Himalayas act like a high wall, blocking the winds from passing into Central Asia, thus forcing them to rise. With the gain in altitude of the clouds, the temperature drops and precipitation occurs. Some areas of the subcontinent receive up to 10,000 mm (390 in) of rain.

The southwest monsoon is generally expected to begin around the start of June and fade down by the end of September. The moisture-laden winds on reaching the southernmost point of the Indian Peninsula, due to its topography, become divided into two parts: the *Arabian Sea Branch* and the *Bay of Bengal Branch*.

The *Arabian Sea Branch* of the Southwest Monsoon first hits the Western Ghats of the coastal state of Kerala, India, thus making the area the first state in India to receive rain from the Southwest Monsoon. This branch of the monsoon moves northwards along the Western with precipitation on coastal areas, west of the Western Ghats. The eastern areas of the Western Ghats do not receive much rain from this monsoon as the wind does not cross the Western Ghats.

The *Bay of Bengal Branch* of Southwest Monsoon flows over the Bay of Bengal heading towards North-East India and Bengal, picking up more moisture from the Bay of Bengal. The winds arrive at the Eastern Himalayas with large amounts of rain. Mawsynram, situated on the southern slopes of the Eastern Himalayas in Shillong, India, is one of the wettest places on Earth. After the arrival at the Eastern Himalayas, the wind turns towards the west, travelling over the Indo-Gangetic Plain, pouring rain all along its way. June 1 is regarded as the date of onset of the monsoon in India, as indicated by the arrival of the monsoon in the southernmost state of Kerala.

The monsoon accounts for 80% of the rainfall in India. Indian agriculture is heavily dependent on the rains, for growing crops especially like cotton, rice, oilseeds and coarse grains. A delay of a few days in the arrival of the monsoon can badly affect the economy, as evidenced in the numerous droughts in India in the 1990s.

Bangladesh and certain regions of India like Assam and West Bengal, also frequently experience heavy floods during this season. And in the recent past, areas in India that used to receive scanty rainfall throughout the year, like the Thar Desert, have surprisingly ended up receiving floods due to the prolonged monsoon season.

9.5.2. Northeast monsoon

Around September, with the sun fast retreating south, the northern land mass of the Indian subcontinent begins to cool off rapidly. With this air pressure begins to build over northern India, the Indian Ocean and its surrounding atmosphere still holds its heat. This causes the cold wind to sweep down from the Himalayas and Indo-Gangetic Plain towards the vast spans of the Indian Ocean south of the Deccan peninsula. This is known as the **Northeast**

Monsoon or **Retreating Monsoon**

While travelling towards the Indian Ocean, the dry cold wind picks up some moisture from the Bay of Bengal and pours it over peninsular India and parts of Sri Lanka. Cities like Chennai, which get less rain from the Southwest Monsoon, receive rain from this Monsoon. About 50% to 60% of the rain received by the state of Tamil Nadu is from the Northeast Monsoon. In Southern Asia, the northeastern monsoons take place from December to early March when the surface high-pressure system is strongest.

9.5.3. East Asian Monsoon

The East Asian monsoon affects large parts of Indo-China, Philippines, China, Korea and Japan. It is characterized by a warm, rainy summer monsoon and a cold, dry winter monsoon. The rain occurs in a concentrated belt that stretches east-west except in East China where it is tilted east-northeast over Korea and Japan. The seasonal rain is known as *Meiyu* in China, *Changma* in Korea, and *Bai-u* in Japan, with the latter two resembling frontal rain.

The onset of the summer monsoon is marked by a period of pre-monsoonal rain over South China and Taiwan in early May. From May through August, the summer monsoon shifts through a series of dry and rainy phases as the rain belt moves northward, beginning over Indochina and the South China Sea (May), to the Yangtze River Basin and Japan (June) and finally to North China and Korea (July). When the monsoon ends in August, the rain belt moves back to South China.

9.6. AUSTRALIAN MONSOON

Also known as the **Indo-Australian Monsoon**. The rainy season occurs from September to February and it is a major source of energy for the Hadley circulation during boreal winter. The *Maritime Continent Monsoon* and the *Australian Monsoon* may be considered to be the same system, the Indo-Australian Monsoon.

It is associated with the development of the Siberian High and the movement of the heating maxima from the Northern Hemisphere to the Southern Hemisphere. North-easterly winds flow down Southeast Asia, are turned north-westerly/westerly by Borneo topography towards Australia. This forms a cyclonic circulation vortex over Borneo, which together with descending cold surges of winter air from higher latitudes, cause significant weather phenomena in the region.

9.7. EUROPEAN MONSOON

The **European Monsoon** (more commonly known as the **Return of the Westerlies**) is the result of a resurgence of westerly winds from the Atlantic, where they become loaded with wind and rain. These Westerly winds are a common phenomenon during the European winter, but they ease as Spring approaches in late March and through April and May. The winds pick up again in June, which is why this phenomenon is also referred to as "the return of the westerlies".

The rain usually arrives in two waves, at the beginning of June and again in mid to late June. The European monsoon is not a monsoon in the traditional sense in that it doesn't meet all the requirements to be classified as such. Instead the Return of the Westerlies is more regarded as a conveyor belt that delivers a series of low pressure centers to Western Europe where they create unseasonable weather. These storms generally feature significantly lower than average temperatures, fierce rain or hail, thunder and strong winds.

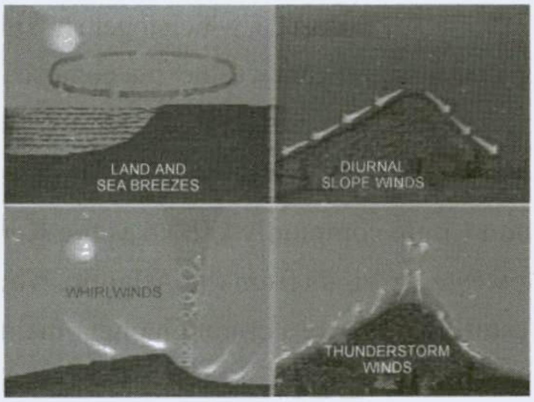
The Return of the Westerlies affects Europe's Northern Atlantic coastline, more precisely Ireland, Great Britain, Western Germany, Northern France and parts of Scandinavia.

9.8 LOCAL WINDS

Local winds are winds that blow over short distances caused by unequal heating of the earth's surface in a small area. Local winds blow over a much smaller area than global winds and have a much shorter time span. Hot winds originate in vast anticyclones over hot deserts and include the Santa Ana (California), the Brick fielder (south-east Australia), the Sirocco (Mediterranean), the Haboob (Sudan), the Khamsin (Egypt), and the Harmattan (WestAfrica)

9.9 COMMON LOCAL WINDS

Winds of local origin, convective winds, can be as important in fire behavior as the winds produced by the large-scale pressure patterns. In many areas, they are the predominant winds in that they overshadow the general winds. If their interactions are understood and their patterns known, local convective winds can be predicted with reasonable Some common local, convective winds are:



9.10 LAND AND SEA BREEZES

The surface properties that cause land surfaces to become warmer than water surfaces during the daytime. As a result of this local-scale temperature and pressure difference, a sea breeze begins to flow inland from over the water, forcing the warm air over the land to rise and to cool adiabatically. In the absence of strong general winds, this air flows seaward aloft to replace air which has settled and moved toward shore, and thus completes the circulation cell. The surface sea breeze begins around midmorning, strengthens during the day, and ends around sunset.

The land breeze at night is the reverse of the daytime sea breeze circulation. At night, land surfaces cool more quickly than water surfaces. Air in contact with the land then becomes cooler than air over adjacent water. Again, a difference in air pressure develops over the land and the water causing air to flow from the land to the water. The air must be replaced, but return flow aloft is likely to be weak and diffuse and is diminished in the prevailing general winds. The land breeze begins 2 to 3 hours after sunset and usually ends shortly after sunrise.

Another combination of convective winds results in slope winds. Slope winds are local diurnal winds present on all sloping surfaces. They flow upslope during the day as the result of surface heating, and down slope at night because of surface cooling. Slope winds are produced by the local pressure gradient caused by the difference in temperature between air near the slope and air at the same elevation away from the slope.

During the daytime, the warm air sheath next to the slope serves as a natural chimney and provides a path of least resistance for the upward flow of warm air. The layer of warm air is-turbulent, increasing in depth as it progresses up the slope. This process continues during the daytime as long as the slope is receiving solar radiation. When the slope becomes shaded or night comes, the process is reversed.

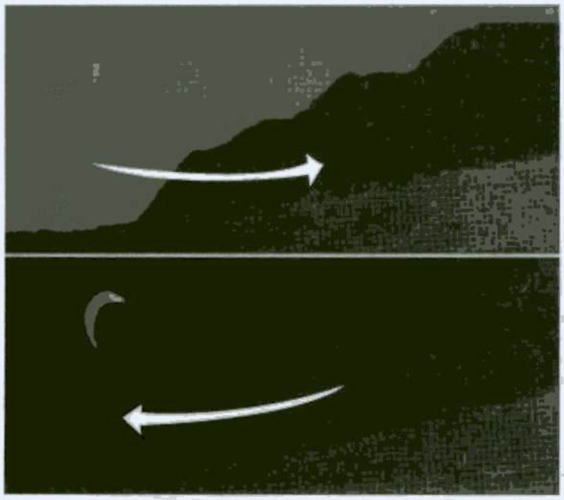
9.11. SLOPE AND VALLEY WINDS

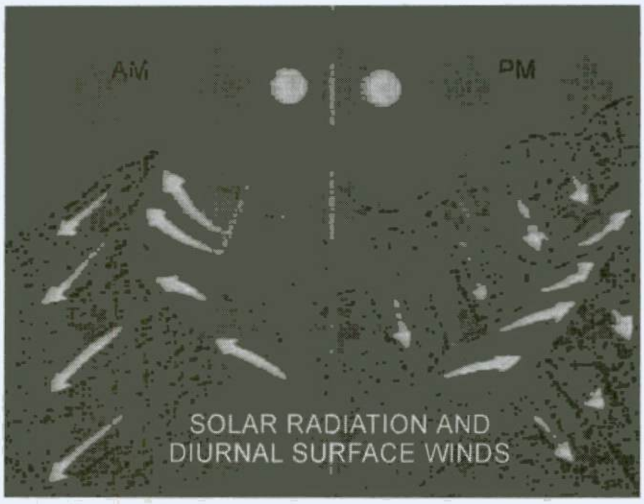
The figure below illustrates the valley winds. During the day, air in mountain valleys and canyons tends to become warmer than air at the same elevation over adjacent plains or larger valleys, thus creating a pressure gradient and resulting in upvalley winds. The main difference between upslope winds and upvalley winds is that the upvalley winds do not start until most of the air mass in the valley becomes warmed. Usually this is middle or late afternoon, depending largely on the size of the valley. These winds reach their maximum speeds in early afternoon and continue into the evening.

The transition from upvalley to downvalley flow takes place in the early night. The transition is gradual: first the downslope winds, then a pooling of cool, heavy air in the valley bottoms. The cool air in the higher valley bottoms will flow to lower elevations and increase in velocity as the pool of cool air deepens. This continues through the night and diminishes after sunrise.

The velocities of the slope and valley winds vary considerably by terrain and current weather conditions. For example, slope and valley winds develop better under clear skies when the heating and cooling processes are more pronounced.

We can give you some broad ranges to indicate typical wind speeds in mountain topography. Upslope winds usually range from 8 to 12 miles per hour, while downslope winds are somewhat less; 2 to 7 miles per hour. Upvalley winds typically are stronger, 12 to 20 miles per hour, while downvalley winds can be 8 to 14 miles per





The illustrations of slope and valley winds to this point might suggest that upslope and upvalley winds occur on all slopes at the same time. This is not usually the case. For one example, see the graphic above. Let's suppose we have a ridge line and canyon parallel to each other running north and south. In the morning, the east aspects will be heated by the sun, but the west aspects are shaded. Upslope winds can occur on the east slopes, while downslope winds occur on the west slopes. As the sun passes overhead and into the afternoon positions, the west slopes become heated and the east slopes become shaded. The slope winds can reverse from those of the morning.

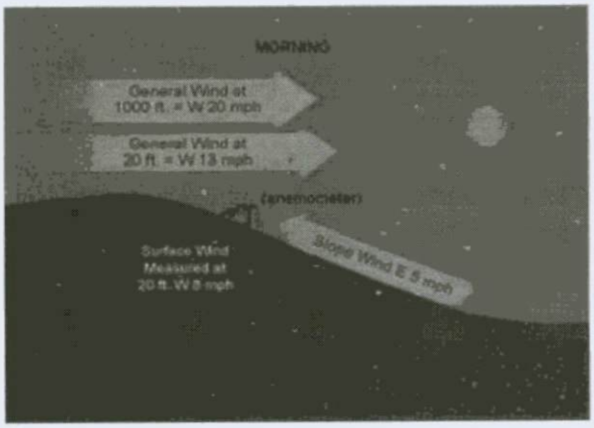
9.12. SURFACE WINDS

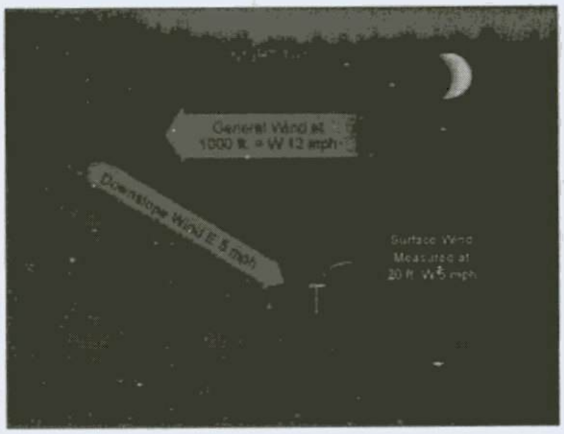
In this example, the general wind at 1000 feet is west at 10 miles per hour. As this wind drops closer to the surface, its speed is reduced to 7 miles per hour by frictional drag. We will refer to this windspeed as the general wind component. The upslope wind or the local wind component is 5 miles per hour. We can add the two components together to arrive at the surface wind speed of 12 miles per hour.1

In this example, the general wind is blowing in the opposite direction and opposing the east slope wind. At the anemometer, the general wind component is stronger than the local slope wind component. The surface wind at that point would probably be the difference between the two opposing windspeeds, or a west wind at 8 miles per hour.

This example shows a nighttime situation where an inversion layer has developed in the valley. Here the general wind is confined to levels above the inversion by the stable air and therefore affects surface winds only at higher elevations. The surface wind at the anemometer will be the same as the downslope wind component.

From these examples, you can see how surface winds are dependent on time of day, position on slope, and the strength and direction of the various wind components.





9.13. LET US SUM UP

Seasonal winds are movements of air repetitively and predictably driven by changes in large-scale weather patterns. Seasonal winds occur in many locations throughout the world. The name assigned to a particular seasonal wind—and the underlying physical forces that drive the winds—depend upon the unique geographic location. **Local winds** are small scale convective winds of local origin caused by temperature differences. Local terrain has a very strong influence on local winds, and the more varied the terrain, the greater the influence.

9.14. KEY WORDS

Monsoon, south Asian Monsoon, Local and seasonal winds

9.15. QUESTIONS FOR SELF STUDY

1. What is Southwest Monsoon? Explain the causes of Southwest monsoon
2. Explain the mechanism of monsoon and describe the south Asian Monsoon in detail.
3. Distinguish local and seasonal winds and explain some of the common local winds with a neat diagram
4. Describe the prominent Monsoon regions of the world other than India
5. Write a short note on Southeast monsoon

9.16. FURTHER READINGS

Climatology

1. Barry R.G. & Chorley, R.J. : "Atmosphere, Weather and Climate", Routledge, 1998.
2. Critchfield H : "General Climatology" Prentice-Hall, New York, 1975.
3. Das P.K. : The Monsoons, National Book Trust, New Delhi, 1968.
4. Lal D.S : "Physical Geography"Sharada Pustak Bhavan, Allahabad, 2009
5. Lydolph Paul, E. : The Climate of the Earth, Rowman and Allanheld, Totowa N.J., 1985.
6. Mather, J.R. : Climatology, McGraw-Hill, New York, 1974.
7. Patterson S. : Introduction of Meteorology, McGraw-Hill Book Co., London 1969.
8. Stringer E.T. : Foundation of Climatology, Surjeet Publications, Delhi, 1982.
9. Trewartha G.T. : An Introduction to Climate, International Students Edition, McGraw Hill, New York, 1980

UNIT-10 : TROPICAL CYCLONES AND THUNDERSTORMS

Structure:

10.0. OBJECTIVES

After studying this unit, you will be able to ;

- better understanding of Tropical Cyclones
- study the origin and characteristics of tropical cyclones and the regional distribution

10.1 INTRODUCTION

Geographically tropical atmosphere lies between the Tropic of Cancer and the Tropic of Capricorn. But in meteorology, the boundaries of the tropical atmosphere are determined by the high pressure cells of the subtropics. There are various kinds of weather disturbances exist within the tropics. Great deals of variations are observed in weather elements like temperature, precipitation and pressure etc. It is due to the amount of insolation received in the tropics. Ocean currents are also contributes a lot to the transfer or heat to the higher latitudes. The rate of exchange of energy between the oceans and atmosphere is greater in the tropics.

10.2 TROPICAL DISTURBANCES ARE CLASSIFIED IN TO FOUR CATEGORIES

1) Easterly waves 2) Tropical depressions 3) Tropical storms

4) Hurricane and Typhoons

1) Easterly waves: These are the migratory waves which move from east to west at a lower speed. The source of the occurrence lies between 5^0-30^0 latitudes in both the hemisphere. These waves travel in east to west direction at the rate at 32^0-48^0 kms per day.

2) Tropical depressions: Petterssen defines the tropical depressions as the center of low pressure around which the wind velocity hardly exceeds 40 km/hr. The depressions can occur any where, but they are quite frequent in the vicinity of Inter Tropical Convergence Zone (ITCZ). These depressions never grow in to storms of hurricane intensity; rather they die out as weak disturbances.

3) Tropical storms : Most favorable atmospheric conditions for their occurrence exist during summer season. Bay of Bengal and Arabian Sea offer ideal conditions for the origin of these storms. These storms produce heavy precipitation and bring about change in Weather. They are more violet and destructive type of tropical storms.

4) Tropical cyclones (Hurricane or Typhoons) : Hurricane is a severe tropical cyclone having a maximum speed of 119 kms/hr. the name 'hurricane' is given to the tropical cyclone in N. Atlantic and eastern N Pacific Ocean. In the western N pacific are know as typhoons. In Australia they call it as Willy-Willy, where as in the Indian Ocean they are called cyclones. In Philippines it is called 'bagnio'. Japanese call these storms as 'taifu.'. Elsewhere they are just called as 'tropical cyclones'.

Hurricanes present the most violent, most awesome, and most feared of all the atmospheric disturbances. According to Byers the tropical cyclones differ from the mid latitude cyclones. The tropical cyclones are found at certain seasons in well defined areas it the tropics. They form only over ocean having a high surface temperature (27^{0}c). They do not have fronts nor are they associate with moving cyclones. They derive their energy from the latent heat of condensations.

10.3 CHARACTERISTICS OF TROPICAL STORMS

The chief characteristics of these violent tropical storms are low pressure at the center and high wind velocity. Tropical hurricanes are nearly circular measuring 500 to 600 kms in diameter. It extends almost 12,000 mts. above MSL. They last for many days, in certain cases more than a week. According to Triwartha, there is a spiralling inflow of air at lower levels, a rapid movement at intermediate levels and a spiraling out wand flow aloft.

From the central low pressure core of the cyclone, winds converging from all directions are whirled upward. As a result of the lifting of air, condensation starts producing cumulonimbus clouds.

10.3.1. Structure

At the center the pressure is lowest. This is called the hurricane eye. The diameter ranges from 20 to 40 kms. In this central zone the winds are light & variable. The temperature is abnormally high. The hurricane eye is undoubtedly the warmest part of the storms. Heaviest precipitation is also recorded in the vicinity of this region.

In a well developed hurricane the movement of the wind in the Northern hemisphere in an anticlockwise and clockwise in the southern hemisphere. The pressure gradients are always steep. The velocity of the wind will be around 120 to 200 kms.hr. They produce large waves on the oceans. Near the core of the hurricane, there is a thick mass of clouds which yields heavy rainfall. In extreme cares more than 50 cms of precipitation may accumulate in one place. Rainfall diminishes towards the center where there is no rain at all.

10.4. ORIGIN OF TROPICAL CYCLONES (HURRICANES)

Tropical cyclone is like a heat engine that is energized by the latent heat of condensation. The amount of energy released in a hurricane is estimated to be equal to the total amount of electricity consumed in the US over 6 month's period. The energy liberated within a hurricane in one day is almost ten thousand times the daily power consumptions in the entire US. The energy released within a hurricane is equal to about 1,000 bombs of megaton strength (Donn, William, Meteriology 1975, p 338)

10.4.1. Movement and tracks of Hurricanes:

Hurricanes after their formation usually move towards the west and always from the equator. Their average speed is about 15 to 30 kms/hr. They also move along the trade winds and westrlies. Warm ocean currents also affect the path of cyclones. After reaching the western part of the tropical oceans, the cyclones curve towards the pole. When they meet westerlies, the hurricane move with a speed of 100 kms/hr. Whenever a tropical cyclone moves on land, the severity is reduced due to the absence of moisture. In other words no energy is available on land to maintain a cyclone. Therefore tropical cyclones always originate over oceans than land.

On Indian Ocean the movement of the tropical cyclones is different because these storms are influenced by monsoon circulation, and they move in northerly direction along with the monsoon currents. Storms originating over Caribbean Sea regions move westward towards Texas and Mexico. The storms that develop in the western part of the north pacific region move through the Philippines and north and toward China and Japan. In north Atlantic region high frequencies of tropical cyclones are fond in the months of Aug. Sept & Oct. The period from December to May is free from cyclones in the south western north pacific. Greatest frequencies are seen from July to October. There are no cyclones from february to April in these regions. There are no hurricane in south Atlantic due to the fact that the inter tropical convergence zone remains to the north of the equator so that no weak tropical disturbance develops over this ocean.

10.5. REGIONAL DISTRIBUTION OF TROPICAL CYCLONES

There are six regions of tropical cyclones

1) Tropical North Atlantic – West Indies, Gulf of Mexico and Caribbean sea,

2) Western part of the tropical North Pacific – Philippines, the China Sea and areas around Japan

3) Eastern part of the tropical North pacific – western coastal areas of Mexico and central America

4) The Bay of Bengal and Arabian sea

5) The South Indian oceans – Fiji Islands and east coast of Australia

10.5.1. Environmental importance of tropical cyclones

Tropical cyclones are the most destructive and violent type of storms. Islands and costal settlements are the targets of there cyclones.

Cyclones are associated with high pressure gradients and consequent strong winds, these in term generate storm surge. A storms surge is an abnormal rise of sea level near the cost caused by severe tropical cyclones, as a result sea water enters in to the low lying areas of coastal regions drowning human beings and live stocks, eroding beaches and destroying vegetation. Very strong winds may damage installations, dwellings, communication systems, trees, etc. resulting in loss of life and property. Heavy and prolonged rains may cause river floods, pollute drinking water sources causing outbreak of epidemics.

It may be mentioned that all the factors mentioned above occur simultaneously and, therefore, relief operations for distress mitigation become difficult. So it is imperative that advance action is taken for relief measures before the commencement of adverse weather conditions due to cyclones.

The most destructive element associated with an intense cyclone is storm surge. Past history indicates that loss of life is significant when surge magnitude is 3 metres or more and catastrophic when 5 meters and above.

10.6 THUNDER STORMS AND TORNADOES

Thunder and tornadoes are the violent storms represent external events and atmospheric hazards. They discharge large amount of energy in an extremely short time. Tornadoes are the most violent of all such storms and wreak great havoc. They are too small in horizontal extent and hardly appear in weather charts. Because of the destruction and death they leave, they have always been an important subject for investigation.

The most amazing feature of these storms is the fact that they are too small and short lives as to make their prediction very difficult. They strike with lightening speed so that within few minutes they destroy buildings and damage standing crops, make human life miserable.

Thunder storms have been defined as "storms produced by cumulonimbus clouds and always accompanied by lighting and thunder, followed by heavy rain and sometimes hail.

10.6.1. Origin and structure of Thunder storms

Thunder storms originate from cumulonimbus clouds. According to Trewartha thunder storms is like a thermo dynamic machine in which the potential energy of the latent heat of indentation is rapidly converted in to the kinetic energy of ascending air currents. Thunder storms represent the weather phenomenon which combines strong wind, thunder, lightning and torrential rains.

The vertical extent of a thunder storm depends on the intensity of ascending air currents. The height of thunder storms ranges from 4 to 20 kms. Besides there is a marked seasonal and latitudinal variation in the heights usually thunder storms develop in summer in tropical and the middle latitude regions due to the adequate supplies of moisture.

Thunder storms form when moist, unstable air is lifted vertically in to the atmosphere, lifting of this air results in condensation and the release of latent heat. Immediately after lifting begins, the rising warm moist air begins to cool because of the adiabatic expansion. At certain height the dew point is reached resulting in condensation and formation of a cumulus cloud. The cumulus clouds grow in to cumulonimbus cloud. When these clouds reaches a height of 20 kms, they create thunder, lightning, intense rain and tornadoes.

10.6.2. Two types of thunder storms are common

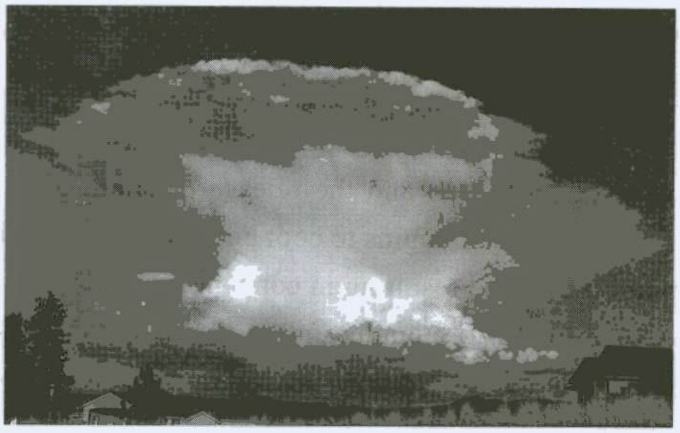
1) Air mass thunder storms of the mid latitudes in summer and at the equator all year along

2) Thunder storms associated with mid latitude cyclones

Air mass thunder storms normally develop in the late afternoon. The life cycle of these thunder storms have three stages: 1) Cumulus stage, 2) Mature stage 3) Dissipating stage.

Cumulus stage: In this stage, the parcel of humid warm air rises and cools to form cumulus clouds. When the updraft reaches maximum altitude of 12 to 14 kms, they change their direction 180^0 and become down drafts.

1) Mature stage: With the down drafts, precipitation begins to form and becomes cumulonimbus cloud. In this stage the thunder storms is several kms in diameter. The mature air mass thunder storm creates heavy rain, thunder and lightning.



2) Dissipating stage: In this stage the thunder storms begins to decrease in intensity and the convective storms move down ward. Within 1 hour the storm is finished and precipitation has stopped.

Distribution: In the N & S hemisphere from latitude 60^0 pole ward the frequency of thunder storms is least. They are most frequent in humid regions of the tropics. According in Blair, in Panama, Java and equatorial Africa, the average number of thunder storms is about 200 per year. The rocky mountain regions of US will have a maximum of 73 thunder storms per year.

10.7. TORNADOES

A tornado is a dark funnel-shaped cloud made up of violently rotating winds that can reach the speeds of up to 450 kms per hour. The diameter of a tornado can vary between a few meters and a kilometer, and its track can extend from less than a kilometer to several hundred kilometers. Tornadoes generally travel in a northeast direction (depending on the prevailing winds) at speeds ranging from 40-100 kms per hour. .

A Tornado is a vortex of rapidly moving air associated with serve thunderstorms. Winds within the tornado tunnel may exceed 900 kms per hr. High velocity of winds cause most of the damage associated with these weather events. The air pressure at the tornado center is approximately 800 mbs. The destructive path of the tornado is usually about half a km wide and no more than 25 kms long. The velocity of the tornado is measured by Fujita Tornado Intensity Scale also called as F-scale. According to the F scale strong tornado can have a wind speed between 182 and 332 kms per hour. The F4 & F5 [333 to 513km] tornados are very destructive and violent, but they are very rare.

Tornados occur in many parts of the world, notably South Africa, Australia, Europe, New Zeland, Northern India, Canada, Argentina and the United States. In US about 40,000 tornadoes have occurred in the last 50 years. Oklahoma receives more tornados then any other part of the world.

10.8. LET US SUM UP

Tropical storms, tornadoes and thunderstorms can be destructive and extremely dangerous weather phenomenon. Tropical storms bring high winds and sometimes severe flooding. Tornadoes, nature's most violent storms, can appear suddenly and without warning. Thunderstorms bring dangerous lightning, one of the leading causes of weather-related deaths in the United States each year. On the other hand tornadoes are dark, funnel-shaped clouds containing violently rotating air that develops below a heavy cumulonimbus cloud mass and extends toward the earth. In comparison with a cyclone, a tornado covers a much smaller area but is much more violent and destructive. The atmospheric conditions required for the formation of a tornado include great thermal instability, high humidity, and the convergence of warm, moist air at low levels with cooler, drier air above.

10.9 KEY WORDS

Key Words : Hurricane, Tornado

10.11. QUESTIONS FOR SELF STUDY

1. Explain the characteristics of tropical cyclones
2. Write a note on the origin and structure of Thunder storms
3. Explain how are tropical cyclones different from tornadoes?
4. Differentiate between tropical cyclones and mid-latitude cyclones?
5. How are tropical cyclones different from tornadoes?
6. Explain in detail the formation of tropical cyclones
7. What is a hurricane, typhoon, or tropical cyclone?

10.10. FURTHER READINGS

1. Barry,R.G. & Chorley, R.J. : "Atmosphere, Weather and Climate", Routledge, 1998.

2. Critchfield, H : "General Climatology" Prentice-Hall, New York, 1975.

3. Das,P.K. : The Monsoons, National Book Trust, New Delhi, 1968.

4. Lal D.S : "Physical Geography"Sharada Pustak Bhavan,Allahabad, 2009

5. Lydolph Paul, E : The Climate of the Earth, Rowman and Allanheld, Totowa, N.J., 1985.

6. Mather J.R : Climatology, McGraw-Hill, New York, 1974.

7. Patterson S : Introduction of Meteorology, McGraw-Hill Book Co., London, 1969.

8. Stringer E.T. : Foundation of Climatology, Surjeet Publications, Delhi, 1982.

9. Trewartha G.T : An Introduction to Climate, International Students Edition, McGraw Hill, New York, 1980

UNIT-11 : TEMPERATE CYCLONES (EXTRA TROPICAL CYCLONES)

Structure:

11.0. OBJECTIVES

After studying this unit, you will be able to ;

- Better understanding of the atmospheric disturbances
- Know the cyclones and anticyclones

11.1. INTRODUCTION

Cyclones are low pressur system that occur in the middle latitudes. They are neither ptropical. nor polar. Both are related with cold, warm and occluded fronts. Tropical Cyclones from in the tropics which can regenerate into extra-tropical cyclones on moving to higher latidues.

11.2. CYCLONES AND ANTICYCLONES

The storms we usually associate with the word "cyclone" are large storms which occur in the tropics, and may move north into the temperate zones in the form of hurricanes or typhoons. However, cyclones can and do occur at any latitude and in any climate. Those that are born within 30 degrees of the equator (north or south of that line) are tropical cyclones. Those found above 60 degrees north or south of the equator are arctic or polar cyclones.

The cyclones which occur between 30 and 60 degree latitude are called extra tropical or temperate cyclones. Tropical cyclones that move north into the temperate zones eventually become extratropical cyclones.

The atmospheric disturbances which involve a closed circulation about a low pressure center, anticyclone in the northern hemisphere and clock wise in the southern hemisphere are called cyclone.

There are two broad categories.

- Extra tropical cyclones
- Tropical cyclones

11.3. EXTRA TROPICAL CYCLONES

We come across cloudy weather in temperature zones is a result of traveling cyclones in mid latitude zones. The term "extra tropical" "temperate" or "depressions" are used to denote the moving cyclones in the mid latitudes zones. Since the mid latitudes are the areas of convergence, where contrasting air mass gradually meet. It is there that the cyclones and anticyclones travel with westerly winds as centers for converging and rising of air produce cloudiness and precipitation. Extra tropical cyclones develop in regions lying between 30 deg to 60 deg N&S latitudes. Where polar and tropical air masses meet and form what is known as polar front. On weather map cyclones is shown as a low pressure area enclosed by number of isobars. They are circular or elliptical in shape.

11.3.1. Shape and size:

There is a great degree of variation in shape and size of a mid lat cyclones and anticyclones. Generally the isobars are circular and elliptical but in certain cases the isobars take the shape of the "V". The axis of the type of depression is SW to NE direction. The diameter of the temperate cyclone varies from 160 km to 3,200 kms. But most of the cyclones have the diameters measuring 3,00 to 1500 kms. The estimated area covered by an average cyclone in US is about 1.6 million Sq Kms. The vertical extent is about 10- 12 km. Air pressure in a cyclone is lowest at the center and increases towards outer margin (as low as 940 – 930mb). The moderate cyclone may have about 1000 mb.

The air pressure in a cyclone is lowest at the center and increases towards its outer margins. The strong cyclonic circulation may have as low as 940 to 930 mbs. The pressure differences between the center and the outer margins of low may vary from 10 to 20 mbs.

11.4. PATH AND MOVEMENT OF EXTRA TROPICAL CYCLONES

The mid latitude cyclones are subjected to the general westerly flow of atmosphere in the temperate zone. The heavy concentration of storm tracks in the vicinity of the Aleutian and Icelandian low are the most important paths followed by the mid latitude cyclones. There is a seasonal shift of the path of cyclone and there is a altitudinal shift. During winter months opposing air masses have greater contrast and there are more number of cyclones in the mid latitude zones. And they are more intense. There is a greater variation in weather in temperate zone during winter than summer. Most of the cyclones and anticyclones in the westerly wind belt move from west to east. They "see" west in predicting the weather.

On an average the cyclones may cover a distance about 1000 km per day. Sometimes it varies from 500-2000 kms/day. The cyclones invariably move towards higher latitudes where as anticyclones originating in the mid latitudes mainly travel equator ward to the sub tropical region.

The most favorable areas for the rejuvenation of weather storms are Colorado and Alberta. Cyclones forming in Canada move south wards to the Great lake regions and then they turn towards northeast and move out in to Atlantic Ocean. Great lake regions are the strongest region in North America.

There are two major source regions in North America where the temperate cyclones originate. They are 1) Sierra Nevada regions 2) Eastern Colorado.

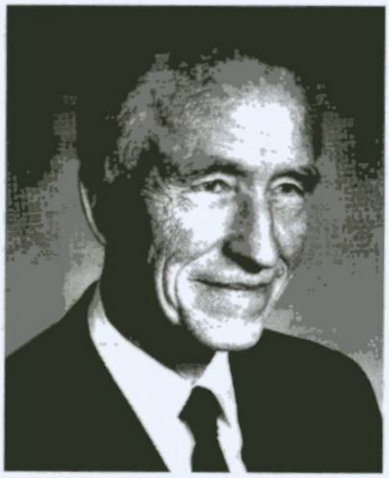
These storms move towards the Great lake regions and they produce heavy rain and snow. Great lake regions are the breading place for number of winter storms because of the steep temperature gradients. The Gulf of Mexico is another region where a number of storms originate.

In central Europe the large number of winter cyclones form over the Baltic Sea.

Cyclones move towards higher latitudes where as anticyclones originated in mid latitudes and travel towards equator and subtropical regions. Most of the temperate cyclones originating in north pacific off the eastern coast of Asia, move north word towards Gulf of Alaska – where they merge with Aleutian low.

Number of storms form over Mediterranean basin they move north ward reaching Soviet Union and the east as for as North India. In summer there are no temperate cyclones in the subtropical regions. In southern hemisphere the Antarctic frontal zone – storm occur all the year around.

11.5. ORIGIN OF TEMPERATE CYCLONES



Vilhelm Bjerknes (FATHER)

Jacob Aall Bonnevie

Bjerknes (SON)

It was toward the end of the First World War that the Norwegian meteorologists Vilhelm Bjerknes and his son J Bjerknes studied the structure of number of cyclones in Europe. Their efforts brought about major advances in the understanding of extra tropical cyclones. The theory that they put forth is called “the Bjerknes theory of the origin of cyclones”

Cyclones according to Bjerknes form along a front where polar and tropical air masses with contrasting physical properties are moving parallel to it in opposite directions. Middle latitudes are the areas of convergence where cold polar and warm tropical air masses generally meet.

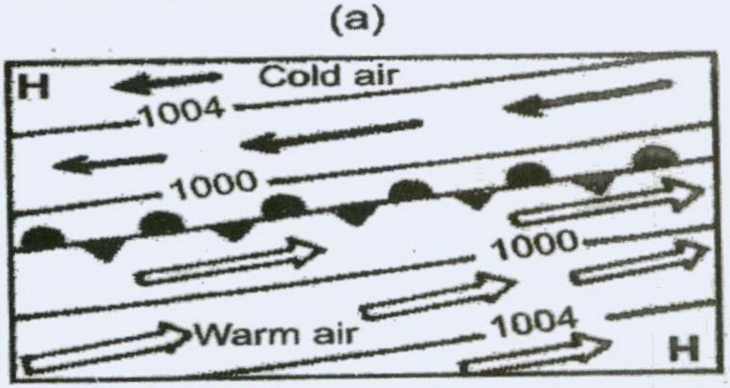
11.6. LIFE CYCLE OF EXTRA TROPICAL CYCLONES

There are four stages in the extra tropical cyclones in the northern hemisphere.

- Initial stages
- Incipient stage
- Mature stage
- Occlusions stage

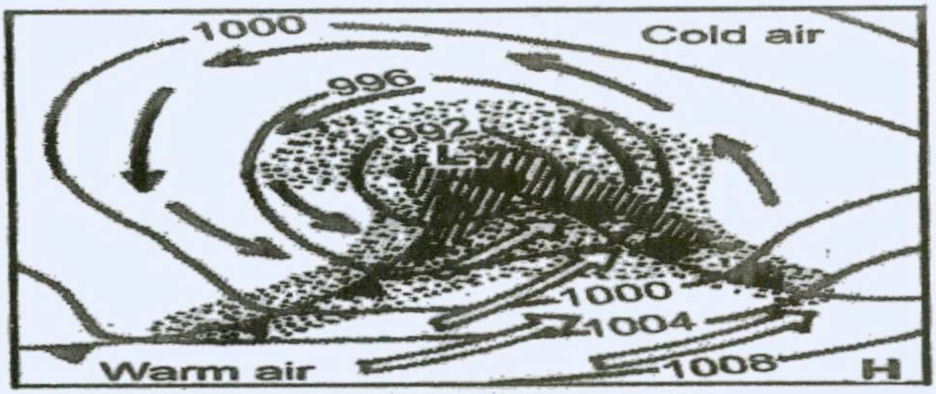
11.6.1. Initial stage

In the initial stage the polar and tropical air currents on the opposite sides of the polar front blow parallel to the isobars and the front. In the cold air mass to the north of the polar front the flow of the air is from east to west. In the warm air mass to the south of the front the flow of the air is from west to east. Therefore, the wave disturbance is produced; the front is quasi-stationary and is in perfect equilibrium.



11.6.2. Incipient stage

In the second stage wave is formed in the southerly direction and warm air in a northerly direction. There is an encroachment of each air mass in to the domain of the other. In this stage the isobars become almost circular in shape.



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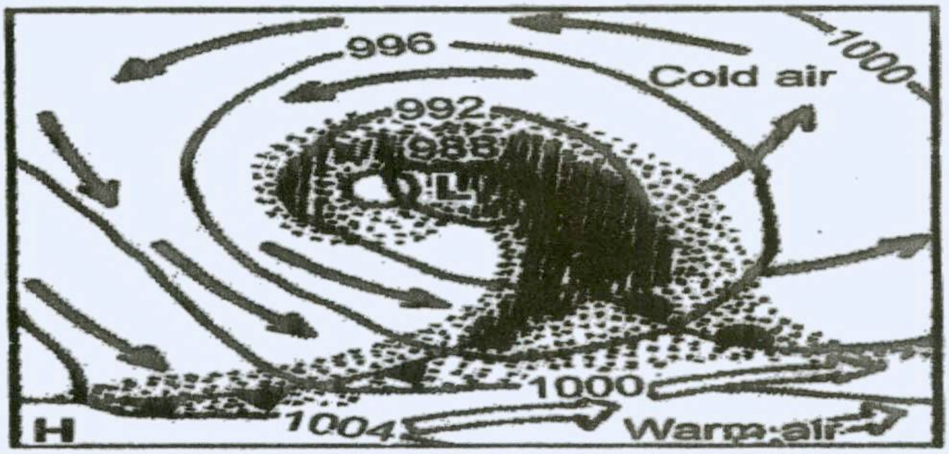
11.6.3. Mature stage

In the third stage the intensity of cyclone increases. The air in the warm sector starts flowing from the south west towards the cold air flowing from the south east. Now the cyclone is fully developed. There are well marked warm and cold sectors. Warm air in this stage moves faster than the cold air. The direction of the movement is perpendicular to the warm front. Infat, the warm air is moving in to a region previously occupied by the cold air. Each of these fronts is convex in the direction of its movements. If the rising air mass is moist, there will be condensation and precipitation along the warm as well as cold fronts.



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11.6.4. Fourth Stage

In the final stage, of the cold front ultimately overtakes the warm front which results in the formation of an occluded front. Finally the two air masses mix across the front. Now the cyclone dies out. The life span of a single frontal cyclone is normally about five to seven days.

11.7. EXTRA TROPICAL ANTICYCLONES

Anticyclones in the temperate regions play much less important role in the weather drama. The term "anti cyclone" was first used by **Sir Francis Galton** in 1861. It denotes an atmospheric system that is just the opposite of the cyclonic system. However, the anticyclones form one of the most important factors in weather forecasting. All the important cyclones are found over the Oceans in the vicinity of 30 N and S latitude

11.8. ORIGIN AND STRUCTURE OF ANTICYCLONES

Anticyclones are the high pressure systems around which the wind blows clock wise in the northern hemisphere and antilock wise in southern hemisphere.

There are two types of anticyclones:

- Cold core anticyclones of the higher latitudes
- Warm core anticyclones of the lower latitudes.

These rapidly moving anticyclones move southward towards the lower latitudes. In North America they originate Northern Canada and move southward and SE ward cross the central eastern United States.

In Asia they originate in the eastern part of Siberia and move towards China and Japan.Velocity of wind and pressure gradients is never so high in cyclones. On the other hand

Anticyclones have always high winds. Anticyclones are always associated with scanty rain fall. Anticyclones do not favor condensation and cloud formation. On occasions the cold north westerly wind may produce snowfall.

The surface conditions of the anticyclone depend upon temperature of the air masses involved, humidity of air, and season of the year.

In winter, the cold anticyclones originating in snow covered sub polar regions always bring with them very cold temperature. In summer, the air of the tropical or subtropical origin produce extremely high temperatures called heat waves. The range of temperature is bound to be large.

In winter there are two regions

North Western Canada, East central Siberia Nevada, Utah have the largest anticyclones Cold Canadian anticyclones which travels from their Centre of origin to mid Atlantic states brings cold waves. In Europe there are only few anticyclones moving south ward from the peninsular of Scandinavia. The great lake regions have maximum anticyclones in summer.

11.9. TYPES OF ANTICYCLONES

On the basis of the structure storms tracks and general characteristics anticyclones are divided in to the following types.

11.9.1. Sub tropical high:

These anti cyclones develop in the sub tropical regions, having large areas elongated in shape and very deep in vertical extent. They are almost permanent high pressure systems positioned in the high pressure belts. These anticyclones are well developed over the oceans, where there is low pressure over the continents.

11.9.2. Polar continental high:

These anti cyclones form over the continental surface in winter. They are produced by traditional cooling of the earth surface. At about 2500 mts above MSL they lose their identity. They are made up of very shallow layers of cold air.

11.10. LET US SUM UP

Extra-tropical cyclones are low pressure systems that occur in the middle latitudes. They have neither tropical nor polar characteristics. They are associated with cold, warm and occluded fronts. They derive energy from the horizontal temperature contrasts that exist in the atmosphere. They are more frequent in winter. On the other hand, tropical cyclones form in the tropics which can regenerate into extra-tropical cyclones on moving to higher latitudes; but extra-tropical cyclones never move into the tropics. Tropical cyclones derive their energy from the latent heat of condensation of the ascending moist air leading to cloud formation. Tropical cyclones originate in the summer and early autumn of each hemisphere and have isobars which are more symmetrical and circular than those in the extra-tropical one. Tropical cyclones have calm rainless centers (eye) which are absent in extra-tropical storms.

11.11. KEY WORDS

Extra tropical cyclones, Cyclones and Anticyclones

11.12. QUESTIONS FOR SELF STUDY

1. How are extra tropical cyclones different from tropical cyclones?
2. Explain the distributional patterns of extra tropical cyclones
3. Differentiate between cyclones and anticyclones
4. Explain the path and movements of temperate cyclones
5. Explain the life cycle of an extra tropical cyclone
6. Write a note on the origin and structure of anticyclones
7. What is the difference between a tornado and a cyclone?

11.13. FURTHER READINGS

1. Barry R.G. & Chorley, R.J. : "Atmosphere, Weather and Climate", Routledge, 1998.

2. Critchfield H : "General Climatology" Prentice-Hall, New York, 1975.

3. Das P.K. : The Monsoons, National Book Trust, New Delhi, 1968.

4. Lal D.S : "Physical Geography"Sharada Pustak Bhavan, Allahabad, 2009

5. Lydolp, Paul, E. : The Climate of the Earth, Rowman and Allanheld, Totowa, N.J., 1985.

6. Mather J.R. : Climatology, McGraw-Hill, New York, 1974.

7. Patterson S. : Introduction of Meteorology, McGraw-Hill Book Co., London, 1969.

8. Stringer E.T : Foundation of Climatology, Surjeet Publications, Delhi,1982.

9. Trewartha G.T. : An Introduction to Climate, International Students Edition, McGraw Hill, New York, 1980

UNIT-12 : AIR MASSES AND FRONTS

Structure:

12.0. OBJECTIVES

After studying this unit, you will be able to ;

- Know the air mass and fronts
- Identify temparate regions in both northern and sadaren hemispher
- Distinguish between tropical cyclones and anticyclones

12.1. INTRODUCTION

An air mass is a large body of air with similar temperature and/or humidity.

Air masses form in stable "source regions" such as in the sub tropics or near to the poles.Study of air mass provides an essential background for understanding the atmospheric disturbances. It brings about changes in day today weather particularly in mid latitudes. It plays a dominant role in producing different type of climate changes in the weather are the result of the interaction of air mass. Temperate regions in the northern hemisphere are the battle fields in the middle latitudes where warm tropical and cold polar air mass are brought together. These areas (temperate regions) are characterized by cyclones and anti cyclones. Air mass also carries large quantity of atmospheric moisture from ocean to continents and to yield precipitation.

The concept of air mass was developed by two Norwegian meteorologists Vilhem and Jacob (father and son) during the First World War. In 1920 -30 witnessed the development of this concept. It helps to predict weather conditions with in 24-36 hours.

12.2. DEFINITION AND CHARACTERISTICS

Air mass is an immense body of air usually 1600 kms to several kms thick with homogeneous physical properties at any given latitude. The body of air that moves over the land and sea surface acquires temperature and humidity characteristics which are uniform in horizontal direction at different levels. Since it may extend through 20 degree or more latitude covers hundreds to millions of square kms. Since air mass traverses an area in several days the region will have the same weather conditions. Along the margins of the air mass the weather changes very sharply.

When air remains in contact with the surface for a couple of days, it acquires the temperature and moisture of that area. If the surface is warm the heat is transferred due to the conduction process. If the surface is cold, the air above will be cooled and heat will be removed, similarly with moisture. The air is always tending to be in equilibrium. Such large uniform surface is called AIR MASS SOURCE REGION. When the air mass moves on the upper part of the atmosphere they retain the physical properties of the source region.

Two characteristics of an air mass control the weather.

- Vertical distribution of temperature
- Moisture content of the air

Air mass is associated with planetary wind system. Ex. Tropical maritime and tropical continental air masses are found in the trade wind belts. Therefore these air masses play an important role in removing latitudinal imbalance of heat.

Air mass with temperature lower than that of underlying surface is called cold air mass. Air mass with temperature warmer than underlying surface is called warm air mass.

If warm air mass moves from cold land surface to warm ocean surface, it is known as cold air mass. When they come in contact with each other they do not merge. But they retains the identity. Cold air masses are more instable than the warm air masses.

12.3. SOURCE REGIONS

Source regions are the areas where air masses are form or originate. The nature of the source region largely determines the temperature and humidity characteristics of an air mass.

12.3.1. What makes the ideal source region?

It must be an extensive and broadly uniform surface. The source region should have a gentle and divergent air flow for a long period of time. Therefore, the regions with high barometric pressure and low barometric gradient are the ideal source regions. Air masses are generally confined to tropical or polar regions. No major source regions are found in the middle latitudes. Tropical Atlantic ocean, tropical Pacific Ocean around Hawaii, the Sahara desert, Siberia, is the primary source regions. North Pacific Ocean, North Atlantic Ocean, between Canada and N Europe, SW of US is the secondary source regions. Air mass normally migrates from their source region to other regions. They not only modify the weather of the area they move, but they also get modified. When they move from source region, they retain their physical properties. They are uniform in their horizontal extent, but there will be some variations in their vertical distribution.

12.4. MODIFICATION OF AIR MASS

- When an air mass moves away from its source region, it will begin to change its temperature and moisture properties to that of the new underlying surface
- If an air mass is heated from below, that will lead to instability
- If an air mass is cooled from below, stability will increase
- For example, when cP air moves over the Great Lakes in the late-fall, heat and moisture is gained which results in "lake effect" snow showers
- Air masses also may be modified by ascent and descent (mP moves up a mountain, precipitation removes the moisture, the air mass is more like cP on the other side)

There are two types of air mass modifications.

- Thermodynamic modifications
- Mechanical modifications

These modifications may occur either separately or in combinations.

12.5. THERMODYNAMIC MODIFICATIONS

Thermodynamic processes include such effects as heating from the below which decreases the vertical stability.

The modification of an air mass depends upon

a) Initial characteristics of air mass (temperature and moisture)

b) The nature of the underlying surface,

c) The path followed by the air mass

d) Time taken to reach the point of observation.

The air masses moving over a surface that is warmer than the ground temperature is bound to be heated from the below with the consequent laps rate and instability. These changes create the changes of condensation and precipitation. On the other hand an air mass moving over a colder surface is cooled from the below. This condition favors the formation of surface inversion which increases with stability of the air mass. It is clear that polar air masses move out of their source region tend to become more and more unstable. The tropical air mass on the other hand undergo a second type of modification develop an increased stability.

K and W letters are used to indicate Cold and Warm air mass

12.6. MECHANICAL MODIFICATIONS

The mechanical process of lifting an air mass over elevation of land, over colder air masses, or to compensate for horizontal convergence produces a change in an air mass. Turbulence mixing and the sharing action of wind also cause air mass modifications. The sinking of air from high elevations to relatively lower lands or from above colder air masses and the descent in subsidence and lateral spreading are also important mechanical modifications of air masses.

12.7. CLASSIFICATION OF AIR MASSES

Physical properties of air mass determine the weather. Satisfactory classification of an air mass must encompass these transitions. Air masses are classified on the basis of location of the source region and the nature of the surface.

According to Trewartha:

- Polar air mass (P)
- Tropical air mass (T)
- Further he sub divides in to
- Continental Air mass———c (small c letter)
- Maritime Air mass ————m (small m letter)

Continental air mass originates over the continents and maritime am originates on the Oceans. Maritime air mass will have large quantity of moisture, on the other hand continental am are originally dry.

- On the basis of source regions air mass may be of
- Continental Polar (cP)
- Maritime Polar (mP)
- Continental Tropical (cT)
- Maritime Tropical (mT)
- More elaboration classification of air mass (15 type)
- Wintertime Continental Polar (cP)
- Wintertime Continental Polar (cP)

- Summertime Continental Polar (cP)
- Wintertime Maritime Polar (mP)
- Summertime Maritime Polar (mP)
- Wintertime Maritime Tropical (mT)
- Summertime Maritime Tropical (mT)
- Continental Tropical (cT)

12.7.1. Wintertime Continental Polar (cP)

These air masses have their source region in the central Canada and Siberia. They are extremely cold, dry and stable. Since the surface is covered with snow. These are the coldest wintertime air masses. They create severe cold waves when they move. There are no clouds. They are modified when they move towards warm regions.

12.7.2. Summertime continental Polar (cP)

Source region: central part of high latitude continents. central Canada-surface heating-absence of snow –cool, dry-not necessarily stable-these are the modified air masses of wintertime cP.- heated from the lower layers-when cPK air mass moves out to oceanic surface, modified in to cPW

12.7.3. Wintertime Maritime Polar (mP)

These air masses are cool and moist and from over oceans in the higher latitudes. They are originally cP air masses undergone modifications over oceans. Few clouds in their source region. They are dragged in to cyclones, forced to ascend mountain barriers, resulting in heavy precipitation. Their lower layers are moist and unstable, dry and cold in their upper parts.

12.7.4. Summertime maritime polar (mP) air mass

These air masses originate in the source regions of mP air masses. They are cool and moist in the lower parts, temperature inversion takes place. They are stable and general temperature is slightly higher than that in the mP air masses

12.7.5. Wintertime tropical maritime (mT) air masses

Their source region is over warm oceans in both the hemisphere. They are warm, moist and unstable. They release abundant precipitation whenever they occur. The moisture is well distributed to high levels. When these air masses are lifted over high mountains, they produce heavy rainfall.

12.7.6. Summertime tropical maritime (mT) air masses

The source region is on the tropical oceans including the Caribbean Sea. They are very warm, moist and very unstable. The air masses have convective instability

12.7.7. Continental tropical (cT) air masses

They originate at the subtropical high pressure belts. They have high temperature and low moisture content. They do not spread extensively beyond it's source region. In US they are dry in both the season. In summer they are very hot. They produce thunderstorms or tornadoes.

12.8. FRONTS

In the previous section of this unit we have seen that air mass move with the general circulation of atmosphere. They differ in their temperature and moisture content. They also differ in their pressure and density. When two different air masses with sharp contrast in their physical characteristics, temperature, pressure and density resulted in the general circulation the front occur. They do not mix easily. Infact, they come in contact with one another along sloping boundary. Fronts are the transitional zones. Weather conditions with in the air mass are comparatively uniform. There is a discontinuous change in weather elements.

The 'Front" is synonymous with 'line of discontinuity'. It is the transitional zone between two air masses with 'different density'. The "Front" is given by the Norwayen meteorologist. Borrowed by analogy from the military front during I world war. Since air mass are 3 Dimensional- vertical as well as horizontal extents. Frontal surface may be defined as the 3 dimensional transitional zones between contrasting air mass. Air mass may be vast in size covering tens and thousand miles. In the narrow frontal zones there will be an abrupt change in temp, pressure and humidity. With in 3 kms sometimes there will be a change in temperature between 10 to 20 °C

General frontal characteristics

Fronts differ in their types, location, or aerial extent.

Temperature: there is a large difference in temperature across a front. Change may be abrupt or gradual depending upon the nature of the opposing air mass

Larger the difference in temperature, thinner the frontal zone & vice versa.

***Air pressure**:* Generally the isobars in a given air mass are smooth curves and there are no sharp bends. The bend is always towards the direction of low pressure.

Wind: wind movement is always controlled by the pressure gradient and coriolis force

Therefore the wind always blows from higher to lower pressure crossing the isobars at an acute angle.

Cloud and precipitation: Frontal activity is invariably associated with the cloudiness and precipitation. Since warm air moves up along the frontal surface, it cools adiabatically-which results in cloudy condition and precipitation. Clouds formed on slopping frontal surface extend for hundreds and thousands of Kms. Upward moving warm air above the wedge of cold and dense polar air mass. It is from these clouds that precipitation occurs.

12.9. FRONTOGENESIS AND FRONTOLYSIS

Tor Bergeron used the term "Frontogenesis' Latin meaning 'creation of altogether new fronts' or regeneration of decaying fronts already in existence. When contrasting air masses have convergent movement, the frontogenesis occurs. The temperature contrast in the converging air mass is another important prerequisite for the process of frontogenesis to occur. The fronts come in to existence only when the above two conditions are fulfilled simultaneously. In other words, the convergence of air mass with different temperature and densities is conducive for frontogenesis.

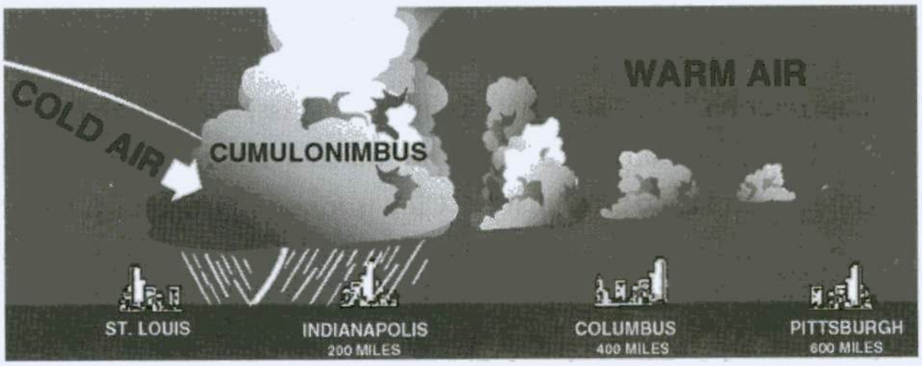
12.10. CLASSIFICATION OF FRONTS

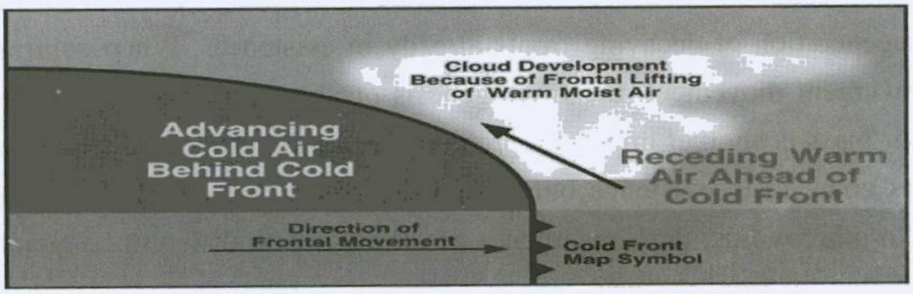
- Cold front
- Warm front
- Occluded front
- Stationary front

12.10.1. COLD FRONT

- It is a front along which cold air is invading the warm air zone. Since the cooler air is denser, it remains at the ground and forcibly uplifts the warmer and lighter air mass. The zone of transition is called cold front. The steepness of the front is closely related with the velocity- higher the velocity the greater the slope. When the cold front moves over a rough terrain, the lower air is retarded by the effect of friction at the ground. If the cold air moves over a warm water surface, the lower air absorb heat and moisture which results in heavy rainfall.

COLD FRONT



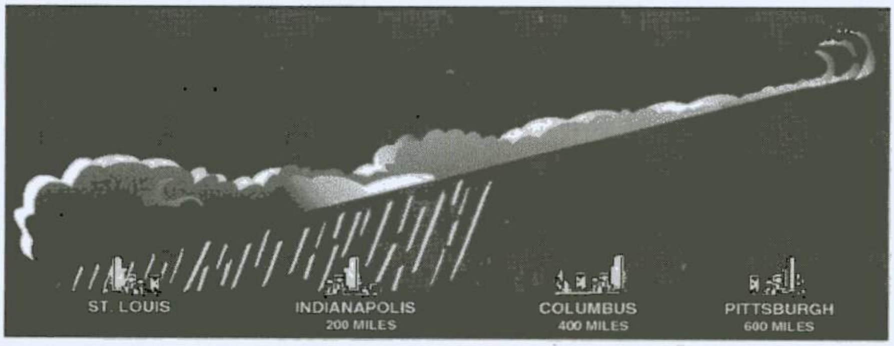


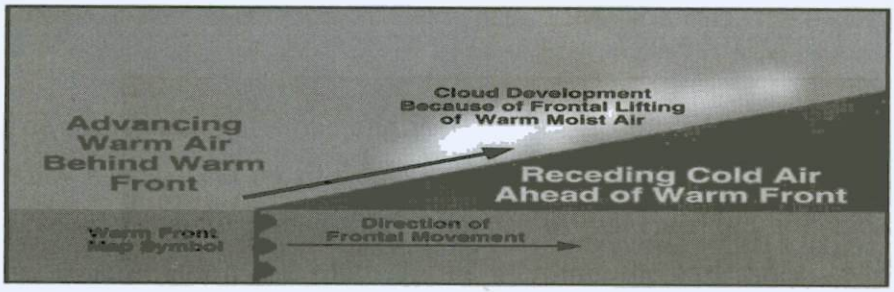
- Cold fronts are marked on weather maps as a **blue line** with blue triangles pointing in the direction of movement
- Temperature and humidity quickly drops after the cold front passes
- A decrease in pressure is also observed before the front, and an increase afterward
- Winds ahead of the front blow south/southwesterly while winds behind the front blow west/northwesterly
- Lifting of warm air along the cold front is pronounced
- Precipitation tends to be showery due to cumuliform clouds and limited to near the front itself
- Travel faster than any other kind of front

12.10.2. WARM FRONT:

It is a gently sloping frontal surface in which there is active movement of warm air over cold air. The warm air occupies the territory formerly covered by the

WARM FRONT



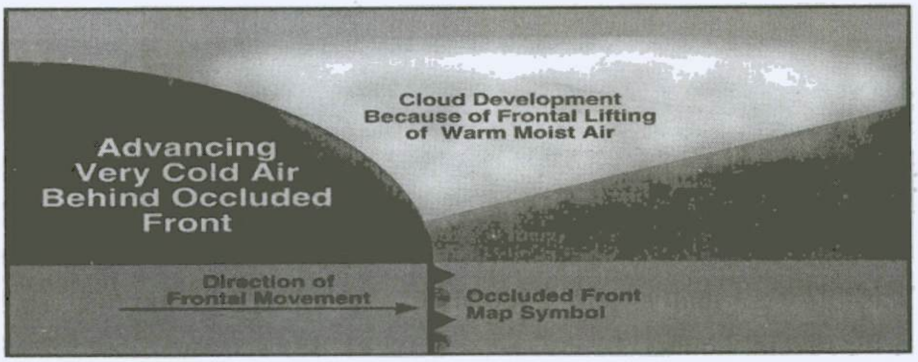


- cooler air. Unlike the cold front, the changes in temperature and wind direction are gradual. Warm fronts usually yield moderate to gentle precipitation over a relatively larger area for several hours.
- Marked on a weather map as a **red line** with red semicircles pointing in the direction of frontal movement.
- Temperature and humidity increase after frontal passage.
- Front is located in a region of lower pressure than the surroundings.
- Winds ahead of the warm front are easterly, while winds behind the front are southerly.
- Has a gentler slope than a cold front.
- Warm air can't push the cool air in front of it out of the way.
- The height of the clouds decrease as the front approaches.

12.10.3. OCCLUDED FRONT:

- Defend as front formed when cold front over takes a warm front. Cold front moves more rapidly when warm front with the result warm front progressively reduced in size. Ultimately the cold front over takes the warm front and completely displaces the warm air at the ground. Finally the cold and the warm front combine in to one.

OCCLUDED FRONT



- Occluded fronts are marked on a weather map with a **purple line** containing alternating warm and cold front symbols (both in purple) on the same side of the line indicating the movement of the front.
- Because warm fronts travel slower than cold fronts, cold fronts can overtake warm fronts.
- When this happens, the warm air is forced aloft as cold air surrounds the low pressure.
- A cold occlusion results if the cold air behind the cold front is the coldest air on the map.
- A warm occlusion results if the cold air behind the front is warmer than the cold air ahead of the warm front.

12.10.4. STATIONARY FRONT

- There are situations where the surface position of a front does not move. Therefore such a front is called a stationary front. The wind motion on either side of such a boundary is parallel to the position of the front.
- Stationary fronts are marked with a line containing alternating warm and cold front symbols (in their respective colors) showing the way the warm air or cold air would move if it could.
- Little or **no movement** of the frontal zone occurs at the surface
- The air aloft will usually be overrunning, producing clouds
- Weather conditions are usually similar to a warm front, but milder
- Extended periods of cloudiness and light precipitation can develop along the cooler air.

12.11. LET US SUM UP

An air mass is a large body of air whose properties of temperature and humidity are fairly similar in any horizontal direction.

A front is a transition zone between two air masses of different densities. The density contrast results from difference in temperature and humidity. The frontal zone (surface) is the upward extension of the front. Sometimes the frontal zones can be very sharp. The intensity of the weather along the front depends on the contrast of the air mass properties. The type of front depends on both the direction in which the air mass is moving and the characteristics of the air mass.

12.12. KEY WORDS

Air masses, fronts, Frontogenesis and Frontolysis

12.13. QUESTIONS FOR SELF STUDY

Climatology

1. Explain the characteristics of an air mass.
2. Discuss the factors responsible for the modification of air masses.
3. Give an account of the classification of air masses.
4. What are Frontogenesis and Frontolysis?
5. Explain the characteristics of warm and cold fronts.

12.14. FURTHER READINGS

1. Barry R.G. & Chorley, R.J. : "Atmosphere, Weather and Climate", Routledge, 1998.
2. Critchfield H : "General Climatology" Prentice-Hall, New York, 1975.
3. Das P.K. : The Monsoons, National Book Trust, New Delhi, 1968.
4. Lal D.S : "Physical Geography"Sharada Pustak Bhavan, Allahabad, 2009
5. Lydolph Paul E. : The Climate of the Earth, Rowman and Allanheld, Totowa N.J., 1985.
6. Mather, J.R. : Climatology, McGraw-Hill, New York, 1974.
7. Patterson, S. : Introduction of Meteorology, McGraw-Hill Book Co., London, 1969.
8. Stringer E.T. : Foundation of Climatology, Surjeet Publications, Delhi, 1982.
9. Trewartha G.T. : An Introduction to Climate, International Students edition, McGraw Hill, New York 1980.

UNIT-13 : JET STREAMS AND ANTI CYLCONES

Structure:

13.0. OBJECTIVES

After studying this unit, you will be able to;

- You will learn about the jet streams and anticyclones
- Know Air currents and their possible impact upon the surface weather conditions
- Know the study the inter relationship between jet streams and anticyclones

13.1. INTRODUCTION

Jet streams are defined as swift geostropic air streams in the upper atmosphere that meanders in relatively narrow belts. These are the strong cores of upper level westerly winds which flow meandering path.

It was towards the end of the Second World War that the existence of jet streams in the upper layer troposphere was made known to the meteorologists. During the Second World War American bomber pilots try to fly towards Japan at an altitude of 13,000 meters. They encountered strong head winds which greatly reduced their ground speed (sometimes to zero) but while returning to their bases in the east they found that the speed became much faster and at times even doubled because of high velocity tail wind. This upper level wind blowing with terrific speed is called jet stream. It is believed that there were certain clues to the existence of the jet streams as early as 1904. The early investigators while studying the high speed cirrus clouds pointed out that the existence of high velocity winds in the upper troposphere.

According to Trewartha, the jet streams are relatively narrow bands of stronger winds bounded by slower moving air. Jet stream is also described as a westerly air current in the form of a flattened narrow core or tube, thousands of kilometers in length, a few hundred kilometers in width. According to Patterson, the jet stream is almost entirely a thermal wind and its strength is proportional to the temperature contrast through the whole layer below.

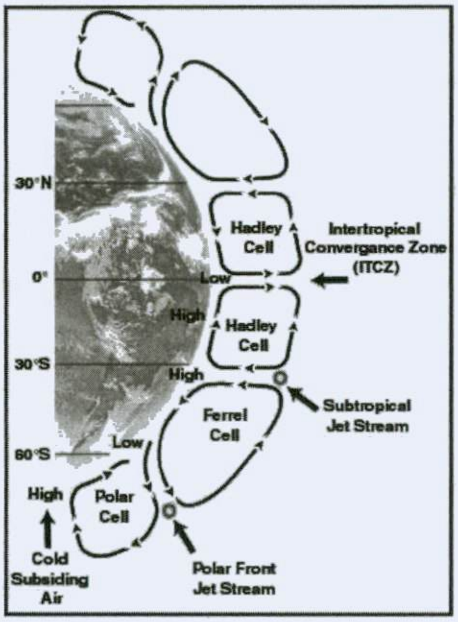
Because of the steep north –south temperature gradients the north south pressure gradients increases with height up to the level of the jet. This is the basic reason for the existence of jet stream. The westerly jet stream occur at elevation from 9,000 to 12,000 mts in the lower circumpolar in character. However the jet stream does not always blow from due west, but have some pole ward or equator ward component. They appear as North West wind at some longitudes and as south west wind at others. The jet streams of the middle latitudes follow a wavy and irregular path while moving around the earth. The deviations in the path of the jet streams are caused partly by the disturbing influence of continents particularly in the northern hemisphere and partly by the large travelling centers of high and low pressure (cyclones and anticyclones) at the sea level.

13.2. CHARACTERISTICS OF JET STREAMS

Jet streams are characterized by great seasonal variations. During the colder part of the year they migrate towards the equator and their velocity also increases. In summer the wind speed in jet stream are reduced to about half of the winter because of horizontal temperature gradients. In winter the jet stream extend far in the tropics.

According to Cole, such seasonal variations are linked with the seasonal changes in atmosphere at lower levels of the atmosphere. The mean velocity of the jet stream is about 144 kilometers per hour. But at times the wind velocity in the inner core of jet stream may be as high as 480 kilometers per hour or even more. During the cold season generally the wind travels at a speed of 160 to 240 kms per hour at the core of the jet stream.

Within the troposphere, there are two zones of high winds. These are called the "Jet Streams" and they move perpendicularly to the vertical wind cells previously discussed. These winds move from east to west rather than from the north to south or vice versa. At the Polar Front, the region along where the cold and dense polar air mass meets the warmer and less dense tropical air, there is a large temperature difference. Due to this large temperature difference there is a correspondingly large pressure difference which causes significant high level winds perpendicular to the front. These winds are known as the Polar Front Jet Stream. There is a similar temperature and pressure difference that occur at high levels between the Ferrel and Hadley Cells that create winds known as the Sub-tropical Jet Streams. Jet streams are defined as being those winds that exceed velocities of 30 m/s.



There are two types of jet streams: The polar front jet streams and the sub tropical jet streams. The polar front jet stream is a primary jet stream. It has the maximum speed of 215 kms per hour. Sometimes the polar front jet encircles the entire globe. There are diurnal variations in the position and the speed of the jet stream. At higher latitudes, the wind velocity is relatively higher on the right than on the left of the jet core. On the contrary at lower latitudes the wind of the right of the jet core is relatively slower than that on its left. The polar front jet is always associated with the polar front while the sub tropical jet does not seem to have any relationship with any frontal zone.

The strongest jet streams are the **Polar jets**, at around 7–12 km (23,000–39,000 ft) above sea level, and the higher and somewhat weaker **Subtropical jets** at around 10–16 km (33,000–52,000 ft). The Northern Hemisphere and the Southern Hemisphere each have both a polar jet and a subtropical jet. The northern hemisphere polar jet flows over the middle to northern latitudes of North America, Europe, and Asia and their intervening oceans, while the southern hemisphere polar jet mostly circles Antarctica all year round.

Jet streams are caused by a combination of a planet's rotation on its axis and atmospheric heating (by solar radiation and, on some planets other than Earth, internal heat). Jet streams form near boundaries of adjacent air masses with significant differences in temperature, such as the polar region and the warmer air towards the equator.

Meteorologists use the location of some of the jet streams as an aid in weather forecasting. The main commercial relevance of the jet streams is in air travel, as flight time can be dramatically affected by either flying with the flow or against the flow of a jet stream. Clear-air turbulence, a potential hazard to aircraft passenger safety, often is found in a jet stream's vicinity. One future benefit of jet streams could be to power airborne wind turbines.

Other jet streams also exist. During the northern hemisphere summer, easterly jets can form in tropical regions, typically in a region where dry air encounters more humid air at high altitudes. Low-level jets also are typical of various regions such as the central United States.

13.3. DISCOVERY OF THE JET STREAM

The exact first discovery of the jet stream is debated today because it took some years for jet stream research to become mainstream around the world. The jet stream was first discovered in the 1920s by Wasaburo Ooishi, a Japanese meteorologist who used weather balloons to track upper level winds as they ascended into the Earth's atmosphere near Mount Fuji. His work significantly contributed to knowledge of these wind patterns, but was mostly confined to Japan.

In 1934, knowledge of the jet stream increased when Wiley Post, an American pilot, attempted to fly solo around the world. To complete this feat, he invented a pressurized suit that would allow him to fly at high altitudes and during his practice runs, Post noticed that his ground and air speed measurements differed, indicating that he was flying in a current of air.

Despite these discoveries, the term "jet stream" was not officially coined until 1939 by a German meteorologist named H. Seilkopf when he used it in a research paper. From there, knowledge of the jet stream increased during World War II as pilots noticed variations in winds when flying between Europe and North America.

13.4. DEVELOPMENT OF JET STREAMS

A jet stream develops where air masses of differing temperatures meet. For this reason, surface temperatures determine where the jet stream will form. The greater the difference in temperature, the faster the wind velocity inside the jet stream. Jet streams can flow up to 200 mph (322 km/h), are 1000's of miles long, 100's of miles wide, and a few miles thick.

Cold polar air flowing down from the north meets the warmer air mass over the United States causing the **polar jet stream** to form. Areas of high and low pressure act like a moving riverbed, buckling and snaking the path of the jet stream as it flows to the east. During the winter, a second jet stream forms in the lower latitudes. It separates the air mass over the U.S. from warmer air masses rising from south of the equator. This is called the **subtropical jet stream**.

Within the jet stream, currents travel at varying speeds but are greatest at the core. Jet streaks are areas inside the jet stream where the velocity is higher than the rest of the stream. Jet streaks cause air to rise, which lowers pressure at the surface. When surface low pressures form the rising air can cause clouds, precipitation and storms. Therefore understanding and observing the jet stream is instrumental in accurate weather forecasting.

The jet stream can also contain *windshear*, a violent and sudden change in wind direction and speed. Windshear can occur outside the jet stream as well, even at the surface. When vertical winds blast downward it can cause an airliner that is in the process of take off to suddenly lose altitude and potentially crash. For this reason all commercial planes in the U.S. since 1996 have been equipped with windshear warning systems.

The jet stream was discovered in the final days of World War II when fighter planes flying to Japan found they were not making headway against the strong easterly winds. They ultimately changed altitude to make the flight. Today trips to the east coast by commercial airliner are shorter in duration than trips to the west coast, due to the jet stream pushing planes east.

There are those who have "walked" in the jet stream. Mt. Everest at over 29,000 feet (8,839 m) is so high that its summit actually sits in the jet stream with prevailing winds at about 118+ mph (190 km/h). Standing on the summit is a dangerous business and one has to pick the right moment carefully. Most prefer to summit in early May or fall when the jet stream pushes northward over Tibet.

13.5. DESCRIPTION AND CAUSES OF THE JET STREAM

It is understood today that there are two main jet streams in the northern hemisphere. While jet streams do exist in the southern hemisphere, they are strongest between latitudes of 30°N and 60°N. The weaker subtropical jet stream is located closer to 30°N. The location of these jet streams shift throughout the year however and they are said to "follow the sun" since they move north with warm weather and south with cold weather. Jet streams are also stronger in the winter because there is a large contrast between colliding Arctic and tropical air masses. In the summer, the temperature difference is less extreme between the air masses and the jet stream is weaker.

Jet streams typically cover long distances and can be thousands of miles long. They can be discontinuous and often meander across the atmosphere but they all flow east at a rapid speed. The meanders in the jet stream flow slower than the rest of the air and are called Rossby Waves. They move slower because they are caused by the Coriolis Effect and turn west in respect to the flow of air they are embedded in. As a result, it slows the eastward movement of the air when there is a significant amount of meandering in the flow.

13.6. IMPORTANCE OF THE JET STREAM

In terms of commercial usage, the jet stream is important for the airline industry. Its use began in 1952 with a Pan Am flight from Tokyo, Japan to Honolulu, Hawaii. By flying well within the jet stream at 25,000 feet (7,600 meters), the flight time was reduced from 18 hours to 11.5 hours. The reduced flight time and aid of the strong winds also allowed for a reduction in fuel consumption. Since this flight, the airline industry has consistently used the jet stream for its flights.

One of the most important impacts of the jet stream though is the weather it brings. Because it is a strong current of rapidly moving air, it has the ability to push weather patterns around the world. As a result, most weather systems do not just sit over an area, but they are instead moved forward with the jet stream. The position and strength of the jet stream then helps meteorologists forecast future weather events.

In addition, various climatic factors can cause the jet stream to shift and dramatically change an area's weather patterns. For instance, during the last glaciation in North America, the polar jet stream was deflected south because the Laurentide Ice Sheet, which was 10,000 feet (3,048 meters) thick, created its own weather and deflected it south. As a result, the normally dry Great Basin area of the United States experienced a significant increase in precipitation and large pluvial lakes formed over the area.

The world's jet streams are also impacted by El Nino and La Nina. During El Nino for example, precipitation usually increases in California because the polar jet stream moves farther south and brings more storms with it. Conversely, during La Nina events, California dries out and precipitation moves into the Pacific Northwest because the polar jet stream moves more north. In addition, precipitation often increases in Europe because the jet stream is stronger in the Northern Atlantic and is capable of pushing them farther east.

Today, movement of the jet stream north has been detected indicating possible changes in climate. Whatever the position of the jet stream though, it has a significant impact on the world's weather patterns and severe weather events like floods and droughts. It is therefore essential that meteorologists and other scientists understand as much as possible about the jet stream and continue to track its movement, to in turn monitor such weather around the world.

13.7. TYPES OF JET STREAMS

13.7.1. Polar jet

The polar jet stream can be thought of as the result of this frontogenesis process in midlatitudes.

13.7.2. Subtropical jet

A second factor which contributes to jet sharpness is more appropriate for the subtropical jet. The subtropical jet forms at the poleward limit of the tropical Hadley cell and to first order this circulation is symmetric with respect to longitude. Tropical air rises to the tropopause, mainly because of thunderstorm systems in the Intertropical Convergence

Zone, and moves pole ward before sinking; this is the Hadley circulation. As it does so it tends to conserve angular momentum, since friction is slight above the ground. In the northern hemisphere motions are deflected to the right by the Coriolis force, which for poleward (northward) moving air implies an increased eastward component of the winds. Around 30 degrees from the equator the jet wind speeds have become strong enough that were the jet to extend further polewards the increased windspeed would be unstable; thus the jet is limited.

13.8. OTHER UPPER LEVEL JETS

Polar night jet

The polar-night jet stream forms only during the winter months, i.e., polar nights, of the year in their respective hemispheres at around 60° latitude, but at a greater height than the polar jet, of about 80,000 feet (24,000 m).During these dark months the air high over the poles becomes much colder than the air over the equator. This difference in temperature gives rise to extreme air pressure differences in the stratosphere, which, when combined with the Coriolis effect, create the polar night jets, racing eastward at an altitude of about 30 miles (48 km). Inside the polar night jet is the polar vortex. The warmer air can only move along the edge of the polar vortex, but not enter it. Within the vortex, the cold polar air becomes cooler and cooler with neither warmer air from lower latitudes nor energy from the sun during the polar night.

13.9. LOW LEVEL JETS

There are wind maxima at lower levels of the atmosphere that are also referred to as jets.

13.9.1. Barrier jet

A barrier jet in the low levels formed just upstream of mountain chains, with the mountains forcing the jet to be oriented parallel to the mountains. The mountain barrier increases the strength of the low level wind by 45 percent. In the North American Great Plains a southerly low-level jet helps fuel overnight thunderstorm activity during the warm season, normally in the form of mesoscale convective systems which form during the overnight hours. A similar phenomenon develops across Australia, which pulls moisture poleward from the Coral Sea towards cut-off lows which form mainly across southwestern portions of the continent.

13.9.2. Valley exit jet

A valley exit jet is a strong, down-valley, elevated air current that emerges above the intersection of the valley and its adjacent plain. These winds frequently reach a maximum of 20 m/s (45 mph) at a height of 40-200m above the ground. Surface winds below the jet may sway vegetation but are significantly weaker.

They are likely to be found in valley regions that exhibit diurnal mountain wind systems, such as those of the dry mountain ranges of the US. Deep valleys that terminate abruptly at a plain are more impacted by these factors than are those that gradually become shallower as down valley distance increases.

13.9.3. African Jet

The mid-level African easterly jet occurs during the Northern Hemisphere summer between 10°N and 20°N above West Africa, and the nocturnal poleward low-level jet occurs in the Great Plains of east and South Africa. The low-level easterly African jet stream is considered to play a crucial role in the southwest monsoon of Africa, and helps form the tropical waves which march across the tropical Atlantic and eastern Pacific oceans during the warm season. The formation of the thermal low over northern Africa leads to a low-level westerly jet stream from June into October.

13.10 ANTI CYCLONES

Origin and structure

Anticyclones are high pressure systems around which the wind blows clockwise in the northern hemisphere, and counterclockwise in the southern hemisphere. There are various types of anticyclones such as the cold-core anticyclones of the high latitudes and the warm-core anticyclones of lower latitudes.

According to some other meteorologists there is a third category of anticyclones which are described as the sluggish systems filling the spaces between moving temperate cyclones.

Cold anticyclones of the middle latitudes are also called 'polar outbreak highs'. Sometimes the last member of a cyclone family draws cold air masses from the sub-polar regions in its rear part. These rapidly moving anticyclones move southward towards the lower latitudes.

This produces the cold waves so often experienced in the southern parts of the temperate regions. When they enter into the subtropical regions, they undergo a gradual transformation and ultimately become warm anticyclones.

In North America they originate in northern Canada and, move southward and southeastward across the central eastern United States. In Asia they originate in the eastern part of Siberia and move towards China and Japan.

The exact mechanism of the formation of anticyclones is still not clear. But the most probable cause of their formation seems to be the radiational cooling of the layers of atmosphere lying close to the snow-covered surface.

According to Trewartha, the southward surge of extremely cold and dense polar air is caused by the combined effect of an upper-air long wave and an expulsion of cold Arctic Basin air aloft. Since there is subsidence within these anticyclones, there is subsidence inversion produced in the atmosphere which results in atmospheric stability. Under certain conditions, an anticyclone may undergo distinct development and may become intense.

These developments are invariably associated with intense cyclonic activity in the neighboring areas. Even then the anticyclones never develop such intensities as are acquired by well-developed cyclones.

However, it is to be remembered that the individual anticyclones are made up of different types of air masses at different times. Therefore the weather associated with them always shows different characteristics.

But one characteristic is always shared by all the anticyclones, i.e. they are never affected by advection from extraneous sources. The weather produced by any anticyclone is very much regional and diurnal in character.

Anticyclone circulation is characterized by subsidence and surface divergence. Anticyclone wind system is not so well developed as is the case with a cyclonic circulation. In the eastern part of a moving anticyclone, there are north-westerly winds, while on the westward side or on the rear the southeasterly winds prevail.

Pressure gradient is never so steep and the wind-velocities are never as high as in a cyclone. On the other hand, anticyclones have always high winds. The front part of cold-core anticyclones is always marked by cold waves and blizzards in the middle latitudes.

Unlike cyclones, the anticyclones are always associated with scanty rainfall. Subsidence and divergent wind system within an anticyclone do not favour condensation and cloud formation.

But in case the southeasterly air is moist, there may be some precipitation on the rear of an anticyclone.

On occasions, the cold northwesterly winds may produce snowfall. Whatever uncertainty in weather is produced, it is because the anticyclones are often capped by cyclonic circulation aloft.

The surface temperature conditions in an anticyclone depend upon temperature of the air masses involved, humidity of air, and season of the year.

In winter, the cold anticyclones originating in the snow-covered sub-polar legions always bring with them very low temperatures and blizzards which render the winter chill unbearable. The middle-latitude anticyclones always produce the lowest temperatures of the season.

In summer, the stagnant type of warm anticyclones associated with the air of subtropical or tropical origin produce extremely high temperatures, called 'heat waves'. Clear weather allows the maximum receipts of solar radiation during the day. Tropical air masses carry heat to the north as the high pressure system moves into the sub-polar regions. Since the anticyclone conditions favour clear weather, the diurnal range of temperature is bound to be large.

13.11. DISTRIBUTION OF ANTICYCLONES

The regions of origin and paths of movement of the cold and warm anticyclones are different. Sub-polar regions give birth to cold anticyclones which always move towards the south.

The warm anticyclones generally move from west to east. However, the source regions as well as the tracks followed by anticyclones tend to shift towards the north in summer and south in winter.

In winter, there are two regions of high frequency of cold anticyclones: the extensive plateau of the Rocky Mountains in northwestern Canada and east central Siberia. The states of Nevada, Utah, and Idaho have the largest number of anticyclones.

The area extending from Alaska to the Great Plains has high frequency of high pressure systems. These anticyclones are cold and shallow highs comprising the polar continental air (cP).

The cold Canadian anticyclones, which travel from their centers of origin to the Middle Atlantic States, bring with them cold waves, blizzards or snow storms and lowest temperatures to the Mississippi Valley. Some of these anticyclones push their way to the Gulf States where they are called 'norther', the most dreaded weather phenomenon.

Cold anticyclones originating in east central Siberia travel towards northern China and reach the mouth of the Yangtze River. They sometimes cross over to Japan.

In Europe, there are only a few cold anticyclones moving southward from the Peninsula of Scandinavia.

In summer, as stated earlier, the storm paths and their centers of maximum frequency shift towards the north. The Great Lake region has a maximum of anticyclone frequency in summer, whereas the cold anticyclones of the winter months avoid this region because of intense cyclonic development there.

In eastern Asia too, the number of anticyclones is greatly reduced. Some of the feeble anticyclones move across China in summer. Now, the subtropical anticyclones follow a more northerly route.

Their frequency over the eastern Pacific is high, and there are only a few high pressure systems in the western part.

This is so because in this part of the Pacific the summer monsoon dominates the weather drama. A number of warm subtropical anticyclones pass over the Mediterranean Sea.

13.12 CHARACTERISTICS OF ANTICYCLONES

It may be noted that in winter the anticyclones form with a great regularity in the higher latitudes of the continents. Since these anticyclones result from radiational cooling of the earth's surface, they are also called thermal anticyclones.

In the upper troposphere they either disappear or shift towards the lower latitudes. On the contrary, the anticyclones that form over the ocean surface have warm air in their upper parts. Such anticyclones are called dynamic anticyclones. These anticyclones maintain their vigour up to considerable heights.

The warm season anticyclones are invariably associated with clear weather, but some of the winter highs produce cumulus or cumulonimbus clouds. In winter, the anticyclonic conditions are conducive to the formation of radiation fogs during night.

On the rear of these anticyclones warm and moist air currents from over the oceans produce advection fogs. On certain occasions, the day-time surface heating causes the dissipation of fog at the surface, but the remaining fog still persists at higher levels.

When looked at from the surface of the earth, these upper-level fogs appear as low stratus clouds. These foggy layers do not allow the light rays to reach the surface in toto. In the middle-latitude regions this phenomenon of subdued day-light is termed the 'anticyclonic gloom'.

13.13. LET US SUM UP

A jet stream is defined as a current of rapidly moving air that is usually several thousand miles long and wide, but is relatively thin. They are found in the upper levels of Earth's atmosphere at the tropopause - the boundary between the troposphere and stratosphere. Their paths typically have a meandering shape; jet streams may start, stop, split into two or more parts, combine into one stream, or flow in various directions including the opposite direction of most of the jet. Jet streams are important because they contribute to worldwide weather patterns and as such, they help meteorologists forecast weather based on their position. In addition, they are important to air travel because flying in or out of them can reduce flight time and fuel consumption.

13.14. KEY WORDS

Jet streams, anticyclones

13.15 QUESTIONS FOR SELF STUDY

1. Explain the characteristics of jet streams
2. Discuss the importance of jet streams
3. Explain different type of jet streams
4. Explain the origin and structure of anticyclones
5. Explain the characteristics of anticyclones

13.16 FURTHER READINGS

1. Barry R.G. & Chorley, R.J. : "Atmosphere, Weather and Climate", Routledge, 1998.
2. Critchfield H : "General Climatology" Prentice-Hall, New York, 1975.
3. Das P.K. : The Monsoons, National Book Trust, New Delhi, 1968.
4. Lal D.S : "Physical Geography"Sharada Pustak Bhavan, Allahabad, 2009
5. Lydolph Paul, E. : The Climate of the Earth, Rowman and Allanheld, Totowa, N.J., 1985.

6. Mather J.R. : Climatology, McGraw-Hill, New York, 1974.

7. Patterson S. : Introduction of Meteorology, McGraw-Hill Book Co.,London, 1969.

8. Stringer E.T : Foundation of Climatology, Surjeet Publications, Delhi, 1982.

9. Trewartha G.T. : An Introduction to Climate, International Students edition, McGraw Hill, New York, 1980.

UNIT-14 : CLASSIFICATION OF CLIMATE KOPPENS CLASSIFICATION

Structure:

14.0. OBJECTIVES

After studying this unit, you will be able to

- Better understanding of climatic classification proposed by Koeppen.
- Toknow the determinants factors in the Koeppen classification of climate

14.1. INTRODUCTION

The concepts of devising climate classes that combine temperature and precipitation characteristics, but of setting limits and boundaries fitted into known vegetation and soil distributions were actually carried out in 1918 by Dr. Wladimir Koppen of the University of Graz, in Austria. Koppen was both a climatologist and a plant geographer, so his main interest lay in finding climate boundaries that coincided approximately with boundaries between major vegetation types. Although he was not entirely successful in achieving his goal, his climate system has appealed to geographers because it is strictly empirical and allows no room subjective decisions.

Wladimir Köppen (1846-1940), a German climatologist and botanist, designed the Köppen classification system, widely used for its ease of comprehension. First published in stages, his classification began with an article on heat zones in 1884. By 1900, he was considering plant communities in his selection of some temperature criteria, using a world vegetation map prepared by French plant physiologist A. de Candolle in 1855. Letter symbols then were added to designate climate types. Later he reduced the role played by plants in setting boundaries and moved his system strictly toward climatological empiricism. The first wall map showing world climates, co-authored with his student Rudolph Geiger, was introduced in 1928 and soon was widely used. The Köppen system is best viewed for what it is: a valuable tool for general understanding, best limited to small scale hemispheric and world maps showing general climatic relationships and patterns. Most criticism of his system stems from asking the classification model to do what it was not designed to do, that is, produce specific climatic descriptions for local areas.

The Köppen Climate Classification System is the most widely used for classifying the world's climates. Most classification systems used today are based on the one introduced in 1900 by the Russian-German climatologist Wladimir Köppen. Köppen divided the Earth's surface into climatic regions that generally coincided with world patterns of vegetation and soils.

The classification was subsequently revised and extended by his students to become the most widely used of climatic classifications for geographical purposes.

14.2 WHAT ARE THE DIFFERENCES BETWEEN A GENETIC AND AN EMPIRICAL CLASSIFICATION SYSTEM?

Classification is the process of ordering or grouping data or phenomena in related classes. A classification based on causative factors—for example, the genesis of climate based on the interaction of air masses–is called a genetic_classification. An empirical_classification is based on statistics or other data used to determine general categories. Climate classifications based on temperature and precipitation data are empirical classifications.

14.3. BASIS FOR CLASSIFICATION

The Koppen system is strictly empirical. This is to say that each climate is defined according to fixed values of temperature and precipitation, computed according to the averages of the year or of individual months. In such a classification, no concern whatsoever is given to the causes of the climate in terms of pressure and wind belts, air masses, fronts, or storms. It is possible to assign a given place to a particular climate sub-group solely on the basis of the records of the temperature and precipitation of that place, provided, of course, that the period of record is long enough to yield meaningful averages. Air temperature and precipitation are the most easily obtainable surface weather data, requiring only simple equipment and a very elementary observer education. A climate system based on these data has a great advantage, in that the area covered by each sub-type of climate can be delineated (outlined, profiled) for large regions of the world. Of the several schemes of climatic classification, the one devised by Wladimir Koppen, a German botanist and climatologist, still remains the most widely known descriptive system.

It is a quantitative as well as empirical classification of climate. Koppen proposed his first classification in 1900, using the world vegetation map of de Candole, a French plant physiologist. This classification scheme uses certain critical values of temperature of the warmest and the coldest months and precipitation of the wettest and the driest months.

It uses numerical values for delimiting the boundaries of different climatic regions and types. Koppen's climatic regions in many cases coincided with the distinct vegetation regions.

The plant classification proposed by A. de Candole in 1874 was accepted by Koppen. The following are the five principal biological groups that are largely controlled by temperature and moisture.

14.3.1 (A) Megatherms

This group includes plants which require uniformly high temperature and abundant supply of moisture. The season is winterless, the average temperature of the coldest month being above 18°C.

There is at least one month of heavy precipitation. Certain areas of this belt are characterized by two rainy seasons. The characteristic vegetation is the tropical rain forest.

14.3.2 (B) Xerophytes

Plants that prefer aridity and need high temperatures, even though for a short season, are classed as Xerophytes.

This class of vegetation is found in the semi-arid steppes and hot deserts. These plants are also found in the warmer parts of the middle latitude zone. The type of vegetation varies with the soil types.

14.3.3 (C) Mesotherms

This group of vegetation consists of plants that are adapted to moderate heat and a moderate amount of moisture. Certain types of plants are not adapted to low winter temperatures, while others shun dryness of the warm season.

These plants are found in regions lying between latitudes 22° and 45°N and S. The average values of temperatures are usually below 18°C for the coldest month and 22°C for the warmest month.

14.3.4 (D) Microtherms

Plants that need lower mean values of annual temperature, summers cool and short, and winters colder are called microtherms. The monthly mean temperature for the warmest month is at least 10°C and less than 22°C.

The mean temperature for the coldest month is below 6°C. Occasional snow in winter and adequate precipitation during the warmer months suit the climatic requirements of these plants. Evergreen deciduous forests and steppes are the natural vegetation regime.

14.3.5. (E) Hekistotherms

This group of vegetation comprises of plants of the snow-bound Arctic region, beyond the polar limits of tree growth. Mosses, lichens, etc. are the natural vegetation.

Not satisfied with his first scheme of climatic classification, Koppen revised and modified it several times during his own life time.

Koppen revised his classification first in 1918, when he paid greater attention to the monthly and annual averages of temperature and precipitation, and their seasonal distribution. Thereafter several modifications were incorporated in his classification by the author himself.

The latest world map by the author himself appeared in 1931 in his book, Grundriss der Klimakunde, Berlin. Even after this the Koppen classification continued to be modified. Koppen-Geiger world climatic map was published in 1936.

However, a further modified version of Koppen's original classification was published in 1953, which is known as Koppen-Geiger-Pohl's classification of world climate.

In classifying climate Koppen placed reliance on his belief that the distribution of natural vegetation was the best expression of the totality of climate. Consequently, many of the climatic boundaries he selected were based on vegetation limits.

The Koppen system recognizes five principal categories of climate; each category is designated by a capital letter as follows:

14.4. HUMID TROPICAL CLIMATES

Winterless climates; it is hot all seasons; all months have a mean temperature above 18°C. Moist Tropical Climates are known for their high temperatures year round and for their large amount of year round rain.

14.5 DRY CLIMATES

In these climates evaporation exceeds precipitation; there is a constant water deficiency. Dry Climates are characterized by little rain and a huge daily temperature range. Two subgroups, **S** - semiarid or steppe, and **W** - arid or desert, are used with the **B** climates.

14.6 HUMID MESOTHERMAL CLIMATES OR WARM TEMPERATE RAINY CLIMATES

These climates have mild winters; the average temperature of the coldest month is below 18°C but above - 3°C; the average temperature of the warmest month over 10°C. In this group of climate both the seasons, winter and summer, are found. In Humid Middle Latitude Climates land/water differences play a large part. These climates have warm, dry summers and cool, wet winters.

14.7 HUMID MICRO-THERMAL CLIMATES OR COLD SNOW-FOREST CLIMATES

Continental Climates can be found in the interior regions of large land masses. Total precipitation is not very high and seasonal temperatures vary widely. These climates have severe winters; the average temperature of the coldest month is below -3°C and that of the warmest month exceeds 10°C.

14.8. POLAR CLIMATES

Cold Climates describe this climate type perfectly. These climates are part of areas where permanent ice and tundra are always present. Only about four months of the year have above freezing temperatures. These are summer-less climates; the warmest monthly mean is below 10°C.

It may be noticed that four of the principal categories of climatic gioups (A, C, D, E) are based on temperature characteristics, while the fifth, the B category, has precipitation as its fundamental criterion.

Further subgroups are designated by a second lower case letter which distinguish specific seasonal characteristics of temperature and precipitation.

f - Moist with adequate precipitation in all months and no dry season. This letter usually accompanies the **A**, **C**, and **D** climates.

m - Rainforest climate in spite of short, dry season in monsoon type cycle. This letter only applies to **A** climates.

s - There is a dry season in the summer of the respective hemisphere (high-sun season).

w - There is a dry season in the winter of the respective hemisphere (low-sun season). To further denote variations in climate, a third letter was added to the code.

a - Hot summers where the warmest month is over 22°C (72°F). These can be found in **C** and**D** climates.

b - Warm summer with the warmest month below 22°C (72°F). These can also be found in **C**and **D** climates.

c - Cool, short summers with less than four months over 10°C (50°F) in the **C** and **D** climates.

d - Very cold winters with the coldest month below -38°C (-36°F) in the **D** climate only.

h - Dry-hot with a mean annual temperature over 18°C (64°F) in **B** climates only.

k - Dry-cold with a mean annual temperature less than 18°C (64°F) in **B** climates only.

14.9. KOPPEN SYSTEM OF CLIMATIC CLASSIFICATION SCHEME

A	**Tropical humid**	Af	Tropical wet	No dry season
		Am	Tropical monsoonal	Short dry season; heavy monsoonal rains in other months
		Aw	Tropical savanna	Winter dry season
B	**Dry**	BWh	Subtropical desert	Low-latitude desert
		BSh	Subtropical steppe	Low-latitude dry
		BWk	Mid-latitude desert	Mid-latitude desert
		BSk	Mid-latitude steppe	Mid-latitude dry
C	**Mild Mid-Latitude**	Csa	Mediterranean	Mild with dry, hot summer
		Csb	Mediterranean	Mild with dry, warm summer
		Cfa	Humid subtropical	Mild with no dry season, hot summer
		Cwa	Humid subtropical	Mild with dry winter, hot summer
		Cfb	Marine west coast	Mild with no dry season, warm summer
		Cfc	Marine west coast	Mild with no dry season, cool summer
D	**Severe Mid-Latitude**	Dfa	Humid continental	Humid with severe winter, no dry season, hot summer
		Dfb	Humid continental	Humid with severe winter, no dry season, warm summer
		Dwa	Humid continental	Humid with severe, dry winter, hot summer
		Dwb	Humid continental	Humid with severe, dry winter, warm summer
		Dfc	Subarctic	Severe winter, no dry season, cool summer
		Dfd	Subarctic	Severe, very cold winter, no dry season, cool summer
		Dwc	Subarctic	Severe, dry winter, cool summer
		Dwd	Subarctic	Severe, very cold and dry winter, cool summer
E	**Polar**	ET	Tundra	Polar tundra, no true summer
		EF	Ice Cap	Perennial ice
H	**Highland**			

14.10 ADVANTAGES

Koppen used the temperature and precipitation statistics in his classification of the climate. These two weather elements are easy to measure. Since Koppen's classification is based on statistical parameters, each climatic region can be presisly defined.

Besides, the temperature and precipitation are the most effective weather elements that exhibit the effects of climatic controls more clearly than any other weather elements. Obviously, the system of classification devised by Koppen is directly related to those aspects of environment which are clearly visible to us. His climatic classification system is based on the relationship between the types of plants at a particular place and the climatic characteristics of the place. Thus, his scheme is not a mere abstraction. Further. Koppen introduced the concept of effective precipitation which depends on the rate of potential evopotranspiration. Potential evopotranspiration is largely controlled by temperature. . Thus, in Koppen's classification the relationship between heat and moisture factors gets due recognition. The moisture requirements for plants vary with the rate of evopotranspiration. For example, the amount of precipitation sufficient to support coniferous forests in the cool temperature zone may support little plant life in a low latitude desert.

Another advantage of this classification is that it is possible to assign a given place to a particular climatic sub group only on the basis of certain easily acquired statistics about an area's temperature and precipitation. Another unique feature of Koppen's classicication system is that it uses a short hand code of letters for the climatic types, so that repetition of descriptive terms becomes unnecessary. Lastly the classification is so simple and detailed that it can be easily used at different educational levels.

14.11. LIMITATIONS

As with any regional classification, this system is not universally applicable. It utilizes, for example, only the data or mean monthly temperature and precipitation. There is not provision for variations in the strength or constancy of winds, temperature extremes, precipitation intensity and range, amount of cloud cover, or the net radiation balance. Its greatest inadequacies perhaps lie in its application to humid dry boundaries, and it should not be considered for land management and planning purposes, where more precise and varied factors should be utilized.

14.12. LET US SUM UP

Köppen climate classification, widely used, vegetation-based empirical climate classification system. His aim was to devise formulas that would define climatic boundaries in such a way as to correspond to those of the vegetation zones that were being mapped for the first time during his lifetime. Köppen published his first scheme in 1900 and a revised version in 1918. He continued to revise his system of classification until his death in 1940. Other climatologists have modified portions of Köppen's procedure on the basis of their experience in various parts of the world.

Köppen's classification is based on a subdivision of terrestrial climates into five major types, which are represented by the capital letters A, B, C, D, and E. Each of these climate types except for B is defined by temperature criteria. Type B designates climates in which the controlling factor on vegetation is dryness rather than coldness. Aridity is not a matter of precipitation alone but is defined by the relationship between the precipitation input to the soil in which the plants grow and the evaporative losses. Since evaporation is difficult to evaluate and is not a conventional measurement at meteorological stations, Köppen was forced to substitute a formula that identifies aridity in terms of a temperature-precipitation index (that is, evaporation is assumed to be controlled by temperature). Dry climates are divided into arid (BW) and semiarid (BS) subtypes, and each may be differentiated further by adding a third code, h for warm and k for cold.

As noted above, temperature defines the other four major climate types. These are subdivided, with additional letters again used to designate the various subtypes. Type A climates (the warmest) are differentiated on the basis of the seasonality of precipitation: Af (no dry season), Am (short dry season), or Aw (winter dry season). Type E climates (the coldest) are conventionally separated into tundra (ET) and snow/ice climates (EF). The mid-latitude C and D climates are given a second letter, f (no dry season), w (winter dry), or s (summer dry), and a third symbol (a, b, c, or d [the last subclass exists only for D climates]), indicating the warmth of the summer or the coldness of the winter. Although Köppen's classification did not consider the uniqueness of highland climate regions, the highland climate category, or H climate, is sometimes added to climate classification systems to account for elevations above 1,500 metres (about 4,900 feet). The table, which includes the highland climate category, gives the specific criteria for the Köppen-Geiger-Pohl system of 1953.

14.13. KEY WORDS

Koppen's classification of climate, Climatic classification

14.14 QUESTIONS FOR SELF STUDY

1. Review Köppen's development of an empirical climate classification system and compare his with other ways of classifying climate.
2. Explain briefly the classification of climate proposed by Koppen.
3. Explain the basis of Koppen's classification of climate.
4. Discuss the advantage and disadvantages of Koppen's classification of climate.
5. Describe the A, C, D, and E climate classification categories and *locate* these regions on a world map.

14.15 FURTHER READINGS

1. Barry, R.G. & Chorley, R.J. : "Atmosphere, Weather and Climate", Routledge, 1998.

2. Critchfield, H : "General Climatology" Prentice-Hall, New York, 1975.

3. Das, P.K : The Monsoons, National Book Trust, New Delhi1968.

4. Lal D.S : "PhysicalGeography"SharadaPustak Bhavan, Allahabad, 2009

5. Lydolph, Paul, E. : The Climate of the Earth, Rowman and Allanheld, Totowa, N.J., 1985.

6. Mather, J.R. : Climatology, McGraw-Hill, New York, 1974.

7. Patterson, S. : Introduction of Meteorology, McGraw-Hill Book Co., London, 1969.

8. Stringer, E.T. : Foundation of Climatology, Surjeet Publications, Delhi, 1982.

9. Trewartha, G.T. : An Introduction to Climate, International Students edition, McGraw Hill, New York, 1980.

UNIT - 15 : CLASSIFICATION OF CLIMATE: THORNTHWAIT CLASSIFICATION

15.0 OBJECTIVES

After studying this unit, you will be able to

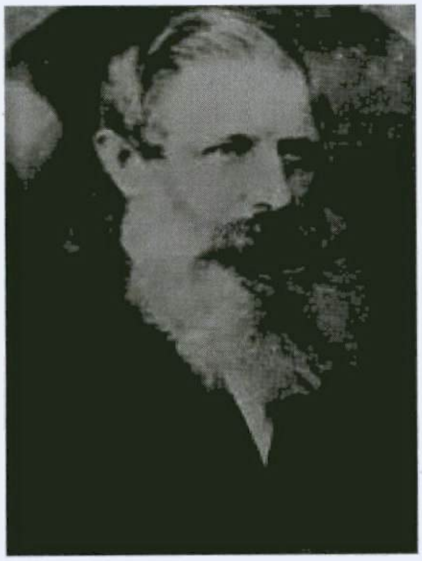
- Know the Climatic classification by C.W. Thornthwaite's system.
- Understanding to temperature and precipitation information on animal species diversity and potential impacts of climate changes.

15.1 INTRODUCTION

Although Köppen's System is the most widely used climate classification system, there are several others that have been used as well. One of the more popular of these is the climatologist and geographer C.W. Thornthwaite's system. This method monitors the soil water budget for an area based on evapotranspiration and considers that along with total precipitation used to support an area's vegetation over time. It also uses a humidity and aridity index to study an area's moisture based on temperature, rainfall and vegetation type. The moisture classifications in Thornthwaite's system are based on this index and the lower the index is, the drier an area is. Classifications range from hyperhumid to arid.

15.2. THORNTHWAITE CLIMATE CLASSIFICATION

A system for describing climates devised in 1931 and revised in 1948 by the American climatologist Charles Warren Thornthwaite (1889–1963) which divides climates into groups according to the vegetation characteristic of them, the vegetation being determined by precipitation effectiveness (*P/E*, where *P* is the total monthly precipitation and *E* is the total monthly evaporation). The sum of the monthly *P/E* values gives the/*E* index, which is used to define five humidity provinces, with associated vegetation. A *P/E* index of more than 127 (wet) indicates rain forest; 64–127 (humid) indicates forest; 32–63 (subhumid) indicates grassland; 16–31 (semi-arid) indicates steppe; less than 16 (arid) indicates desert. In 1948 the system was modified to incorporate a moisture index, which relates the water demand by plants to the available precipitation, by means of an index of potential evapotranspiration (PE), calculated from measurements of air temperature and day



length. In arid regions the moisture index is negative because precipitation is less than the PE. The system also uses an index of thermal efficiency, with accumulated monthly temperatures ranging from 0, giving a frost climate, to more than 127, giving a tropical climate.

15.3 THORNTHWAITE'S 1931 CLASSIFICATION

In 1931 Thornthwaite devised a complex and empirical classification, which is very close to Koppen's scheme. It also attempts to define climatic boundaries quantitatively and is based on plant associations. Like Koppen's this classification also employs combination of letter symbols to designate the climatic types, its sub divisions and other groups.

However, Thornthwaite's classification is based on precipitation effectiveness and thermal efficiency (temperature efficiency). Under this classification climatic types were subdivided by the use of a term to denote the seasonal distribution of precipitation. The climatic types and their boundaries were defined empirically by observing the characteristics of natural vegetation, soil, and the drainage pattern.

Thornthwaite established the fact that not only the amount of precipitation, but the rate of evaporation as well is significant for the growth of natural vegetation. Thus, besides the precipitation amount and the evaporation rate, temperature was made a very important basis for Thornthwaite's climatic classification. An expression for precipitation efficiency was obtained by relating measurements of pan evaporation to temperature and precipitation. For each month the ratio 11.5 (rt-10)10/9 where r=mean monthly rainfall (in inches)

t = mean monthly temperature (in °F) is calculated.

The sum of the 12 monthly ratios gives the precipitation effectiveness (also called precipitation efficiency) index. In other words, the effectiveness of precipitation is taken to be a function of precipitation and evaporation and is calculated by dividing the monthly precipitation by the monthly evaporation to get the P/E ratio (precipitation effectiveness ratio).

On the basis of P/E indices and boundary values for the major vegetation regions, five humidity provinces were defined.

15.4 MAIN CLIMATIC GROUPS BASED ON PRECIPITATION EFFECTIVENESS

Humidity Province	Vegetation	P/E Index
A (Wet)	Rain Forest	127
B (Humid)	Forest	64-127
C (Sub humid)	Grassland	32-63
D (Semiarid)	Steppe	16-31
E (Arid)	Desert	16

Thornthwaite introduced an index of thermal efficiency which is expressed by the positive departure of monthly mean temperatures from the freezing point The index is thus the annual sum of (t-32)/4 for each month. In other words, the sum of twelve monthly temperature-efficiency ratios (T/E) gives a T/E index

Again, the world was divided into 6 temperature provinces on the basis of T/E index.

15.5 MAIN CLIMATIC GROUPS BASED ON THERMAL EFFICIENCY

Temperature Province	T/E index
A'-Tropical	127
B'-Mesothermal	64-127
C'-Microthermal	32-63
D'-Taiga	16-31
E'-Tundra	1-15
F'-Frost	0

T/E Index-sum of 12 monthly values of (T-32)14, where T is mean monthly temperature in °;F.

On the basis of the seasonal distribution of precipitation the humidity provinces were subdivided into the following

- r-Rainfall adequate in all seasons
- s-Rainfall deficient in summer
- w-Rainfall deficient in winter
- d-Rainfall deficient in all seasons.

When precipitation effectiveness, seasonal distribution of rainfall, and thermal efficiency are taken together, there would be in all 120 climatic types, at least on theoretical grounds. However, Thornthwaite has shown only 32 climatic types on the world map depicting his 1931 climatic classification.

The following table gives the PE seasonal distribution of RF and thermal efficiency. Together theoretically there are 125 climatic types but he has given only 32 climatic types.

AA'r	BA'r	CA'r	DA'w	EA'd	D'E'F'
AB'r	BA' w	CA' W	DA'd	EB'd	
AC'r	BB'r	CA' d	DB'w	EC'd	
	BB' w	CB'r	DB's		
	BB's	CB' w	DB'd		
	BC'r	CB's	DC'd		
	BC's	CB'd			
	CC'r				
	CC's				
	CC'd				

15.6. SALIENT FEATURES OF 1931 CLASSIFICATION.

This classification is almost similar to Koppen's classification in so far as it defines climatic boundaries quantitatively, and it is also based on vegetation. Like Koppen's scheme it also makes. use of letter combinations to designate climatic types. However, it differs from Koppen's classification on two scores: first, he introduced an expression for precipitation efficiency, and second, he made use of an index of thermal efficiency. Thornthwaite makes moisture the primary classificatory factor for a T/E index of over 31 (the taiga cool temperate boundary). Since Thornthwaite adopted the precipitation effectiveness and temperature efficiency indices for his climate' classification, the delimitation of the climatic boundaries becomes difficult and vague. Besides, under this classification there are almost 32 major climatic types shown on the world map-this is almost three times greater than Koppen's climatic types. But the point to be remembered is that in Thornthwaite's classification the letter symbols used are relatively less in number than those in Koppen's classification.

Lastly, it may be pointed out that the climatic classifications as devised by Koppen and Thornthwaite are more useful and appealing to zoologists, botanists, and geographers.

But these schemes of classification are not so useful for meteorologists and climatologists because the interplay between the weather elements and other climatic factors is not clearly shown.

15.7 THORNTHWAITE'S 1948 CLASSIFICATION

In 1948 Thornthwaite proposed a new classification of climate which is his most important contribution. His second classification is based. on the concept of potential evapotranspiration, which represents the amount of moisture that would be transferred to the atmosphere by evaporation of liquid or solid water plus transpiration from living tissues, principally plants if it (the moisture) were available. The potential evapotranspiration (PE) is calculated from the mean monthly temperature (in °C), with corrections for day length. For a 30-day month (12-hour days):

$PE\ (\text{in cm}) = 1.6\ (10t/1)\ a$

Where I = the sum of 12 months of $(t/5)\ 1.514$

a = a further complex function of I.

The monthly water surplus (S) or deficit (D) is calculated from a moisture budget assessment including stored soil moisture. A moisture index (Im) is given by the following formula:

$IM = (100S\text{-}60D)\ PE$

The most characteristic feature of this classification scheme is that the temperature efficiency is calculated from the PE value, this being a function of temperature. Using computed indices of moisture and heat, Thornthwaite defined the moisture and thermal provinces.

15.8 SEASONAL VARIATION OF EFFECTIVE MOISTURE

Letter	Distribution of precipitation	Aridity Index
	Humid Climates (A,B,C2)	
r	No moisture deficit	0-10
s	Summer deficit (normal)	10-20
w	Winter deficit (normal)	10-20
S2	Summer deficit (acute)	>20
W2	Winter deficit (acute)	>20
	Arid Climates	**Humidity Index**
d	Water surplus negligible	0.16.7
s	Winter moisture surplus (normal)	16.7-33.3
w	Summer moisture surplus (normal)	16.7-33.3
s	Winter moisture surplus (abundant)	33.3
w 2	Summer moisture surplus (abundant)	33.3

Thus, on the basis of potential evopotrnsiration, average annual thermal efficiency, seasonal variation of effective moisture, and summer concentration of thermal efficiency the type of climate of any place can be determined.

15.9. CRITICISM OF THORNTHWAITE'S 1948 CLASSIFICATION

This scheme of climatic classification has been successfully applied to many regions, but because of certain limitations inherent in it no world map has yet been prepared.

This classification system has proved most satisfactory in case of North America where vegetation boundaries nearly coincide with particular PE values. But it is not satisfactory for the tropical and semi arid areas.

However, Thornthwaite does not determine his climatic boundaries on the basis of vegetation boundaries. In this respect, he differs from Koppen in case of his second classification.

This classification is quantitative as well as empirical, but it does not take into account various causative factors of climate. It also employs symbols for designating the climatic types.

The classification involves a lot of calculations, hence it is more difficult to use in determining the climatic type of a particular place or locality. That is why Thornthwaite's system could not enjoy the same degree of popularity as that of Koppen. Lastly, Thornthwaite as a climatologist developed the concept of the soil-moisture balance, and he preferred to use it as the foundation of his climate system.

He was convinced that the soil- moisture balance represents availability of moisture for plants, and an assessment of the availability of surplus moisture to supply stream flow and ground water.

This concept implies that precipitation alone does not indicate the amount of water actually available to plants. The amount and availability of soil moisture is also affected, besides other factors, by the losses due to evapotranspiration. Thus, moisture requirements of plants, according to Thornthwaite, become higher as temperature increases.

Even though this scheme of climatic classification is based on two variables: (1) precipitation, and (2) evapotranspiration, temperature is by no means ignored in it. Temperature is also accounted for while calculating evapotranspiration.

If a comparison is made between the amount of water available from precipitation and the water need, it is easy to assess the moisture conditions to determine the seasonal distribution of moisture deficits or surpluses and whether a climate is wet or dry.

The most significant contribution of Thornthwaite has been that the concept of evapotranspiration has been applied in practical studies of the water balance as regards the problems of water use.

However, in spite of numerous plus points of Thornthwaite's classification of the climate, his system is seldom used in an introductory course because it involves a lot of very complicated calculations.

15.10 LET US SUM UP

Although the Koppen climate classification is the most common climate classification in use today, the 1948 Thornthwaite classification is frequently cited as an improved climate classification system for its rational approach. However, the Thornthwaite classification is infrequently used because it tends to be too complex for use in everyday settings and world maps of the classification were never produced. This classification uses an amended version of the Thornthwaite moisture index, not only to delineate climatic moisture gradients but also to define a single seasonality index responsive to mean seasonal variation in both thermal and moisture conditions. Replacing the two cumbersome seasonality indicators in the original Thornthwaite classification with one variable greatly improves the utility of the classification. Results from this classification are compared to the Koppen and original Thornthwaite climate classification schemes.

15.11 KEY WORDS

Classification of climate, Thronthwaite classification of climate

15.12 QUESTIONS FOR SELF STUDY

1. Critically examine the 1931 and 1948 classification of climate proposed by Thornthwaite.
2. Examine the salient features of 1931 classification of climate proposed by
3. Thornthwaite.
4. Discuss the main criticism of the climatic classification system of Thornthwaite.
5. Review the role of temperature, precipitation, air pressure, and air mass
6. patterns used to establish climatic regions.

15.13. FURTHER READINGS

1. Barry R.G. & Chorley R.J. : "Atmosphere, Weather and Climate", Routledge, 1998.
2. Critchfield, H : "General Climatology" Prentice-Hall, New York, 1975.
3. Das P.K. : The Monsoons, National Book Trust, New Delhi, 1968.
4. Lal D.S : "Physical Geography"Sharada Pustak Bhavan, Allahabad, 2009
5. Lydolph, Paul, E. : The Climate of the Earth, Rowman and Allanheld, Totowa, N.J., 1985.
6. Mather, J.R. : Climatology, McGraw-Hill, New York, 1974.
7. Patterson, S. : Introduction of Meteorology, McGraw-Hill Book Co., London, 1969.
8. Stringer, E.T. : Foundation of Climatology, Surjeet Publications, Delhi, 1982.
9. Trewartha, G.T. : An Introduction to Climate, International Students edition, McGraw Hill, New York, 1980.

UNIT-16: GLOBAL WARMING AND CLIMATE CHANGE

Structure:

16.0. OBJECTIVES

After studying this unit, you will be able to

- Understanding the facts, causes and effects of global warming
- Know the theories associated with climate change.

16.1. INTRODUCTION

Throughout Earth's history, the climate has fluctuated many times. Recently, scientists have become concerned that the Earth is becoming rapidly warmer. This warming will have effects on life across the planet. There are many possible causes to this climate change, some human and some natural. The true cause is likely a complex combination of factors that no one yet fully understands

16.2. FACTS ABOUT GLOBAL WARMING

Global warming is caused primarily by carbon dioxide from burning coal, oil and gas. Certain gases that trap heat are building up in Earth's atmosphere. The primary culprit is carbon dioxide, released from burning coal, oil and natural gas in power plants, cars, factories, etc. The second is methane, released from rice paddies, both ends of cows, rotting garbage in landfills, mining operations, and gas pipelines. Third are chlorofluorocarbons and similar chemicals, which are also implicated in the separate problem of ozone depletion.

Earth's average temperature has risen about 1 degree F in the past 100 years and is projected to rise another 3 to 10 degrees F in the next 100 years. While Earth's climate has changed naturally throughout time, the current rate of change due to human activity is unprecedented during at least the last 10,000 years.

There is scientific consensus that global warming is real, is caused by human activities, and presents serious challenges. Scientists working on this issue report that the observed global warming cannot be explained by natural variations such as changes in the sun's output or volcanic eruptions. According to IPCC (Intergovernmental Panel on Climate Change) global temperature would increase about 3 to 10 degrees F in the next 100 years.

Global warming will have significant impacts on people and nature. As temperatures continue to rise, precipitation is projected to come more frequently in the form of heavy downpours. We can probably expect more extreme wet and dry conditions. Natural ecosystems such as coral reefs, mangrove swamps, arctic tundra, and alpine meadows are especially vulnerable and may disappear entirely in some areas.

Sea level has already risen due to warming and is projected to rise much more. Many people are under the mistaken impression that only if the polar ice caps melt will sea level rise. In fact, average sea level around the world has already risen 4 to 8 inches in the past 100 years due to global warming and is expected to rise another 4 to 35 inches by 2100. The primary reason for this rise is that water expands as it warms. The second reason is that glaciers all over the world are melting, and when land-based ice melts, the water runs to the sea and increases its level. Thousands of small islands and low-lying coastal areas are threatened by the projected sea-level rise for the 21st century.

Each of us can reduce our contribution to global warming by using less greenhouse-gas, choosing fuel efficient cars and appliances, using solar energy where feasible. We can preserve existing forests and plant new ones. But even if we take aggressive action now, we cannot completely prevent climate change because once carbon dioxide is in the atmosphere, it remains there for about a century, and the climate system takes a long time to respond to changes. But our actions now and in the coming decades will have enormous implications for future generations.

Protecting the world's climate by stabilizing atmospheric concentrations of greenhouse gases will require enormous reductions in current emissions. It is estimated that greenhouse gas emissions would have to be reduced to less than one third of current levels to stabilize atmospheric concentrations. This would require a major transformation of the energy sector. A mix of new and existing energy technologies will be needed to achieve this, including large increases in energy efficiency and renewable energy. Researchers are also developing technology to capture and bury carbon dioxide thousands of feet underground. Major increases in public and private research and development are needed to make the necessary technologies available as rapidly and economically as possible.

16.3. CAUSES OF GLOBAL WARMING

16.3.1. Green house gases

A greenhouse gas is defined as any gas that effectively holds and stores heat energy. Water vapor and carbon dioxide are the two most common examples. Both are produced in large quantities by human industrial processes. In the natural environment, both of these substances move through a natural cycle that limits their concentrations. Human activity has upset that balance. Methane, nitrous oxide and chlorofluorocarbons are also powerful greenhouse gases, though they exist in much lower quantities.

16.3.2. Over use of land

The exploitation of natural resources indirectly contributes to climate change in several ways. Trees draw carbon dioxide out of the air, so cutting down forests increases carbon dioxide levels. Wetlands perform a similar function, but they are often drained to make way for human activity. Every time a natural ecosystem is replaced by a factory or highway, the ability of the Earth's climate to naturally moderate itself is impaired.

16.3.3. Volcanoes

Large volcanic eruptions can emit a variety of greenhouse gases. However, the ability of dust and other compounds to reflect sunlight is more powerful than any greenhouse effect. Because eruptions are brief events in geological terms, the effects on Earth's climate are temporary. Short periods of intense volcanism have been linked with cooler periods in Earth's climate history. Global air circulation eventually disperses and removes the particulate matter released by these powerful eruptions.

16.3.3. Solar energy

If the sun were to radiate a greater amount of energy, logically the average temperature on Earth would rise. Scientists have linked ancient warm and cool periods to solar energy output. In modern times, however, the sun's energy has remained fairly stable and so cannot account for the Earth's warming. Measurements indicate that only the lower atmosphere is getting warmer. If the sun were responsible, then the entire atmosphere would warm equally

16.4. EFFECTS OF GLOBAL WARMING

16.4.1. Intense Hurricanes

Global warming heats Earth's oceans. Because hurricanes derive their power from warm ocean waters, the Environmental Defense Fund states that more intense hurricanes will occur as temperatures continue to rise. According to the National Oceanic and Atmospheric Administration, if sea temperatures warm by as little as 2 degrees Celsius, hurricane winds in the tropical Pacific could increase anywhere from 5 to 12 percent.

16.4.2. Extreme Rain

Warmer temperatures are expected to deliver heavier rainfalls. This is because warm air can hold more moisture than cold air. Heavier downpours can cause increased flooding, especially in areas that border rivers and lakes. This could discourage cities from developing in flood-prone areas and encourage the protection of natural wetlands, which help protect against flooding. Increased precipitation may also be impacted by shifts in snowfall patterns, which could delay the onset of spring and make for longer winters.

16.4.3. Flora and Fauna

Global warming will have drastic effects on local ecosystems. Most plants and animals are adapted for a certain environment. Generally, each species does well when the temperature is in a certain range, and the seasons work in a regular way. As things like temperature and seasonal precipitation shift, less robust plants and animals are not going to be able to adapt quickly enough. This will result in widespread extinction.

16.4.4. Effects on Humans

It is hard to predict exactly how severely global warming will affect individual locations. The combination of violent storms, rapid changes in local climates, disruption of the water cycle and extinction of plants and animals will probably cause local food shortages and disruption of infrastructure in some areas. The panic and anxiety over global warming will damage the world economy, as will the population squeeze when people in coastal areas are forced to move inland by rising water levels. No matter how you spin it, it's going to take a toll on the economy—at least in the short term.

16.4.5. Climate Shifts

Global warming will destabilize the weather in other ways. In all likelihood, it will change worldwide weather patterns, leading to droughts in some areas and flooding in others. The Intergovernmental Panel on Climate Change (IPCC) indicates significant changes in the climates of all 5 continents. Although, some of these changes may be positive in the short term, in the long term rising heat waves and unstable weather will have a negative effect.

16.5. POSITIVE EFFECTS OF GLOBAL WARMING

The effects of global warming that scientists are predicting include increased frequency and intensity of extreme weather events like flash floods, droughts, hurricanes, heat waves and wildfires. Rising sea levels that accompany melting glaciers, polar ice caps and permafrost may threaten millions of coastal inhabitants. There are those, however, that project a few positive effects of global warming

16.5.1. Warmer winters

Warmer global temperatures mean more mild winter temperatures, which can lead to fewer big snow storms and lower heating costs.

16.5.2. More Plant Growth

More carbon dioxide in the air has the potential to increase plant growth, which means more food and trees can be grown.

16.5.3. More Shipping Lanes

Shipping lanes that are currently difficult to navigate or are completely impassable will become more open, which could lead to increased traffic between North America, Europe and Asia.

16.5.4. More Habitats

Species whose ranges are bound on the north by harsh winter temperatures will begin to shift northward.

16.5.5. Estuaries

Increased sea levels due to global warming's melting of the ice caps will create new estuaries, which are extremely productive ecosystems.

16.5.6. Tidal Energy

Increased sea levels may increase the energy of ocean's tides; excessive tidal energy may become a popular form of renewable energy.

16.6. NEGATIVE EFFECTS OF GLOBAL WARMING

Global warming refers to the continued increase of the earth's temperature. Some things that have contributed to the earth's increase in temperature have been natural, like volcanic eruptions and changes in the orbit of the earth. However, other human activities like burning fossil fuels and cutting down trees have also contributed to global warming. Burning fossil fuels, like coals and oils, release gases that trap heat in our atmosphere. The more gases that are released, the more the earth's temperature increases. This increase in temperature has a negative global impact

16.7. GREEN HOUSE GASES

Greenhouse gases are gases that trap the heat that would normally be released into space. This happens because the gases absorb infra-red radiation and trap it in our atmosphere. Because this heat does not get released, it stays in the atmosphere, resulting in an increase of the earth's temperature. These greenhouse gases include methane, carbon dioxide, nitrous oxides and chlorofluorocarbons (CFC's). These are by products of burning fossil fuels.

According to the Environmental Protection Agency, "If greenhouse gases continue to increase, climate models predict that the average temperature at the Earth's surface could increase from 3.2 to 7.2ºF above 1990 levels by the end of this century."

16.8. RISK FACTORS

There are several risk factors associated with global warming. As the temperature of the earth increases, our eco-systems change. Where and how things grow is a consequence of global warming. Warmer temperatures can also affect people's health. Some diseases find warmer climates great for breeding and can be spread to more places that will be able to support their growth. Climate also impacts farming. Warm weather and droughts can affect the growth of crops that need cooler temperatures and regular water to thrive. Sea levels are also rising as a result of global warming. This can be detrimental to islands and low-lying areas if it continues.

16.9. PEOPLES' PARTICIPATION

People can play an important function in stopping global warming. By making choices that reduce the amount of greenhouse gases that are released into the environment people can help to slow or reverse global warming. Some of the things people can do in their daily lives include using compact florescent bulbs, lower water heaters to below 120 degrees, take shorter showers and carpool. These actions can reduce the daily output of carbon dioxide. People can also band together and encourage companies to reduce their greenhouse gas output.

16.10. SIGNIFICANCE

As global warming increases, changes in the global climate are inevitable. Land will continue to increase in temperature, the amount of rainfall may increase, and storms will be stronger and more frequent. Ice and glaciers will continue to melt, contributing to the rise in sea levels. Overall, global warming can change the climate of the earth and make it an uncomfortable place to live.

16.11. MISCONCEPTIONS

Many people believe that an individual can't help to reduce global warming. This is not true. Everyone can reduce their carbon dioxide output. For example, switching to fluorescent light bulbs can reduce carbon dioxide output. According to stopglobalwarming.org, if you replace 3 frequently used light bulbs with compact fluorescent bulbs you can save 300 lbs. of carbon dioxide per year.

16.12. GLOBAL WARMING'S EFFECTS ON OZONE DEPLETION

Global warming isn't the direct cause of ozone depletion, but they share many similarities. The man-made CFCs like Freon are mostly responsible for the depletion of the ozone layer. The gases may also act as a greenhouse gas that traps the heat on earth, but to a lesser degree. Many gases that heat up the earth also tear down the ozone layer. In addition, CFCs may still influence the ozone because those gases stay in the atmosphere for a long time. According to the U.S. Environmental Protection Agency, the ozone will return to normal levels by 2050. This is good news, but it won't necessarily influence the rate of global warming.

Ozone is actually a greenhouse gas, contributing to trapping heat in the stratosphere. If the ozone layer depletes, it affects the temperature of the earth. The depletion contributes to a global cool down and significant weather changes in higher areas near the stratosphere.

16.13. THEORIES ON LONG-TERM CLIMATE CHANGE

Most scientists accept that climate change is taking place on a planet-wide scale. The precise causes of climate change, however, are subject to much debate within the scientific community, with some holding the view that climate change is a man-made phenomenon while others believe it's a natural part of the Earth's cycle of heating and cooling. Meanwhile, a variety of theories have emerged to explain the various changes that can be seen taking place with climatic conditions throughout Earth.

16.13.1. A Manmade Phenomenon

The most widely accepted theory of climate change is that burning fossil fuel for more than a century has resulted in greenhouse gases — including carbon dioxide, water vapor, nitrous oxide and methane — becoming released into the atmosphere. These gases trap the heat and light of the sun in the atmosphere. As a result, the overall temperature of the planet rises. Burning fossil fuels has increased significantly since the advent of the Industrial Revolution, and the volume of carbon dioxide in the atmosphere has increased by more than 25 percent since 1860.

16.13.2. The Sun

Another theory of climate change involves the sun. The sun's magnetic field and the solar wind both serve to modulate how much high-energy cosmic radiation makes it to Earth. According to Danish physicist Henrik Svensmark, this theory's inventor, variations in the sun's magnetic activity and solar wind will affect the amount of cosmic rays that hit Earth, which in turn will affect the rate of low-level cloud formation. In a 2007, Svensmark described his theory that the planet is experiencing a period of low cloud cover caused by fewer cosmic rays entering the Earth's atmosphere. High solar activity, he noted, causes a decrease in cloud cover, which results in warmer temperatures, contributing to global warming.

16.14. CARBON DIOXIDE THEORY

The first theory of climate change contends that human emissions of greenhouse gases, principally carbon dioxide (CO2), methane, and nitrous oxide, are causing a catastrophic rise in global temperatures. The mechanism whereby this happens is called the enhanced greenhouse effect. We call this theory "anthropogenic global warming or AGW for short.

Carbon dioxide (CO2) is a chemical compound in the earth's atmosphere. Trees and other plants use this gas as part of photosynthesis, the process by which they produce food. Through photosynthesis, plants remove carbon dioxide from the air.

Some natural processes, such as volcanoes and geysers, add carbon dioxide to the atmosphere. Human activities, however, add far more carbon dioxide than geothermal phenomena and other natural processes. The two main human activities that increase the amount of carbon dioxide in the earth's atmosphere are fossil fuel burning and land clearing. The rising level of carbon dioxide contributes to the change in average global temperatures, also known as global warming.

16.15. ANTHROPOGENIC GLOBAL WARMING: BIO-THERMOSTAT THEORY

The second theory of climate change holds that negative feedbacks from biological and chemical processes entirely or almost entirely offset whatever positive feedbacks might be caused by rising CO2. These processes act as a "global bio-thermostat" keeping temperatures in equilibrium. The increase uptake of carbon dioxide by plants is the best known of these phenomena. Others include carbonyl sulfide, diffuse light, iodocompounds, dimethyl sulfide, and other aerosols.

16.16. CLOUD FORMATION AND ALBEDO THEORY

This theory postulates that changes in the formation and albedo of clouds create a feedback that cancels out the effects of increased carbon dioxide. Albedo is a fancy word for the ability of clouds to reflect solar radiation. Recent work by Dr. Roy Spencer has shown that clouds are a major factor in the Earths temperature profile.

16.17. BURNING FUELS, CLEARING LAND

Fossil fuels contain large amounts of carbon. The burning of these fuels produces large amounts of carbon dioxide as a byproduct. When automobiles and coal-burning power plants, for example, burn fuels, high concentrations of carbon are released. The carbon reacts with oxygen in the atmosphere, producing carbon dioxide.

Land clearing is the second human activity that increases the concentration of carbon dioxide in the atmosphere. Because trees and other plants remove carbon dioxide through photosynthesis, the destruction of forests slows the removal of CO2, resulting in greater concentrations in the environment because there are fewer plants and trees to remove it.

16.18. OCEAN CURRENTS THEORY

This theory contends that global temperature variation over the past century has been due to the slow down of the ocean's Thermohaline Circulation. Major anomalies, such as El Nino, La Nina, and the Pacific Decadal Oscillation have received considerable attention for their apparent impact on the Earth's temperature. However, no one seems to understand what causes these effects.

16.19. ASTRONOMICAL THEORY

The astronomical theory, also known as the Milankovitch theory, posits that slight variations in the Earth's tilt over tens of thousands of years have been responsible for previous heating and cooling periods on the planet. In this theory, devised by Serbian astronomer Milutin Milankovitch, tilts in the Earth as it rotates can result in more severe seasons, such as colder winters and hotter summers. Climate change is seen as a natural byproduct of this tilt, part of an ongoing long-term process that takes thousands of years.

16.20. SOLAR VARIABILITY THEORY

The seventh theory of climate change is that solar variability accounts for most or all of the warming in the late twentieth century and will dominate climate in the twenty-first century regardless of man-made greenhouse gas emissions.

Changes in the brightness of the sun are caused by sunspots – bursts of energetic particles and radiation – that vary in frequency in cycles of roughly 11, 87, and 210 years. These cycles cause changes in the amount of electromagnetic radiation – also called "solar wind" – that reaches Earth and its atmosphere, which in turn affects Earth's climate. Most proponents of the theory that solar variability drives changes in Earth's climate believe positive feedback occurs either by a process involving the influence of the solar wind on cosmic rays, which affects cloud formation, or on the oceans' thermohaline circulation (THC), which affects sea surface temperatures and wind patterns.

16.21. LET US SUM UP

You may already know that this topic creates a lot of controversy. For a while, people didn't believe the earth's temperatures were raising. Now everyone accepts that global warming is real, but they disagree on the causes and need for action. Before we can decide if global warming is "real," we need to define things. Many people think global warming means "human-induced" temperature change on the planet. However, that's not what it really means. Global warming is just one aspect of global climate change; global cooling is another. Climate change is caused both by natural phenomenon and by man-made activity. As for global warming, temperatures have been steadily rising over the last century. You might be surprised that the total rise is only about one degree. However, even a one-degree change in temperature creates big problems! Original models for global warming showed a more gradual rise in temperatures.

16.22. KEY WORDS

Global Warming, Climate Change, Theories of Climate Change

16.23. QUESTIONS FOR SELF STUDY

1. Discuss the various causes for global warming
2. Outline the theories that attempt to explain climatic changes.
3. Explain the carbon dioxide theory of climatic change.
4. Explain the positive and negative effect of global warming.

16.24. FURTHER READINGS

1. Barry, R.G. & Chorley, R.J.	:	"Atmosphere, Weather and Climate", Routledge, 1998.
2. Critchfield, H	:	"General Climatology" Prentice-Hall, New York, 1975.
3. Das, P.K.	:	The Monsoons, National Book Trust, New Delhi, 1968.
4. Lal D.S	:	"Physical Geography"Sharada Pustak Bhavan, Allahabad, 2009
5. Lydolph, Paul, E.	:	The Climate of the Earth, Rowman and Allanheld, Totowa, N.J., 1985.

6. Mather, J.R. : Climatology, McGraw-Hill, New York, 1974.

7. Patterson, S. : Introduction of Meteorology, McGraw-Hill Book Co., London, 1969.

8. Stringer, E.T. : Foundation of Climatology, Surjeet Publications, Delhi, 1982.

9. Trewartha, G.T. : An Introduction to Climate, International Students edition, McGraw Hill, New York, 1980.

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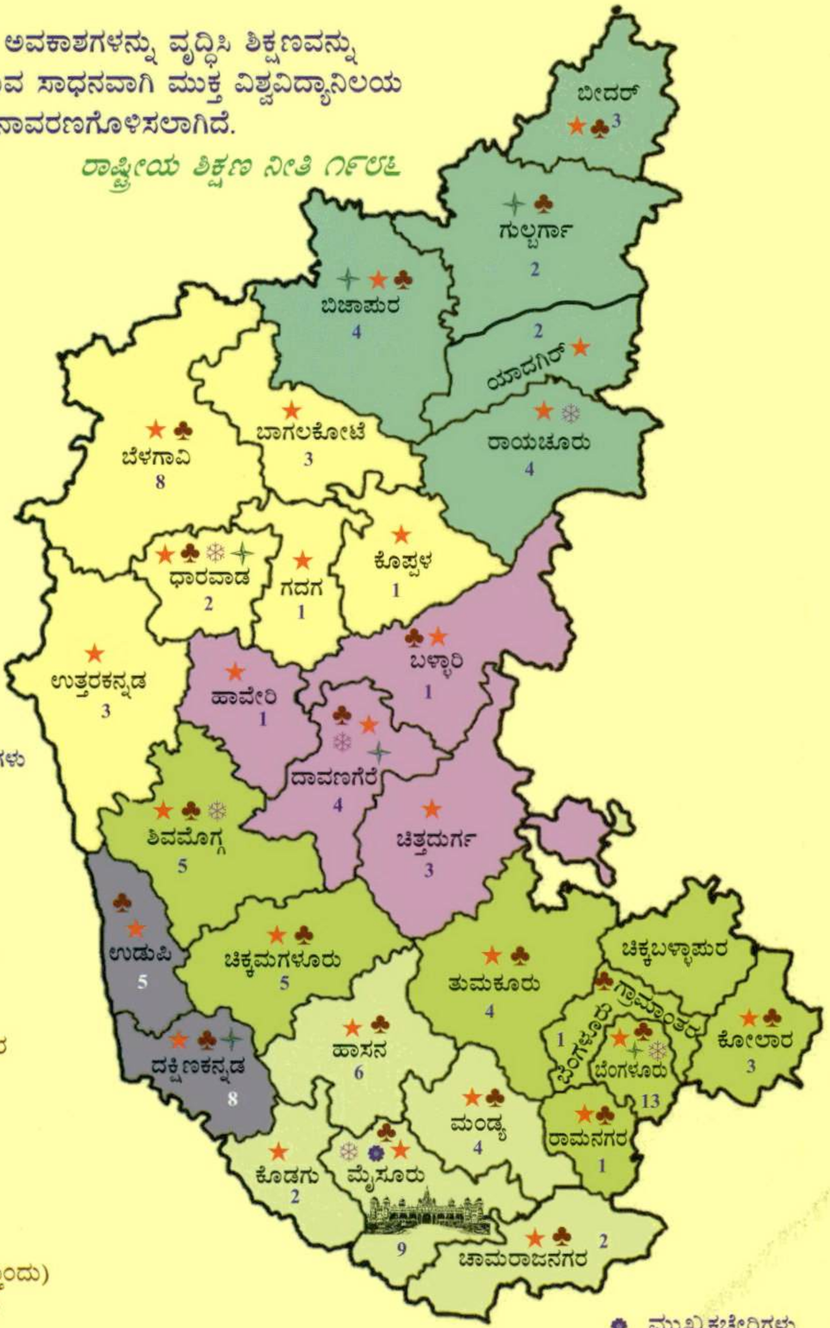

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assignments

supplementary material communication etc.

project

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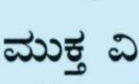

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