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Indira Gandhi National
Open University
School of Sciences

BGGCT-131
PHYSICAL GEOGRAPHY

Block

3

ATMOSPHERE

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Course Design Committee

Prof. (Retd.) H. Ramachandran
Department of Geography,
University of Delhi,
Delhi

Prof. Sachidanand Sinha
Centre for the Study of
Regional Development,
Jawaharlal Nehru University,
New Delhi

Prof. N.R. Dash
Department of Geography,
The MS University,
Baroda

Prof. Milap Chand Sharma
Centre for the Study of
Regional Development,
Jawaharlal Nehru University,
New Delhi

Prof. Vijayshri
Former Director
School of Sciences,
IGNOU, New Delhi

Prof. Mahendra Singh Nathawat
Discipline of Geography,
School of Sciences,
IGNOU, New Delhi

Dr. Vijay Kumar Baraik
Discipline of Geography,
School of Sciences,
IGNOU, New Delhi

Dr. Subhakanta Mohapatra
Discipline of Geography,
School of Sciences,
IGNOU, New Delhi

Dr. Satya Raj
Discipline of Geography,
School of Sciences,
GNOU, New Delhi

Dr. Koppisetti Nageswara Rao
Discipline of Geography,
School of Sciences,
IGNOU, New Delhi

Dr. Vishal Warpa
Discipline of Geography,
School of Sciences,
IGNOU, New Delhi

Block Preparation Team

Dr. R. Anil Kumar (Unit 10,11,12)
Associate Professor and Head (Retd.).,
Dept. of Geography,
University College Thiruvananthapuram,
Former KSCSTE Emeritus Scientist,
Govt. of Kerela

Dr. Jitender Saroha, (Unit 14)
Associate Professor
Dept. of Geography,
Dr BR Ambedkar College,
University of Delhi,
Delhi

Dr. Sudeshna Bhattacharya (Unit 13)
Associate Professor,
Dept. of Geography,
Miranda House,
University of Delhi,
Delhi

Prof. H.S. Sharma,(Content Editor)
Retd. Prof., Dept. of Geography,
University of Rajasthan

Course Coordinators: **Prof. Mahendra Singh Nathawat and**
Dr. Satya Raj

Block Production Team

Sh. Sunil Kumar
AR (P), IGNOU

Graphics Artists/Cartographers: Mr. Tamal Basu, Mohammad Shahnawaj Khan, Dr. Praveen Kumar Mishra, Mohammad Tayyab

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BLOCK 3: ATMOSPHERE

In the previous block, you have studied about lithosphere. So now, you are aware of the materials of the earth's crust, i.e. different types of rock formations. You learnt about endogenetic forces, which is responsible for the current arrangement of continents and oceans on earth. You are now familiar with drifting of continents and how mountains have formed. You have also studied about exogenetic processes, due to which the face of earth is continuously changing.

In this block you will learn about atmosphere which is a gaseous envelop around the earth and processes operating herein which makes earth a suitable home for living organisms. This block is divided into five units

Unit 10 introduces you to the composition and structure of atmosphere. Here you learn about the various gases which make up the atmosphere of earth. Regarding the structure, you will study that our atmosphere has various layers arranged as concentric shells around the earth.

Unit 11 will acquaint you with the process of insolation or incoming solar radiation. You will know the factors governing it, as all parts of earth do not receive the same amount of insolation. This gives rise to varying temperatures around the earth. You will also learn that incoming solar radiation is equal to outgoing terrestrial radiation which is called the heat budget of the earth.

Unit 12 explains the global distribution of surface pressure systems and how the differences in air pressure leads to the winds. You will study about different types of winds, i.e., planetary winds, seasonal wind, local winds etc.

Unit 13 gives a detailed description of atmospheric moisture which is an important determinant of climatic conditions worldwide. Here you will learn about different forms of condensation, that is fog and clouds and their types. You will also study about different forms and types of precipitation.

Lastly in **Unit 14** you will learn about climatic classification of Koeppen. This is important as different climate types results due to combined effect of variations of different elements of climate.

Objectives

After studying this block, you should be able to:

- define atmosphere and describe its composition and structure;
- explain the process of heating of atmosphere and earth;
- correlate with the global distribution of surface pressure systems and the resultant winds;
- summarise atmospheric humidity and identify different forms of condensation and precipitation; and
- classify the world climates on the basis of variations of climatic elements.

So we wish you good luck for studying this block.

UNIT 10

COMPOSITION AND STRUCTURE OF THE ATMOSPHERE

Structure

10.1 INTRODUCTION

In this course so far, you have learnt about geo-tectonics and lithosphere. This helped you to understand the processes related to the origin of earth and the forces that transform the lithosphere. You may recall that in tectonically active regions, earthquakes, volcanoes, fold mountains etc occur with regular frequency, depending on the type of plate margins. Lithosphere is an integral part of Physical Geography; other components being atmosphere, hydrosphere and biosphere. In this unit, you will learn about composition and structure of the atmosphere.

As you know, atmosphere envelops our earth and is a mixture of gases, such as oxygen, nitrogen, carbon dioxide, water vapour etc. These gases are held to our planet by the force of gravity and support various life forms through a delicate balance between fauna and flora, aquatic life and human societies.

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You will learn about composition of atmosphere in Sec. 10.2. Atmosphere is divided into several vertical layers which you will learn in Sec. 10.3. These vertical layers of the atmosphere are classified on the basis of temperature differences and on the basis of uniformity of gaseous compositions. In Sec. 10.4, we have discussed the basics of climatology and its scope. The concept of weather and climate and their controls are discussed in Sec. 10.5.

In the next unit you will learn about insolation and heat budget of the earth and how these help to maintain the temperature on earth.

Expected Learning Outcomes

After studying this unit, you should be able to:

- describe the composition of the atmosphere;
- list the distinguishing features of different layers of atmosphere;
- correlate temperature changes in different layers of the atmosphere;
- identify homosphere and heterosphere on the basis of uniformity of composition of gases; and
- explain the term climatology and differentiate between weather and climate.

10.2 COMPOSITION OF THE ATMOSPHERE

Please watch our Youtube video on composition and structure of the atmoshpere on https://www.youtube.com/watch?v=QKDsoPekCVI
After watching the video start reading the unit.

Altitude is defined as the height above a fixed reference point, which is usually taken as sea level. It is also referred to as elevation.

In your school, you must have learnt about the composition of earth's atmosphere. You may recall that atmosphere is a gaseous envelope surrounding the earth. It contains several gases as well as minute suspended solid and liquid particles. These are held by earth's force of gravity and support life. (The suspended solids and liquid particles are collectively known as aerosols.) In a pollution free environment, we expect that concentration of these constituents will remain constant. However due to human interventions, several changes have occurred. For instance, the concentration of particulate matter in cities has increased to such alarming levels that it has begun to affect human health such as allergies and respiratory troubles among others. It is therefore necessary that we as individuals and collectively as a society do not contribute to disturb the natural balance.

Aerosols include particulates, tiny liquid or ice crystals. Particulates are solids suspended in the atmosphere.

The density of atmosphere decreases with altitude and 97% of the total mass of atmosphere is concentrated in the region up to 25 km altitude and nearly half of the total mass lies upto 5.5 km altitude. Now refer to Table 10.1, where we have given the percentage of gases by volume of dry air in our atmosphere. You will note that nitrogen and oxygen are two major constituent gases that make up about 99% of air. Oxygen is produced by vegetation and removed by a variety of organic and inorganic processes. Oxygen is the most important gas for living organisms as we all inhale it for our survival. Nitrogen mainly serves as a diluent and is relatively chemically inactive. Nitrogen is added to air by decay and burning of organic matter, volcanic eruptions etc., and is removed by certain biological processes. Carbon dioxide and argon, apart from traces of other inert gases, water vapour and ozone, constitute the remaining 1%.

Table 10 .1: Composition of Dry Air in the Lower Atmosphere

Constituent Gas	Chemical Symbol	Per cent of gases by Volume of Dry Air
Nitrogen	N_2	78.084
Oxygen	O_2	20.947
Argon	Ar	0.934
Carbon dioxide	CO_2	0.038
Neon	Ne	0.00182
Helium	He	0.00052
Methane	CH_4	0.00017
Krypton	Kr	0.00011
Hydrogen	H_2	0.00005
Nitrous oxide	N_2O	0.00003
Xenon	Xe	0.00001
Ozone	O_3	Trace to 0.00080

***Source**: Modified after Veriniani (1966) and Williamson (1973)*

It is important to mention here that concentration of nitrogen and oxygen remains constant upto an altitude of 80 km in our atmosphere. However, concentrations of carbon dioxide, water vapour and ozone are subject to spatio-temporal variations. Let us get acquainted with these variable gases.

Carbon dioxide is an important constituent gas of atmosphere. It is used by green plants for photosynthesis. It allows incoming short wave solar radiation to reach the earth but prevents outgoing long wave terrestrial radiation from escaping the lower atmosphere. It reradiates heat back to the earth and increases the temperature of lower atmosphere. So it is also regarded as a greenhouse gas. Due to increasing use of fossil fuels, its concentration is constantly increasing and is now about to reach 0.04% by volume of dry air.

Another important gas is **Ozone** (O_3) which is present at an altitude of about 30 km. You may be aware that it absorbs harmful ultraviolet radiation from the sun. However, due to human interventions, particularly the use of CFCs, HFCs etc, huge hole has been created in this layer due to depletion of ozone molecules in the stratosphere above the polar regions. Refer to Fig. 10.1 which shows false colour view of ozone hole above Antarctica for August 2018. The purple and blue colours show less concentration of ozone gas and thus you can notice that ozone hole has developed over Antarctica. Dobson unit is a measure of total ozone concentration. The depletion of this layer is very harmful to all life forms on the earth. It is important to note that while ozone

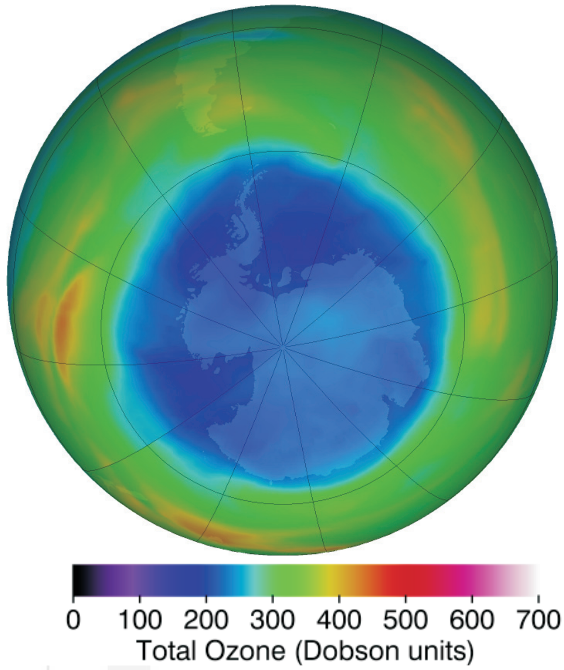

Fig. 10.1: False colour view of Ozone in August 2018. (http://ozonewatch.gsfc.nasa.gov/ NASA Ozone Watch)

acts as a protective shield in the upper atmosphere, it acts as a pollutant near the surface of earth.

Water Vapour is another variable gas in the atmosphere whose percentage varies between 0.02 to 4 percent by volume in dry and humid climates respectively. It is a source of clouds and rainfall and like carbon dioxide absorbs long wave terrestrial radiation and is a greenhouse gas. Just as a greenhouse which allows light but traps heat, some of the naturally occurring greenhouse gases are carbon dioxide, methane, water vapor etc while CFCs are produced by humans in industries. These gases are opaque to outgoing terrestrial radiation and radiate it back to the earth thus heating up the earth and creating a greenhouse effect. Although this effect is needed to maintain a sustainable temperature on earth but recently due to increasing human activities the percentage of greenhouse gases is increasing thus leading to global warming.

Let us now learn about the particulate matter present in the atmosphere. Our newspapers/TV news channels regularly report the levels of particulate matter, particularly in metro cities. You may have noted that it is invariably higher than normal value. The particulate matter is known to exist in sizes ranging from 2.5 μ to 10 μ. As a result, these are adding to various lung related diseases. These particles come from sources like dry soil coming from deserts in arid regions, sea-salts coming from ocean spray in coastal areas. Similarly pollen, seeds, spores etc are lifted from the environment by winds and volcanic ash and soot from the volcanoes in areas near volcanoes. The concentration of particulate matter is relatively more in arid regions as compared to the humid regions. Industrial effluents also add to higher concentration of particulate matter.

You now know about the composition of gases in our atmosphere. You may now logically ask: What is the genesis of the present composition of the atmosphere? It is the result of processes that have occurred during various geological eras since the time of origin of earth about 4.5 billion years ago. In Unit 1of this course you have learnt that primordial earth was a hot gaseous nebula. As it cooled, the crust solidified over the molten core over a period of time. In this process, gases like carbon dioxide, nitrogen and water vapour emanated from molten magma beneath the crust which formed the main constituent gases of atmosphere at that time. Water vapour condensed in the form of rains which lasted for several thousand years and filled up the huge basin areas on the crust leading to the emergence of oceans. Some water vapour escaped to the upper atmosphere and broke into constituent hydrogen and oxygen atoms. Since oxygen is heavier than hydrogen, it gravitated towards the surface of earth while hydrogen atoms, being lighter, escaped to the upper reaches of the atmosphere. Oxygen atoms near the earth's surface combined to form oxygen molecules. Primitive green plants also contributed to the release of oxygen molecules in the atmosphere.

Before proceeding further, you should answer a SAQ to test your progress.

SAQ 1

Spend 5 min

i) State the percentage of nitrogen and oxygen in dry air in earth's lower atmosphere.

ii) List the problems arising due to increase in the percentage of carbon dioxide in lower atmosphere?

Now that you know the composition of earth's atmosphere, it would be interesting to delve in further details. You will learn about vertical structure of atmosphere in the following section.

10.3 VERTICAL STRUCTURE OF THE ATMOSPHERE

The vertical structure of atmosphere has attracted the attention of several meteorologists and scientists since time immemorial for a variety of reasons. We know that air navigation and communication of information via radio/TV signals are facilitated by different regions of the atmosphere. The classification of vertical structure of atmosphere is done based on different criteria, the most important of these being temperature. Accordingly, our atmosphere is said to comprise layered structure. In fact, our atmosphere can be visualised as concentric shells or layers around the earth based on temperature differences.

10.3.1 Classification Based on Temperature

Based on distribution of temperature with height, our atmosphere is said to have the following layers:

(a) Troposphere,

(b) Stratosphere,

(c) Mesosphere,

(d) Thermosphere and

(e) Exosphere.

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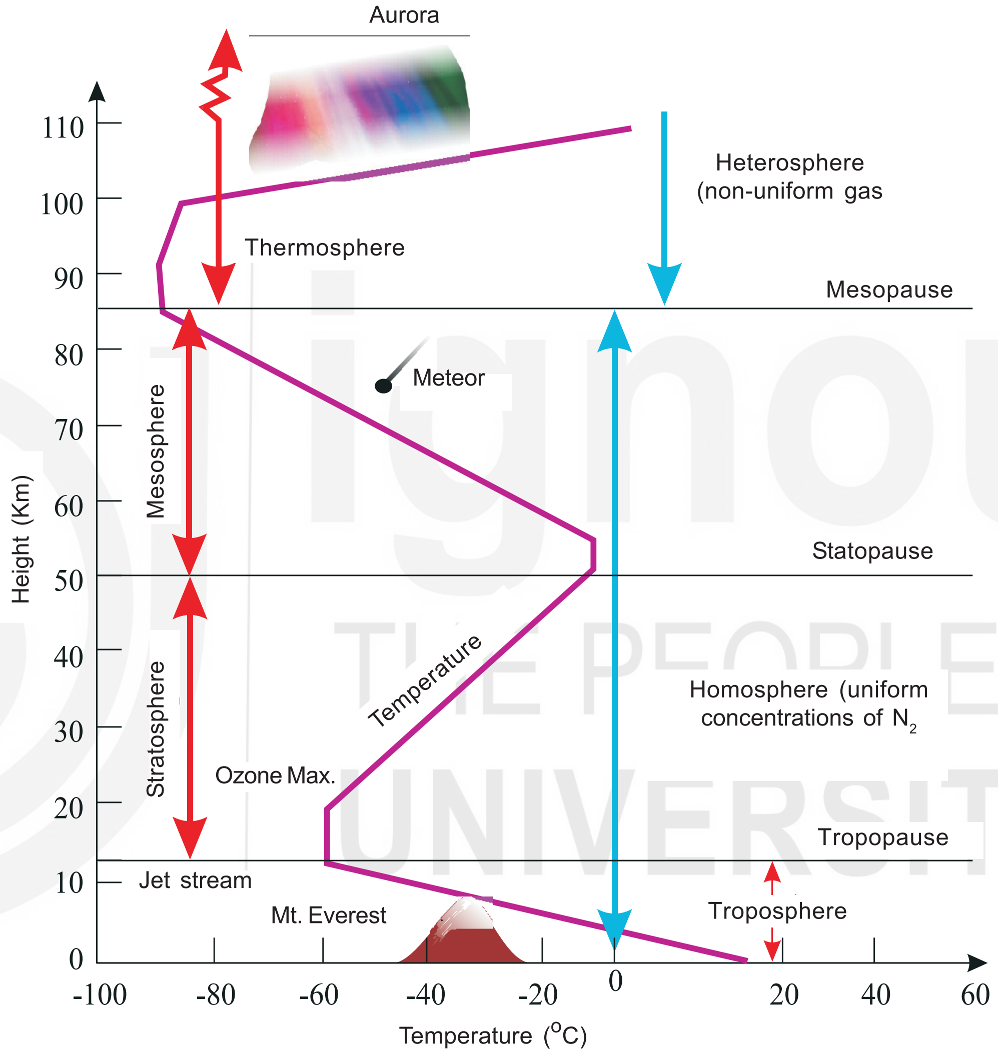
This nomenclature ***'troposphere'*** was first suggested by Tiesserence de Bort. It is derived from two Greek words, i.e., '***tropos'*** which means mixing and ***'sphere'*** which means zone. So the term troposphere means the zone where mixing of gases occurs most readily.

We now discuss each of these layers.

A. Troposphere

Refer to Fig. 10.2, where we have depicted the vertical structure of earth's atmosphere. Troposphere is the lowermost portion of the atmosphere. It comprises three-fourths of the total gaseous mass of the atmosphere. Almost all water vapour and dust particles exist in this layer. Eventually all the convection currents of air occur here. This gives rise to weather phenomena like clouds, lightning, thunderstorms, snowfall etc in this layer.



A temperature inversion exists when the temperature increases instead of decreasing with altitude.

The word ***'tropopause'*** was coined by **Sir Napier Shaw** from two Greek words, i.e., ***'tropos'*** and ***'pause'*** which means the zone where mixing stops.

Fig. 10.2: Vertical structure of the atmosphere.

An essential feature of this layer is that temperature decreases uniformly at the rate of 6.5°C per 1000 m of ascent. This uniform rate of decrease of temperature with altitude is known as the ***normal lapse rate***. Now you can correlate why hill stations like Shimla, Darjeeling and Ooty which are situated at higher altitudes are cooler than plains.

Do you know that the extent or height of troposphere is constant neither in time nor in space? The height of the troposphere at the poles is about 8 km and at the equator it is about 16 km. The reason for this non-uniformity is the high surface temperatures in the equatorial region which causes high convective currents of air compared to poles. The height of troposphere also varies in different seasons. You can now reason out that the height of troposphere increases during summers and decreases during winter. The lower part of the troposphere extending to about 3 kilometers from earth's surface is also called the ***friction layer*** because it experiences maximum friction between the earth and the atmosphere. The layer also exhibits the phenomenon of temperature inversions.

Ozone layer of the stratosphere is depleting and is under tremendous threat due to continuous use of chlorofluorocarbons (used in refrigerators, air-conditioners etc), nitrous oxides (emitted from jet planes), halon etc. In the absence of ozone layer, the harmful ultra-violet radiation would reach the earth surface and cause various disorders in human beings as well as other life forms. It could even destroy many microscopic species from the earth.

At the top of the troposphere there is a transitional zone called ***"tropopause"*** separating the troposphere and next layer of atmosphere, i.e., stratosphere. Like troposphere the height of tropopause is also greater near the equator compared to poles. This is the reason why the lowest temperature in the tropopause occurs over the equator and not over the poles. Tropopause marks the end of decrease of temperature due to normal lapse rate and the temperature attains a minimum of -50°C to -60°C here. You will learn in the next sub-section that this trend in temperature variation reverses in the stratosphere.

B. Stratosphere

On an average, the stratosphere exists between about 12 km to 50 km above the earth's surface. This layer is relatively stable, dry and non-convective in nature and characterised by horizontal, instead of vertical, movement of air. This is precisely the reason why it is preferred to fly aeroplanes to minimise loss of fuel through turbulence and air resistance. The lower part of stratosphere, i.e. up to a maximum of about 25 km from the earth's surface, behaves as an isothermal region (as temperature here does not change with altitude) unlike the troposphere. Formation of cirrus clouds is also seen in lower stratosphere. Above 25 km altitude, a steep increase in temperature with height is observed. This is attributed to the presence of ozone in this part of the stratosphere which absorbs harmful ultra-violet radiation coming from sun. The temperature increases to about 0°C at an altitude of 50 km. The upper boundary of the stratosphere is known as **stratopause** and it extends to an average altitude of 50 km.

You may like to check your progress by answering a SAQ.

SAQ 2

Spend 5 min

i) The height of troposphere is more at the equator than at the poles. Explain.

ii) How does the height of troposphere vary with seasons and why?

iii) Pilots prefer to fly aircrafts through the lower part of stratosphere. Discuss the possible reasons.

C. Mesosphere

So far you have learnt about troposphere and stratosphere. The layer above stratospause is known as mesosphere. You will learn about it now. The mesosphere lies between 50 km and 80 km from the earth's surface. It is also characterised by decrease of temperature with height due to the absence of

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A ***meteor*** is the flash of light that we see in the sky during night, when a small chunk of interplanetary debris burns due to friction while passing through our atmosphere. The debris of the interplanetary matter is called ***meteoroid*** and a few which make their passage to the earth's surface are called ***meteorites***.

Ionisation is the process by which atom or a molecule acquires a negative or positive charge by gaining or losing electrons often in conjunction with other chemical changes.

ozone layer here which increases the temperature of stratosphere by absorbing harmful ultraviolet rays of the sun. The temperature falls to a minimum of -100°C at a height of 80 km. The upper part of the mesosphere is known as **Mesopause**. Thin noctilucent clouds which are seen in mesosphere over high latitudes during summer, shine during night or appear luminescent during twilight. These mesospheric clouds are formed of very tiny ice crystals upto 200 nm in diameter and exist at an altitude of 75-85 km. These are supposed to be the highest altitude clouds. Mesosphere also experiences the disintegration of meteorites due to high amount of friction here. This is because the layers of atmosphere above mesosphere that is thermosphere and exosphere are having extremely low density of air. So, whatever friction meteorites experience after entering the earth's atmosphere, is basically at mesosphere.

D. Ionosphere or Thermosphere

Refer to Fig. 10.2 again and concentrate on the region above mesopause. You will note existence of high temperature region above mesopause. This region is known as thermosphere. The lower part of the thermosphere is called the **ionosphere** which extends between 100-400 km altitude**.** Ionosphere was discovered by Kennelly and Heaviside. This layer is named ionosphere because gaseous atoms or molecules in this layer get ionised due to the solar radiations. This layer is used to reflect electromagnetic waves back to the earth and make radio or TV communication possible.

Another important aspect about Ionosphere is that it is characterised by the occurrence of ***Auroras,*** which usually occurs between 80 and160 km altitude. Auroras are natural display of lights in higher latitudes especially near the magnetic poles and are caused by the excitation of ionosphere by streams of high-energy particles from the sun. In northern hemisphere they are called as ***aurora borealis*** or northern lights and in southern hemisphere they are called as ***aurora australis*** or southern lights.

Ionosphere is further bifurcated into a number of ionised layers namely the D, E, F1 and F2 and G layers. Let us go through the characteristics of each of these layers.

D-Layer

D-Layer is present between 60-99 km alitude during day time and disappears as soon as the sun sets. It absorbs the medium and high frequency waves and reflects the low frequency waves.

E-Layer

E-Layer is used to get medium and high frequency radio waves reflected. This layer is also called Kennelly-Heaviside layer and exists at a height of 90-130 km from the earth's surface. This layer also disappears after sunset.

Sporadic E Layer

Sporadic E layer occurs under special circumstances just like the case of meteors or auroras and is associated with high velocity winds. It reflects very high-frequency radio waves and is found at an altitude of about 110 km.

E2 Layer

E2 layer is the region in the ionosphere above the sporadic E layer. It is formed by the action of ultraviolet photons on oxygen molecules and therefore appearing during day time. So, it vanishes by sunset and forms at a height of about 150 km from earth's surface.

F1 Layer and F2 Layer

Together these are called Appleton Layer and are found at a height of about 150-380 km from the earth's surface. They reflect medium and high frequency radio waves and are important in long distance radio communication.

G Layer

G layer is a reflecting layer and occurs above the F2 layer. It reflects all the waves reflected by the F layer and so it is not detectable. It is found at a height of about 400 km above the earth's surface and is characterised by the presence of free electrons due to the reaction of ultraviolet photons with nitrogen atoms.

Thermosphere extends to several hundred kilometers. At about 500 km altitude, the temperature rises to about 2000^0C. The high temperatures here refer to internal energy or kinetic energy at which the molecules move over here. As the density of air is too sparse in this region, this high temperature cannot be recorded in the thermometer; neither could it be felt as is felt in troposphere where density of air is much higher.

E. Exosphere

This is the outermost layer of the earth's atmosphere starting at about 500 km from the earth's surface and extending to an altitude of around 1000 km. The exosphere is really a transitional zone between the earth's atmosphere and interplanetary space. The density of air at such heights is extremely low. This is the reason why in spite of having very high temperatures of about 5568°C, it is not felt. Hydrogen and helium are the predominant constituents in this region.

So far you have learnt about different layers or spheres of the atmosphere on the basis of temperature. Another criterion for classification is based on the chemical composition. Accordingly, it can be broadly divided into two major spheres: homosphere and heterosphere. The discussion of homosphere and heterosphere forms the subject matter of the next section.

10.3.2 Classification Based on Chemical Composition

The region of the atmosphere extending from the surface of the earth to a height of 80-90 km altitude is known as homosphere. This layer is so named because the proportion of component gases and their chemical compositions (as you have learnt in Sec. 10.2), remains uniform in it. This is notwithstanding some increase in the concentration of gases like carbon dioxide and ozone in the lower atmosphere due to human interventions. Homosphere engulfs troposphere, stratosphere and mesosphere along with their transitional zones.

The heterosphere is above homosphere. In this layer, chemical composition changes with height. Heterosphere consists of a series of concentric layers of molecular nitrogen, atomic oxygen, helium and hydrogen. We identify four regions in the heterosphere.

a) Molecular Nitrogen (N_2) layer encircling the earth from 80km to 200 km

b) Atomic Oxygen layer from 200km to1125 km altitude

c) Atomic Helium layer from 1125 km to 3540 km altitude and

d) Atomic Hydrogen layer extending from 3540 km to the outermost boundary of the atmosphere.

Can you reason out why these concentric layers of gases are arranged like this? You will note that these layers are arranged according to the atomic weights of the constituent gases; nitrogen being the heaviest occurs in the lower part and hydrogen, being the lightest, occupies the topmost part of the atmosphere almost up to its outer limit or boundary. Refer to Fig. 10.3 to get a better picture of vertical layers of atmosphere as per chemical composition.

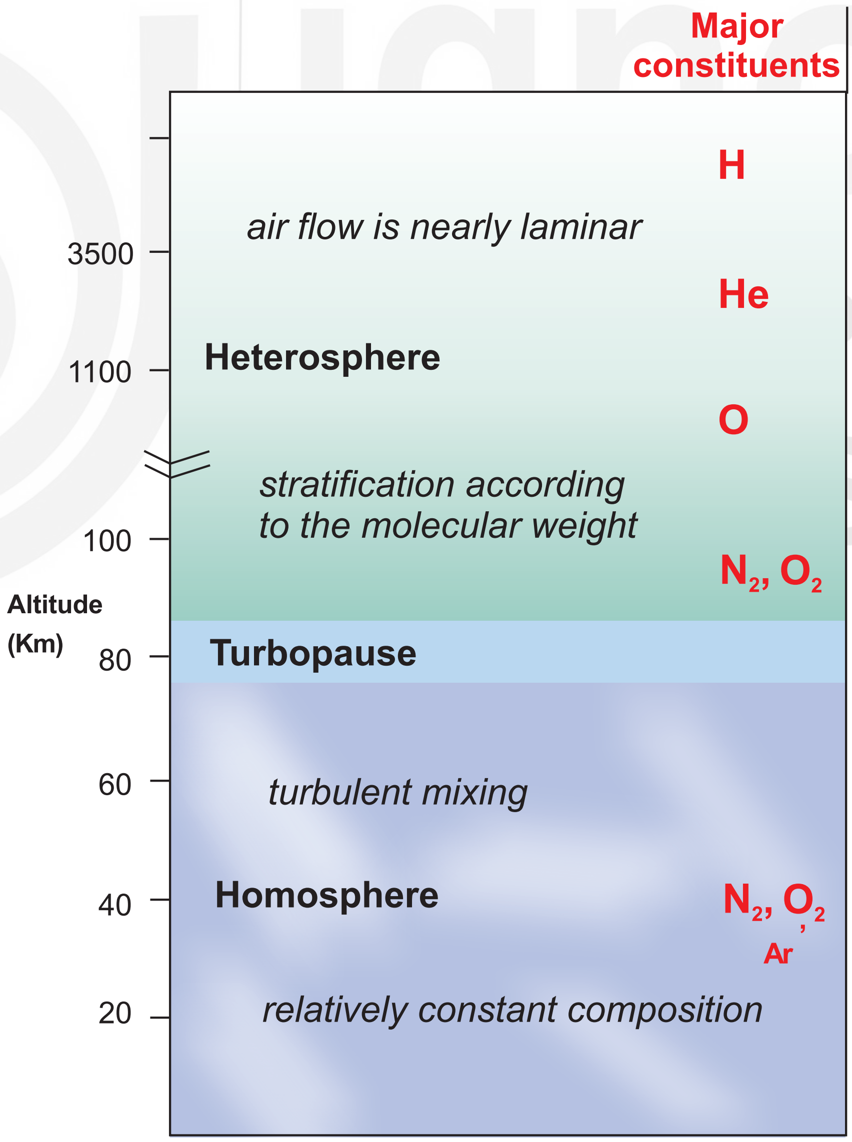

Fig. 10.3: Vertical structure of the atmosphere according to chemical composition.

In this unit so far, we have discussed the composition and structure of our atmosphere. In the following units of this Block, you will learn about other topics related to climatology. So, first let us understand the meaning of ***Climatology***. Climatology is the study of atmospheric conditions of different parts of the earth over a long temporal duration. British climatologist E.T. Stringer is credited with the view that climatology does not come entirely within the fields of meteorology or geography. It is an applied science strictly dealing with the methods of meteorology but whose aims and results are geographical. Meteorology is concerned with day-to- day atmospheric conditions and their causes.

10.4 BASICS OF CLIMATOLOGY AND ITS SCOPE

Climate, which forms an important feature of environment, directly influences all life forms on earth. In India, we have six seasons: spring, summer, rainy, autumn, pre-winter and winter. We wear different clothes in summers and winters. Even harvests, available fruits and vegetables are different in different periods of a year. Similarly, diseases from which we suffer are different in different seasons. That is to say, climate determines what we eat, what we wear, where we dwell and so on. Climate has a strong bearing even on the fauna and flora as well as pests to which an organism is exposed in different parts of the world. Similarly, beautiful physical features on the earth's surface also arise due to different climatic conditions, which causes weathering and sculpturing of the land.

The aim of climatology is to describe and explain the atmospheric phenomena in order to promote a better understanding of the processes and interactions within the atmosphere and between the atmosphere and earth. Hence, climatology falls largely within the domain of geography as climatologists are mainly concerned with defining and describing different climates in different geographical settings.

You should know in brief about six sub-divisions of climatology identified by **Ayoade** in 2004.

i) **Regional Climatology**: It is the description of climates over selected areas of the earth.

ii) **Synoptic Climatology**: It is a new approach to regional climatology which takes into consideration weather and climatic conditions of an area in accordance with the prevailing pattern of atmospheric circulation.

iii) **Physical Climatology**: It investigates the behavior of elements of weather or processes in the atmosphere.

iv) **Dynamic Climatology**: It is concerned with the atmospheric motions in various seasons and general circulation of the atmosphere.

v) **Applied Climatology**: It is the application of climatological knowledge and principles to solve the problems faced by mankind.

vi) **Historical Climatology**: It is the study of the development of climates through time. Based on the scale of extent, historical climatology has two sub-divisions. They are ***Macro Climatology*** and ***Micro Climatology.***

Macro climatology is concerned with climatic features and atmospheric motions on a large scale that covers large areas of the globe. Micro climatology, on the other hand is concerned with the study of climates over relatively small areas especially close to the ground surface.

Our discussion about climatology would not be complete if we do not study about the terms ***weather*** and ***climate*** which to a layman appears synonymous. However, there are marked differences between the two. Let us learn about this in the next section.

10.5 CONCEPT OF WEATHER AND CLIMATE AND THEIR CONTROLS

You do talk of warm evening, a cold morning, sunny afternoon, a rainy day or a chilly night. These remarks about the atmospheric conditions of a particular place at a particular time are related to weather conditions. **Weather** denotes atmospheric conditions at a certain place at some specific time and is essentially a day-to-day, or even an hour-to-hour phenomenon. The weather can vary in the same district or even over a small area. This is the reason why at times, a part of your city experiences sunny weather while some other part may be receiving heavy rains. **Climate**, on the other hand refers to the average atmospheric conditions of an area over a considerable period of time, say about 35 years. This involves the systematic observation, recording and processing of various elements of the climate such as temperature, pressure, winds, humidity, rainfall, clouds, sunshine etc over a long period of time. Let us know about the elements of weather and climate and their controls.

A. Elements of Weather and Climate and their Controls

Even though weather and climate are not identical, their nature is a combination of various elements like solar energy, temperature, pressure, humidity, cloudiness, precipitation, winds etc. These are called elements of weather and climate.

The variation in the intensity and distribution of the weather and climatic elements over the earth function as controls of weather and climate. Due to this weather differs from day to day and climate varies from region to region. Apart from the above mentioned elements, climate is also controlled by the elements such as altitude, distribution of land and water, mountain barriers, air pressure, atmospheric disturbances of various kinds, ocean currents etc. These controls, act in different intensities and produce variations in temperature and precipitation and in turn give rise to the changing patterns of weather and climate on the globe.

As mentioned earlier, weather and climate profusely influence our everyday life. Today we depend on meteorological reports to a great extent. We all know that in spite of vast progress made in the field of science and technology, our farmers still depend on rains for their crops. You may find many more examples like this depicting the importance of weather in our day-to-day lives.

To know more about weather, please watch our Youtube videos at the following links:

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i) Observing Weather (https://youtu.be/EKWrrkI1xrY)

ii) Predicting Weather (https://youtu.be/ZJE2VrdFxDg)

B. Atmosphere in the Past

Have you ever imagined about our premordial atmosphere? Our atmosphere at present is what meteorologists call an *oxidising* atmosphere, while the premodial atmosphere was a *reducing* atmosphere. Can you reason out why? This is because our primitive atmosphere was devoid of oxygen.

As mentioned earlier, the present atmosphere resulted from a gradual release of gases both from the planet's interior and from the metabolic activities of various life forms. Earth's primordial atmosphere developed due to outgassing or venting during its formation. Volcanic eruptions led to gaseous emissions which included water vapour (H_2O), carbon dioxide (CO_2), sulphur dioxide (SO_2), hydrogen sulfide (H_2S), carbon monoxide (CO), chlorine (cl), fluorine (f), diatomic nitrogen (consisting of two atoms in a single molecule), as well as traces of other substances. You should know that 85 percent of volcanic emissions are in the form of water vapour. In contrast, carbon dioxide is about 10 percent of the effluent. Water vapour condensed in the form of rains and those which escaped to upper atmosphere, broke into constituent hydrogen and oxygen atoms. Oxygen being heavier gravitated towards earth while hydrogen being lighter escaped to upper atmosphere.

Before we conclude this unit, you should solve a SAQ to check your progress.

Spend 5 min

SAQ 3

i) What do you understand by Climatology and meteorology?

ii) Distinguish between the terms weather and climate.

10.6 SUMMARY

Atmosphere is a mixture of gases enveloping the earth. Nitrogen and Oxygen account for 99% of our atmosphere. Troposphere, stratosphere, mesosphere, thermosphere and exosphere are the major vertical layers of atmosphere based on temperature differences between them. Troposphere is known for weather phenomena such as clouds, thunder, lightning, rainfall and snow and has 75% of total mass of the atmosphere. Upper stratosphere is composed of the ozone layer which protects earth from the harmful ultraviolet radiation. Ionosphere which forms the part of lower thermosphere is mainly responsible for the reflection of radio signals from the earth. Based on the chemical composition, the atmosphere is divided into Homosphere and Heterosphere.

Climatology is a branch of science that describes and explains the nature of climates and its variation from place to place and its relation to other elements of natural environment, especially human beings. Weather means the condition of the atmosphere at a certain place at some specific time. Climate, on the other hand is the average of atmospheric conditions of an area over a considerable time, say about 35 years. Solar energy, temperature, humidity,

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precipitation and winds are the elements of weather and climate. These elements appear in different combinations to form different weather and climatic types. Both weather and climate influences living organism throughout the globe.

10.7 TERMINAL QUESTIONS

1. Give a detailed description of the composition of atmosphere. How the concentration of some gases is changing and what are the consequences of this change?
2. Describe the vertical layers of atmosphere on the basis of temperature differences between them and bring out the importance of troposphere. How does stratosphere influence human health?
3. Answer the following:
   (a) Difference between Homosphere and Heterosphere
   (b) Describe the different branches of Climatology given by Ayoade
   (c) Briefly explain the evolution of our present day atmosphere.

10.8 ANSWERS

Self-Assessment Question

1\. i) Percentage of nitrogen and oxygen in dry air in lower atmosphere is 78.084 and 20.947 respectively. Together they make up 99% by volume of dry air in lower atmosphere.

ii) As carbon dioxide is not transparent to outgoing long wave terrestrial radiation, it increases the temperature of lower atmosphere. Recently, indiscriminate use of fossil fuels have led to tremendous increase in the percentage of this gas from 0.03% to about 0.038% by volume of dry air. Due to this, temperature across the world has risen and has led to global warming which has severe consequences like melting of polar ice, rise of sea level, inundation of many islands and ports, loss of several species etc.

2\. i) The height of the troposphere is greater at equator due to the presence of hot convective air currents which forms due to higher temperature over here. These air currents push the atmospheric gases upwards along the equator compared to the polar areas.

ii) During summers, the height of troposphere increases and it decreases during winters. This is attributed to higher temperatures during summer which heats up the air due to which the air expands.

iii) The lower part of the stratosphere is a relatively calm area and is characterised by horizontal air movements rather than vertical. This minimises the resistance to flights during their motion and helps in saving fuel as well as in preventing turbulence.

3. i) Climatology is the study of atmospheric conditions over different parts of the earth over a long temporal duration. Meteorology is concerned with day-to- day atmospheric conditions and their causes. Meteorology and climatology represent the study of weather and climate respectively, the difference essentially being the different time scales and approaches used for such study. Meteorologists tend to concern themselves with the analysis of actual weather situations, while climatologists are more concerned with the aggregation of such situations.

   ii) The term weather is used to describe the condition of atmosphere at a certain place at specific time. It denotes day-to-day or even an hour-to-hour phenomenon on a larger or on even a small area. Weather is subjected to drastic changes at any time. On the other hand, climate is the average of atmospheric conditions of an area over a considerable time, say for about 35 years. Climate involves systematic observation, recording and processing of the various elements of the climate such as temperature, pressure, winds, humidity, rainfall etc. It is also controlled by other elements such as altitude, distribution of land and water, mountain barriers, global pressure belts, air masses, atmospheric disturbances and ocean currents. So climate has huge variations for different regions.

Terminal Questions

1. Start your answer with definition of atmosphere and then about the major gases present in atmosphere and their percentage. Mention the percentage of carbon dioxide as it is important and give the names of remaining 1 percent of gases. In the second paragraph explain how concentration of few gases are changing. Refer to Sec. 10.2.

2. First of all list all vertical layers of atmosphere and describe them one by one. Lastly describe how troposphere is important and how stratosphere influences human health. Refer to Sec. 10.3.1.

3. a) Define homosphere and heterosphere and explain the difference while defining. Refer to Sec. 10.3.2.

   b) Give briefly the different branches of climatology given by Ayodade. Refer to Section 10.4

   c) Describe primordial atmosphere and the way it has evolved at present. Refer to Sec. 10.5 (C) and 10.2.

10.9 REFERENCES/FURTHER READING

Critchfield,H., (1981), *General Climatology*, Prentice Hall, New York.

Lal D.S., (2009), *Climatology and Oceanography*, Sharda Pustak Bhavan, Allahabad.

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UNIT 11

INSOLATION AND ATMOSPHERIC TEMPERATURE

Structure

11.1 INTRODUCTION

In the previous unit, you have learnt about composition and structure of the atmosphere and got a general introduction to climatology. In this unit you will learn about the processes involved in the heating of atmosphere and earth and how this heat is transferred from one place to another leading to temperature variations over the earth.

We all know that sun is the prime source of energy for earth. It heats up the atmosphere and earth through the process called insolation which you will study in Sec. 11.2. There are different factors responsible for heating up of the atmosphere and earth which you will study in Sec. 11.3. The distribution of solar radiation across the globe has been covered in Sec. 11.4. Then we discuss about the heat budget of atmosphere and earth in Sec. 11.5. Since you are studying heat budget of atmosphere and earth in this unit you will also learn about temperature and factors controlling distribution of temperature on earth in Sec. 11.6 and 11.7 respectively. Finally horizontal and vertical distribution of temperature forms the subject of Sec. 11.8 and Sec. 11.9 respectively.

In the next unit, you will study about atmospheric pressure and distribution of surface pressure systems and winds.

Expected Learning Outcomes

After studying this unit, you should be able to:

- outline the different processes involved in heating and cooling of the atmosphere and earth;
- explain heat budget of the atmosphere and earth;
- describe the factors influencing horizontal and vertical distribution of temperature over the earth; and
- analyse the variations in distribution of temperature over the earth's surface in the months of January and July.

Please watch our Youtube video on Insolation and Atmospheric Temperature at the following link.

https://www.youtube.com/watch?v=qmL2vDMEOt8

Now let us get introduced to the process of insolation.

11.2 INSOLATION: MEANING AND DEFINITION

The literal meaning of the word 'insolation' is "incoming solar radiation". Do you know that earth intercepts only a minute percentage of solar radiation? This is only about 1/2,000,000,000th (one in two billion) part of sun's energy output which takes 8 minutes 20 seconds to reach the earth's surface. The distance between the sun and earth is about 149 million kilometers. However, this small amount of solar radiation reaching to the earth is of great significance as it controls all the physical and biological phenomena of the earth. The amount of solar radiation intercepted by the earth's surface is approximately 2 calories per square centimeter per minute. It is known as the ***solar constant***. The value is often cited as ***Langley***, which is 1 calorie per square centimeter per minute.

You might know that the sun radiates energy in the form of electromagnetic radiation which consists of a bundle of rays of different wavelength as shown in Fig. 11.1. These range from shorter waves like x-rays, gamma rays to longer radio waves. Incoming solar radiation is referred to as shortwave radiation and comprises of ultraviolet, visible and short infrared radiation. Radiation emitted by earth is the longwave terrestrial radiation and falls in thermal-infrared portion of electromagnetic spectrum. A wavelength of 4 micrometers is considered to be the borderline between longer and shorter wavelengths.

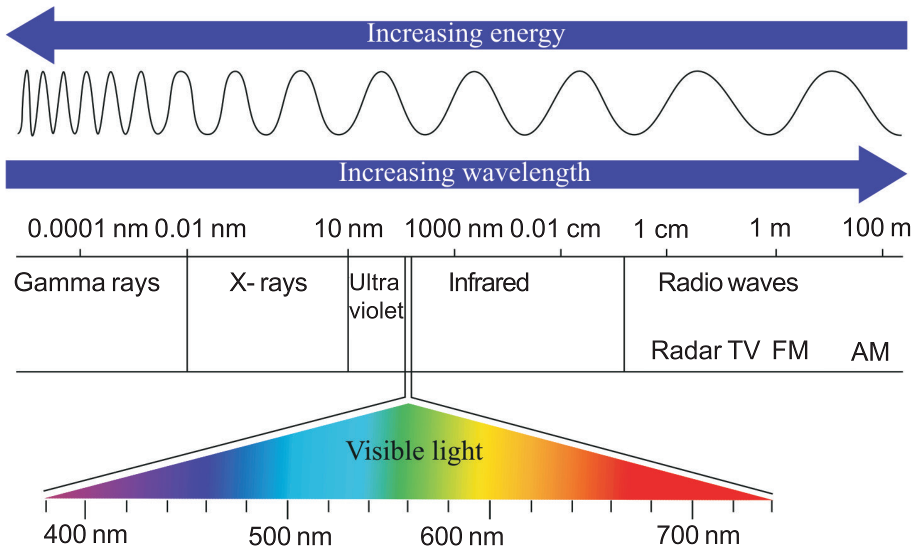

Fig. 11.1: The Electromagnetic Spectrum.

Sun rays after reaching the earth's surface are converted after absorption by the surface, from short wave to long wave radiant energy. This is known as heat. There are various processes responsible for the movement of this heat energy and heating and cooling of the atmosphere. Let us discuss them.

A. Radiation

Radiation is the process by which electromagnetic energy is emitted from a hot body. All hot bodies radiate short wavelengths of energy than the cooler bodies. So the sun being a hot body radiates short wavelengths of electromagnetic energy and earth on the other hand being a cooler body emits longer wavelengths of radiant energy, that is, thermal infrared.

B. Reflection

You should know that earth and its atmosphere reflect a part of the solar radiation back to space. Reflectivity is expressed as a percentage of incident radiation reflected and is also known as albedo or reflection coefficient. You should refer Table 11.1 to learn about albedos of various surfaces to solar radiation.

Albedo is the ratio of amount of radiation reflected to the amount of radiation received. It is also called reflecting power of a surface

Table 11.1: Albedos of Various Surfaces to Solar Radiation

Type of Surface	Albedo (%)
Fresh snow	75 - 95
Clouds	45 - 90
Old snow and sea ice	30 - 40
Dry sand	35 - 45
Desert	25 - 30
Dry savannah	25 - 30
Wet savannah	15 - 20
Grass covered meadow	10 - 20
Asphalt road	5 - 17
Deciduous forest	10 - 20
Coniferous forest	5 - 15
Water	10

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Angles of Inclination of the Sun	Albedo (%)
0°	99+
10°	35
30°	6
50°	2.5
90°	2

***Source*: Climatology-An Atmospheric Science, John E. Oliver, John J. Hidore**

Earth has an albedo of 30% which represents the mean reflectivity from the ocean, land and atmosphere.

C. Scattering

Scattering is a process by which dust particles and gaseous molecules diffuse part of the radiation in different directions. The most obvious effect of scattering in the atmosphere is the colour of sky. Many a times you might have pondered over the reason for different colours of the sky at different times. The only reason our sky appears blue is because of scattering of radiation in short wavelengths of visible light. As the radiation in the visible range enters the outer regions of the atmosphere small gas molecules scatter the shortest wavelengths, the violet, first. As a result the atmosphere scatters and absorbs the violet so the sky does not have a violet colour. Blue scatters next. This randomly diffused radiation in the blue range scattered through the lower atmosphere, gives it its colour. Most of the radiation in the visible range has wave lengths greater than the diameter of the particles in the dry atmosphere.

SAQ 1

Why sky appears orange or red during dawn or sunset and blue at noontime?

Spend 5 mins

D. Absorption

Absorption is defined as a process that retains the incident radiation and converts it to some other forms of energy. Mostly it changes to sensible heat which causes a rise in temperature of the absorbing object. For example sunlight striking the side of a house is absorbed and heats up the wall.

E. Transmission

By this time you must have marked that reflection, scattering and absorption are the processes that deplete the solar beam as it passes through the atmosphere. Transmissivity is the proportion of the solar radiation that ultimately passes through the atmosphere. Transmissivity mainly depends on the distance travelled by solar beam through the atmosphere. The inclined rays have to travel more distance than the vertical ones.

F. Conduction

The movement of energy from one molecule to another molecule without changing their relative positions is called conduction. This enables heat transfer between the adjacent molecules. Earth being a good absorber of heat gets heated during the day and this heat is conducted to the lower portion of atmosphere. Since air is a bad conductor of heat, so only a small portion of air touching the ground surface gets heated. If the earth's surface is cooler, then this transfer of heat is reversed from air to earth and the air above is cooled.

G. Convection

Convection is the transfer of heat through the movement of air itself. The air in contact with the earth's surface gets heated and expands. This warm air has less density and it rises and creates a void which is then filled up by the surrounding air which is relatively cool. Thus a convective circulation is established.

H. Advection

Advection is the process through which wind transfers warm or cool air horizontally from one place to another.

This was a brief discussion about the process related to heating and cooling of atmosphere and earth and the movement of this heat energy. Now let us study the factors governing insolation.

11.3 FACTORS GOVERNING INSOLATION

The amount of insolation reaching the earth's surface and its effectiveness depends on various factors. They are:

(A) the angle of incidence or the inclination of sun's rays,

(B) the duration of sunshine,

(C) distance between the earth and sun and

(D) Transparency of the atmosphere.

A. Angle of Incidence

The angle at which sun's rays strike the earth's surface is called the angle of incidence. It is measured from a line drawn tangent to the surface of earth. The amount of insolation received at the earth's surface varies with the change in the angle of incidence of the sun's rays. When the sun is overhead, angle of incidence is more and its rays are vertical over the surface of the earth and hence more concentrated. Thus, the intensity of insolation is more. While, if the angle of incidence is low, the rays are oblique and therefore more spread out. Consequently, the intensity of insolation is less. Moreover, the oblique rays have to traverse a larger distance through the atmosphere before they strike the surface of the earth and hence it is subjected to the loss of larger amount of energy by various processes like reflection, absorption and scattering as you have already read. At mid-day the insolation is at its maximum and at morning and evening it is less. Also the amount of solar radiation received during the winter months and at high latitudes is of less intensity, as the sun's rays are inclined. As a result, the higher latitudes receive less insolation compared lower latitudes or tropics. Refer to Fig. 11.2 to get a better picture of this. From the above discussion we can conclude that angle of incidence of the sun is determined by latitude of a place, the time of the day and the season.

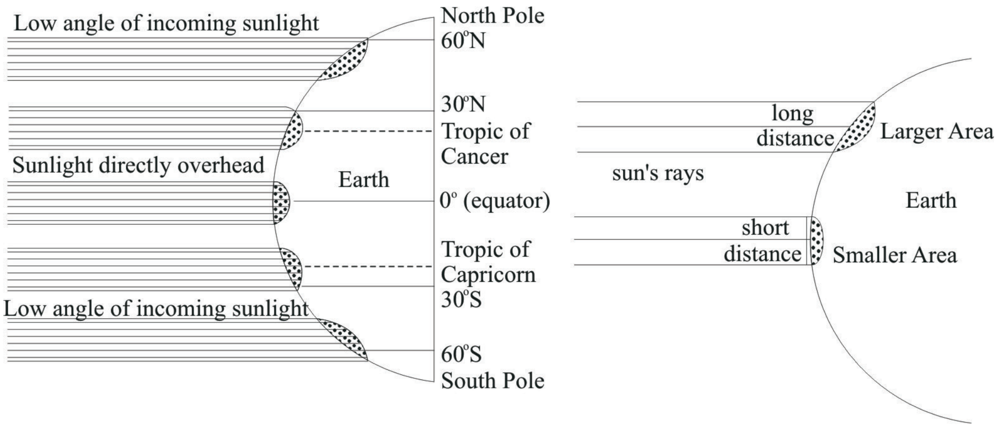

Fig. 11.2: Sun's Angle of Incidence and Its Concentration on the Earth's Surface.

B. Duration of the Sunshine

The duration of day varies with seasons and with latitude of a place. They actually determine the amount solar radiation received by that place. Longer duration of sunshine provides larger amount solar radiation and vice-versa. You can have a look at the length of day in different latitudes from Table 11.2.

Table 11.2: Length of the Day in Different Latitudes

Latitude	Max. Length of day
0°	12 hours
17°	13 hours
31°	14 hours
41°	15 hours
49°	16 hours
58°30'	18 hours
63° 24'	20 hours
66°30'	24 hours
67°24'	1 month
69°48'	2 months
78°12'	4 months
90°	6 months

Source: **Climatology and Oceanography, D. S. Lal**

The above table makes clear that the length of day differs from equator to poles. A study on varying lengths of day and night would give more insight into it.

C. Distance from the Sun

As the earth revolves around the sun in an elliptical orbit the distance between the sun and the earth varies in due course of the year. On July 4, the distance between earth and sun is farthest, i.e., 152,000,000 km and this position is called '*Aphelion*'. So, the insolation received by the earth on this day is less. However, on January 3, the distance between sun and earth is the least i.e., 147,000,000 km. So the amount of solar radiation received on this day is more. This position is called '*Perihelion*'.

D. Transparency of the Atmosphere

The amount of insolation that reaches the earth's surface is significantly controlled by transparency of the atmosphere. Presence of water droplets, dust particles and certain gases causes reflection, scattering and absorption of radiation which results in the reduction of solar radiation received by the earth's surface. The transparency of the atmosphere is subjected to spatio-temporal variations. It is also closely related with latitude. As the sun's rays are more oblique in higher latitudes they have to pass through relatively thicker layers of the atmosphere compared to lower latitudes. Besides all these, the presence of heavy cloudiness and turbid atmosphere causes the earth's surface to receive lesser amount of radiant energy. To sum up, you can say that reflection, absorption and transmission of solar radiation vary with the transparency of the atmosphere which in turn determines the amount of insolation received by the earth's surface.

Now let us study the average annual distribution of solar radiation on a map of world.

11.4 DISTRIBUTION OF SOLAR RADIATION

Fig. 11.3 illustrates the average annual distribution of solar radiation at ground level. The facts derived from the figure are explained below.

A low range of about 70 kg calories per square centimeter is found only in the high latitudes whereas a high of over 220 kg calories per square centimeter has been noted in the eastern Sahara of North Africa. The value is generally more in the equatorial regions and it declines polewards. A general zonal pattern is conspicuous in the middle and higher latitudes. You should also know that solar radiation in higher latitudes is primarily a seasonal affair as these regions receive little radiation in winter and major part of it is received between the spring and autumn equinoxes (March 23 and September 22 respectively).

The lowest annual radiation rates in the high latitudes are recorded in its oceans. This is because of abundant clouds associated with the great semi-permanent, oceanic low pressure cells which accounts for such low amount of radiation there. In the tropics too, due to the abundance of clouds and the presence of strong convection currents the amount of solar radiation received is low, compared to the sub-tropics.

The maximum solar radiation is received in the sub-tropics. This is due to the presence of high pressure cells, many large deserts, and relatively little cloud, especially over the land.

From the discussions, so far, you have learnt about insolation and factors governing it and also the distribution of solar radiation. Let us now study the heat budget of the atmosphere and earth.

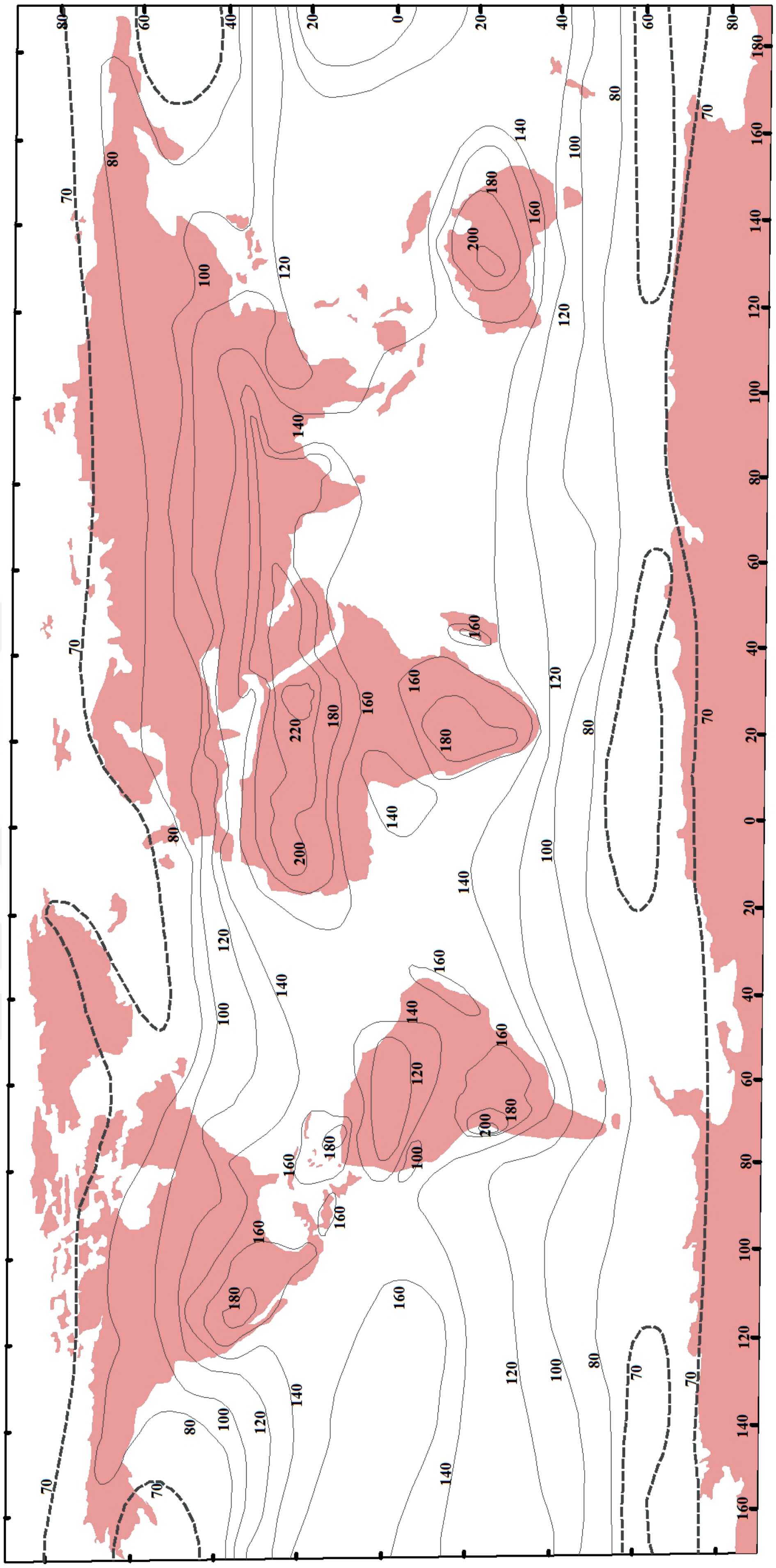

Fig. 11.3: Annual Distribution of Solar Radiation at Ground Level (kg Calories).

11.5 HEAT BUDGET OF THE ATMOSPHERE AND EARTH

Earth is continuously receiving solar energy during day time. Do you know that there exists a perfect balance between the amount of incoming solar radiation and outgoing terrestrial radiation. If the outgoing radiation had not occurred, the surface would have become progressively hotter. This balance between the amount of insolation and outgoing terrestrial radiation is known as the ***Earth's Heat Budget***.

Fig. 11.4 explains heat budget of the atmosphere and earth. Of the total of 100 units of solar radiation reaching the outer atmosphere, 34 units are directly returned to space without attempting to heat the atmosphere. Of the total 34 units, 25 units are reflected by clouds to space, 2 units are reflected by earth's albedo and 7 units is lost as a result of scattering by air molecules and dust particles in the atmosphere. Of the remaining 66 units, 19 units are absorbed within the atmosphere (16 units by gases and 3 units by clouds). The remaining 47 units that reaches the earth's surface, is actually converted to heat energy, out of which 19 units are received at the earth's surface as direct radiation, 23 units as diffused radiation through clouds and 5 units as scattered radiation. Thus a total of 66 units (19 units + 47 units) of effective solar radiation is actually absorbed by atmosphere and earth's land-sea surface. It is effective in heating up the earth's atmosphere. In order to maintain the terrestrial heat balance, the 66 units of solar radiation gained must be balanced by the same amount of energy radiated back to space in the form of long wave terrestrial radiation.

Let us see the operation of the terrestrial heat balance (Refer to Fig. 11.4). The earth radiates 120 units of energy upwards out of which 6 units are radiated to space directly. The atmosphere absorbs the remaining 114 units of long wave earth radiation. Further, 10 units of heat are transported upward by convection currents which the atmosphere gains. The atmosphere also gains 23 units as latent heat carried to it in the hydrologic cycle due to processes of evaporation, condensation, precipitation. 19 units of solar energy were already absorbed directly by the atmosphere as discussed above. Hence the total units absorbed by the atmosphere is equal to 166 (114 + 10 + 23 + 19). Out of 166 units, 106 units are re- radiated back to the earth's surface and only 60 units are radiated to space. These 60 units in addition with 6 units radiated directly by the earth's surface, brings a total of 66 units of energy which is actually radiated back to the space. Thus the amount of incoming solar radiation is balanced by an equal amount of outgoing radiation.

11.6 SURFACE AIR TEMPERATURE

You have already studied that the earth mainly receives thermal energy in the form of electro-magnetic radiation which is transferred to the atmosphere by various means. In this section we will study about temperature. First, how do you define temperature? Temperature is a measure of the intensity or degree of hotness of a body. The temperature of the atmosphere is maintained by a constant input of thermal energy from the sun.

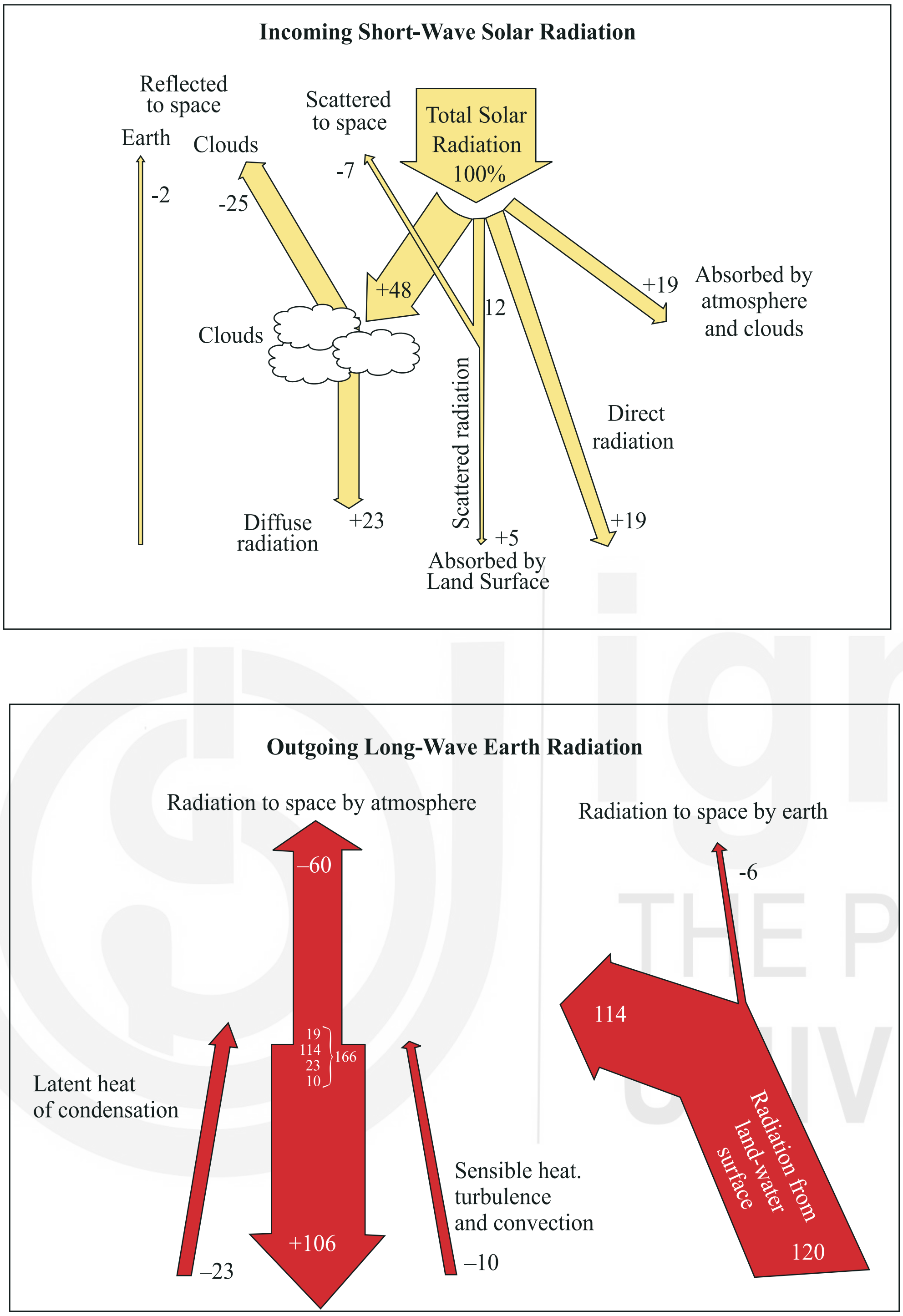

Fig. 11.4: Heat Budget of the Atmosphere and Earth.
(Adapted from Houghton)

The terms 'heat' and 'temperature' may be confusing for you. It is important to know that heat is a form of energy while temperature is measure of intensity of heat. Hence these two terms are distinct. When a body has higher temperature, heat will flow from it to another body which has low temperature. Thus heat flows from a body having higher temperature to a body having lower temperature.

Now let us study how to measure temperature.

11.6.1 Measurement of Temperature

Temperature can be measured in terms of the expansion or contraction in the length of a column of liquid as the result of heating or cooling respectively. The device to measure temperature is called thermometer. For measuring surface air temperatures, thermometers are mounted in lowered instrument shelter. There are also thermometers available to record maximum and minimum temperatures of a day.

In India the centigrade scale (internationally known as Celsius scale since 1948, after the name of its inventor A. Celsius) is used for measuring temperature. On the Celsius scale the boiling point of water is fixed at 100°C and its freezing point at 0°C. The equivalent points on the Fahrenheit scale are 212°F and 32°F respectively.

The formula for converting Celsius temperature to Fahrenheit temperature and vice-versa is as follows:

$$C/5 = (F-32)/9$$

SAQ 2

Spend 5 mins

If the Fahrenheit temperature is 104°. What would be its value in Celsius scale?

Now let us learn about thermometers.

Thermometer is a narrow glass tube filled with mercury or alcohol. It works on the principle that mercury expands when heated and contracts when cooled.

The temperature of a place is in fact the temperature of air near the ground under shade. It is minimum at about 4 am and maximum at about 2 pm.

Six's Maximum and Minimum Thermometer is used to measure the maximum and minimum temperatures of a day. It consists of a U-shaped tube (refer to Fig. 11.5) having a narrow uniform bore. Both the ends of the tube are drawn into bulbs.

The bulb on the left side is completely filled with alcohol while the bulb on right side is partially filled with alcohol and has vacuum at the top. The U-shaped portion of the tube contains mercury. As the temperature rises, alcohol in the left bulb expands due to which the mercury is pushed up in the right portion of tube and maximum temperature is recorded. Above the mercury columns there are two steel indices. These indices move up or down by themselves and remains in position unless pushed upwards by the rising mercury and record the maximum and minimum temperature. Minimum temperature is recorded due to contraction of alcohol due to which mercury falls in the right portion of the tube and rises in the left portion of the tube. Steel springs are attached to the steel indices. They are strong enough to press the indices against the wall of the bore of the tube and thus keep the indices in position.

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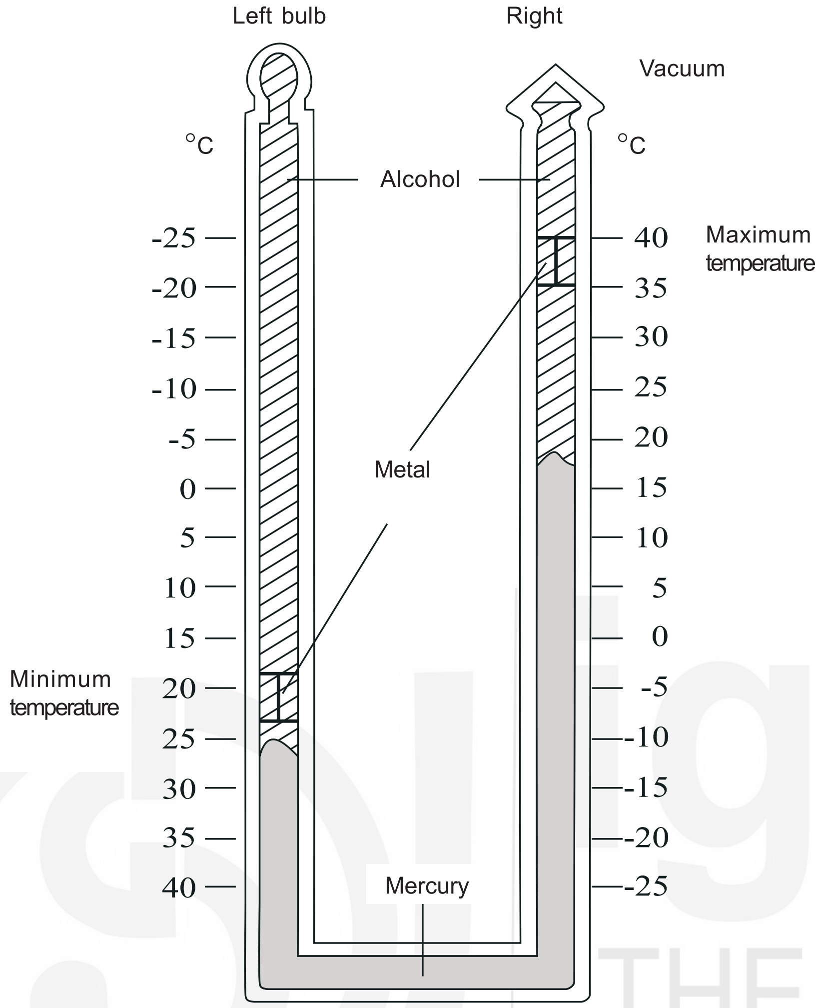

Fig. 11.5: Six's Maximum and Minimum Thermometer.

This thermometer is accompanied with a small horse-shoe magnet. The magnet is used to bring back the steel indices in contact with mercury. The magnet is placed on a steel index and dragged towards mercury until the index touches mercury.

In the meteorological observations instead of Six's Maximum and Minimum Thermometer, two separate thermometers namely Rutherford's Maximum Thermometer and Rutherford's Minimum Thermometer are used to measure temperature. Scientists sometimes use the Absolute or Kelvin scale in which temperature is measured from the point at which molecular movement ceases, that is - 273.15°C or 0°K.

11.6.2 Mean Temperatures and Ranges of Temperature

The average of maximum and minimum temperatures of a day that is within 24 hours is called ***Mean Daily Temperature***. Similarly the mean of daily maximum and daily minimum temperatures of a month is called ***Mean Monthly Maximum Temperature*** and ***Mean Monthly Minimum Temperature*** respectively. Mean of maximum and minimum temperatures of 12 months is called ***Mean Annual Maximum Temperature*** and ***Mean Annual Minimum Temperature*** respectively.

Do you know that the Sun receives maximum insolation at noon. However the maximum temperature at any place is not recorded during noon time. This is because some time is required to convert insolation into heat. So, maximum temperature is recorded around 2 pm to 4 pm. Similarly lowest temperature is recorded between 4-5 am as there is a continuous loss of energy through outgoing terrestrial radiation which exceeds the radiation from sun from 4 pm onwards to the time of sunrise. Thus we have noticed that there is no coincidence between the time of maximum and minimum amount of insolation received and the time of maximum and minimum temperatures of the day. This is called lag of temperature.

The range of temperature means the difference between the maximum and minimum temperatures of a day, also called diurnal range of temperature. Similarly the difference between monthly maximum and monthly minimum temperatures is called ***monthly range of temperature*** and so the ***annual range of temperature*** is the difference between annual maximum and annual minimum temperatures.

Spend 5 mins

SAQ 3

The annual range of temperature of Punjab is 38°C, its annual minimum temperature is 4° C. What is its annual maximum temperature?

11.6.3 Isotherms

The term 'isotherms' is derived from two Greek words, '*Isos*' meaning equal, and, *'thermos'* meaning hottest. So isotherms are imaginary lines drawn on a map connecting places having the same temperature, reduced to mean sea level (that is, supposing the places to be at mean sea level). Let us understand this. For every ascend of 1000 meters from the mean sea level there is a reduction of 6.5°C of temperature. Thus it is possible to calculate the temperatures of every place in the elevated regions to its sea level equivalent. For example, Nainital is about 2084 meters above sea level and its January temperature is 2°C. Therefore its sea level equivalent of temperature is 2°C + 13.5°C= 15.5°C. $\left[\text{Hint: } \frac{6.5}{1000} \times 2084 = 13.5°\text{C}\right]$ The isotherms can be drawn to show the temperature distribution of any given period, such as a day, a month or a season. The isotherms of the months of January and July are more interesting for climatologists as these are the months of climatic extremes in both the hemispheres. Before discussing the January and July isotherms let us get familiar with the factors affecting the horizontal distribution of temperature.

11.7 FACTORS AFFECTING THE HORIZONTAL DISTRIBUTION OF TEMPERATURE

The factors which determine the temperature of a particular place on the earth's surface are latitude, altitude, distribution of land and water, ocean currents, winds, clouds and relief features.

A. Latitude

The amount of insolation received in the equatorial regions is more than in polar regions. The vertical rays of the sun is received between 23°30'N and 23°30'S latitude. As a result, the highest temperatures on the earth are received near these two latitudes. Outside the tropics, the sun's rays reach the earth's surface obliquely and so the temperature is relatively low. You have also studied that the rays falling vertically over the earth's surface heats up a smaller area than those falling obliquely (see Fig. 11.2).

B. Altitude

You have learnt that the temperature decreases with increasing altitude at the rate of 6.5°C for 1000 m of elevation. This is called the ***normal lapse rate*** of temperature. The atmosphere is not directly heated by the radiation from the sun. Instead, it is heated by conduction from the earth's surface. The layers of air near the earth's surface are denser and contain more water vapour and dust particles than the upper layers of atmosphere. As these absorb a large amount of terrestrial radiation, the lower part of the atmosphere has higher temperatures compared to the upper layers of air. Thus as we go to higher altitudes, the temperature goes on decreasing.

C. Distribution of Land and Water

The earth is not a homogenous body. It has irregular distribution of land and water on its surface which reacts differently to the incident solar energy in terms of reflection, absorption and transmission. So their potential for heating the atmosphere varies. There is also a great contrast between the heating of land and water surfaces. This is due to certain factors:

i) Water is mobile,

ii) water is translucent, and

iii) the specific heat of water is higher than any other common substance like land surfaces. (It is 1 calorie/gm °C)

So, landmass are heated and cooled more rapidly than water bodies during the summers and winters respectively. Consequently, the temperature of the air resting over a landmass differs significantly from that of the air resting over an expanse of water in the same latitude. Hence, landmasses tend to experience extreme temperatures, whereas water bodies are more equable and show less temperature variations.

> Specific heat is the amount of heat required to raise the temperature of 1 gram of a substance through 1°C.

D. Ocean Currents

The coastal area temperatures are significantly influenced by ocean currents. Warm ocean currents raise the temperature of the coastal areas, whereas cold currents lower them. In all the oceans, cold currents move from the polar regions to equatorial regions and warm currents move from the tropical regions to polar regions. The North Atlantic Drift offers a typical example of the warming effect of ocean currents on the adjoining land masses. It keeps winter time temperatures in Great Britain and much of western Europe warmer than one would expect for those latitudes. This is because of the fact that the North

Atlantic Drift is an extension of the warm Gulf Stream and carries with it the warm water to the north eastern Atlantic, so that the coasts of Great Britain and Norway do not freeze during the winter despite their location in high latitudes.

The influence of the cold currents is more pronounced in the tropics or during the summer months in temperate regions. The cold California current keeps the summer temperatures of the coastal regions of southern California lower than those of the coasts in sub-tropical United States. Similarly, the cold Benguela current off the western coast of Southern Africa moderates the tropical belt.

E. Winds

Winds also have a great influence in the horizontal distribution of temperature by transporting their characteristics from source regions to destinations. In temperate regions, prevailing winds coming from the land areas lower the temperature during winter and raise it during summer. The situation is reversed when prevailing winds come from oceans where it raises the winter temperature and lowers the summer temperature. Take for example, the temperatures in the central and northern parts of China are much lower than those of other places in the same latitude because they receive cold winds from Central Asia.

Similarly, several local winds also bring marked changes in the temperature of any area. The hot-dusty-dry winds blowing during the summer from Rajasthan raises the temperature of western Uttar Pradesh during summer. The warm dry wind, Chinook, blowing across Rocky Mountains from the west causes considerable rise in temperatures of the Central Plains of USA.

You will learn about prevailing winds and local winds in detail in the next unit.

F. Clouds

Clouds are one of the factors which significantly influence the distribution of temperature over the earth's surface. Cloudiness of the sky affects both incoming solar radiation and outgoing terrestrial radiation. Consequently, the places, where clouds are less, experience daily temperature extremes, that is, high day temperature and cold nights. The cloudy nights are relatively warm because the clouds tap most of the outgoing terrestrial radiation. Thus the atmosphere has more energy available to radiate energy back to the ground. Therefore surface temperatures are higher on cloudy nights. Cloudy regions have smooth daily and annual ranges of temperature than those regions with clear skies. Equatorial regions are characterised by more evaporation of water and the presence of clouds which has resulted into lower range of temperature.

G. Relief Features

The differences in the elevation of land and its slope, markedly controls the temperature of a region. In northern hemisphere, southward facing slopes are exposed to sun for a longer duration. Hence they become warmer than the northward facing slopes. Also the, mountain ranges that trend in north-south direction have a different effect from those trending in east west direction.

11.8 HORIZONTAL DISTRIBUTION OF TEMPERATURE

The distribution of temperatures across latitudes is known as horizontal distribution of temperature. From the discussions made above, it has become clear that a number of factors influence the horizontal distribution of temperature on the earth's surface. You may recall that temperature declines from equator to poles, which itself signifies the influence of latitude in the horizontal distribution of temperature. You have also studied that Isotherms show the horizontal distribution of temperature on earth. However, we should now discuss a few important aspects related to this.

The isotherms in general have an east-west trend and have close correspondence with the parallels of latitude. As a result of variations in the receipt of insolation, the tropics and sub-tropics have the highest temperatures, which decrease gradually towards the poles. Due to differential heating of land and water, temperature over oceans and landmasses varies even on the same latitude. Therefore isotherms get distorted while passing from ocean to land and vice-versa. This sort of deviation is seen more prominently in northern hemisphere due to greater percent of landmasses there. The wide spacing of the isotherms indicates the slow change of temperature. The isotherms are relatively more regular in the southern hemisphere. This is because of the predominance of water over land in the southern hemisphere. Here the controls of latitude over temperature is more visible.

The most important isotherms are the mean monthly isotherms especially for the months of January and July, as these months have the greatest extremes of temperatures. January is the coldest month of the northern hemisphere and the hottest month of the southern hemisphere, while July is the hottest month in the northern hemisphere and coldest month in the southern hemisphere. Now let us study the isothermal maps for July and January which would reveal the changing pattern of global temperature with respect to the change in the apparent position of the sun, distribution of land and water, ocean current, and prevailing winds.

You should refer to Fig. 11.6 and Fig. 11.7 while reading the next sub-section.

11.8.1 Distribution of Temperature in January

During January it is summer in the southern hemisphere and winter in the northern hemisphere. The January isotherms are more irregular and closely spaced in the northern hemisphere and more regularly and widely spaced in the southern hemisphere. On the continents of the northern hemisphere, the isotherms of this month bends sharply towards the equator as the oceans are relatively warmer than the landmasses and over the oceans the isotherms bend towards the poles. In the southern hemisphere, these conditions during January are just the reverse. Please refer to Fig. 11.6 to understand better.

11.8.2 Distribution of temperature in July

For July, the sun is overhead along the Tropic of Cancer. It is the period of

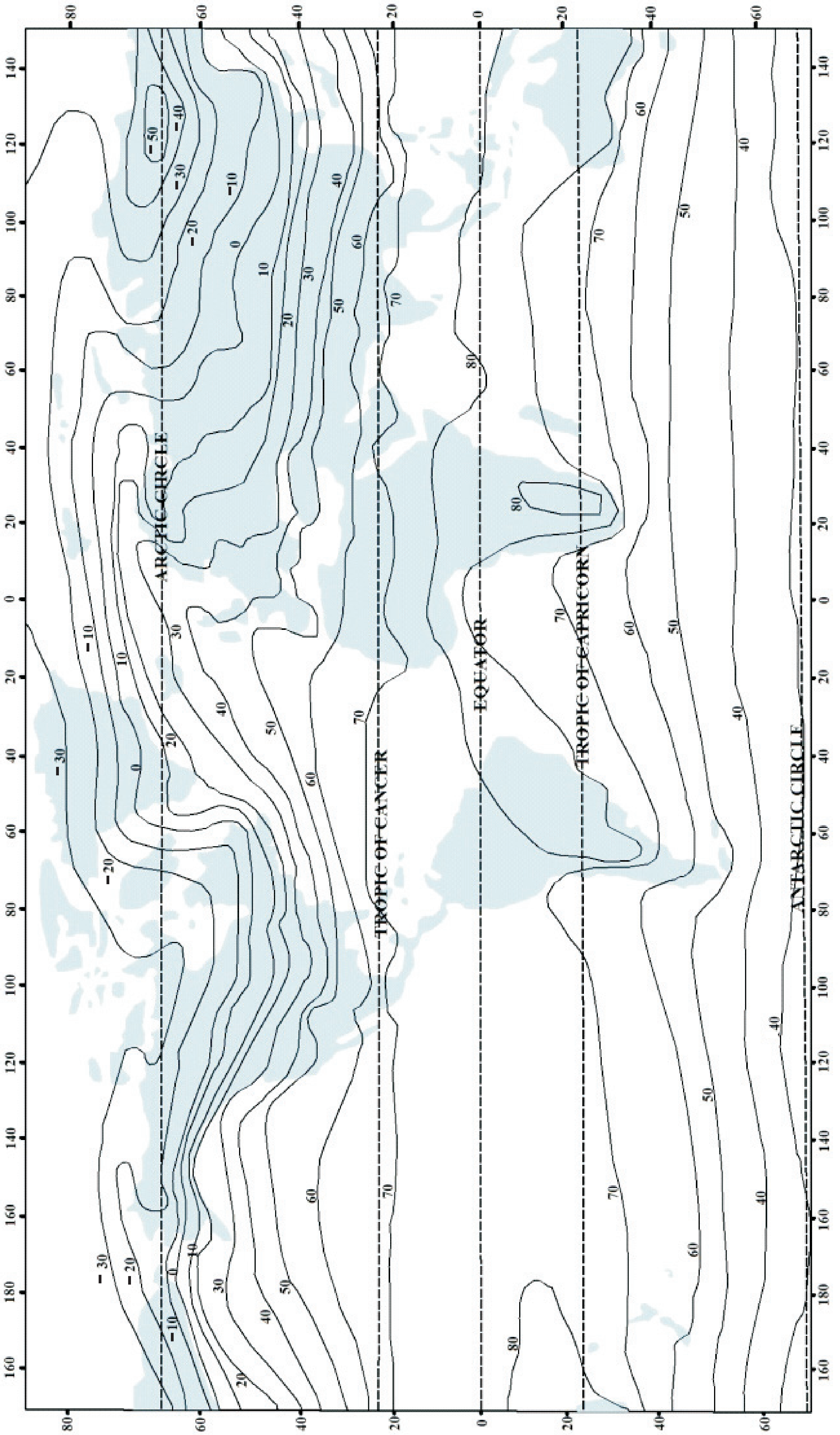

Fig. 11.6: Isotherms Representing Horizontal Distribution of Temperature (°F) in January .

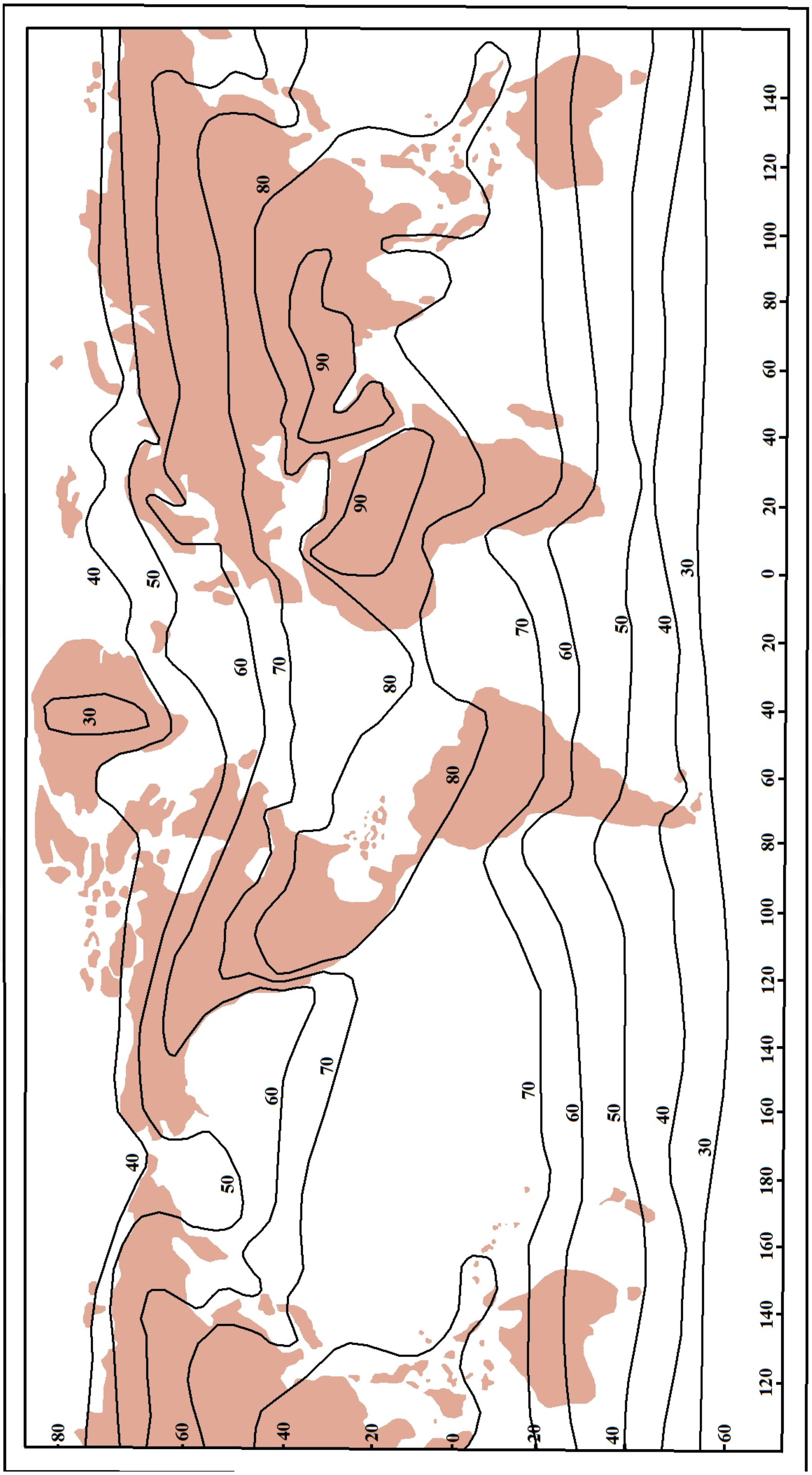

Fig. 11.7: Isotherms Representing Horizontal Distribution of Temperature (°F) in July.

summer in northern hemisphere and winter in southern hemisphere. A high temperature belt is seen extending from North Africa through South-West Asia to the North-Western part of Indian Sub-Continent (see Fig. 11.7). Another belt of high temperature is in the south-western part of the United States of America.

The July isotherms bend equator-wards over the oceans and pole-wards over the continents. This is because the land heats up more rapidly than the sea in similar latitudes. It can also be seen that isotherms are almost regular in the southern hemisphere due to the preponderance of oceans, whereas these are more irregular in northern hemisphere.

In July, all the isotherms are shifted slightly towards the north with the apparent movement of the sun. The thermal equator is also displaced towards the north of the equator. The situation gets reversed in January.

11.9 VERTICAL DISTRIBUTION OF TEMPERATURE

Temperature inversion can be due to a number of factors. The resulting types are called Radiation Inversion, Air Drainage Inversion, Frontal Inversion, Advection Inversion and Subsidence Inversion. We will discuss these in detail at higher levels of study.

By now, you should know that temperature decreases with increasing elevation in the atmosphere. You are also familiar with the term ***normal lapse rate. Vertical temperature gradient*** is another term used to express this phenomenon.

Vertical temperature gradient is partly controlled by energy transfer and partly by the vertical motion in the air. Energy transfers are from the latent heat of condensation and sensible heat transfer from the ground. The descending air currents produced to the high pressure systems cause warming of extensive air masses. On the contrary, ascending air currents produced by low pressure system gets cooled up by expansion. This results in the increase and decrease in vertical temperature gradient, respectively.

Regarding vertical distribution of temperature, you have already studied in the previous unit where you have learnt about vertical layers of the atmosphere. Let us go through it very briefly. In the **troposphere**, the temperature decreases with altitude at an average rate of 6.5°C per kilometer of ascend (***Normal Lapse Rate***). However, normal lapse rate can vary with attitude, location or season. At some latitudes, it can be noticed that temperature increases with attitude, instead of decreasing. This phenomenon is known as temperature inversion. Temperature inversions are particularly common during winter seasons. These days are usually characterised by clear skies and rapid radiations. In the vicinity of the tropopause the temperature varies little with height.

In **stratosphere**, temperature increases with height. Above the stratosphere, that is at **mesosphere**, the temperature falls again reaching a minimum of -100°C at a height of 80 km above the earth's surface. Beyond this height, there is once again increase in temperature as a result of absorption of shortwave solar radiation by the atoms of oxygen and nitrogen in the rarified air of the lower part of the **thermosphere**, the **ionosphere.** Here the temperature rises to a high value of more than 100°C

Above the thermosphere, the temperatures raises abruptly to higher magnitudes even though such temperatures are altogether different from those experienced near the earth's surface. Take a look at Fig. 11.8 to understand this.

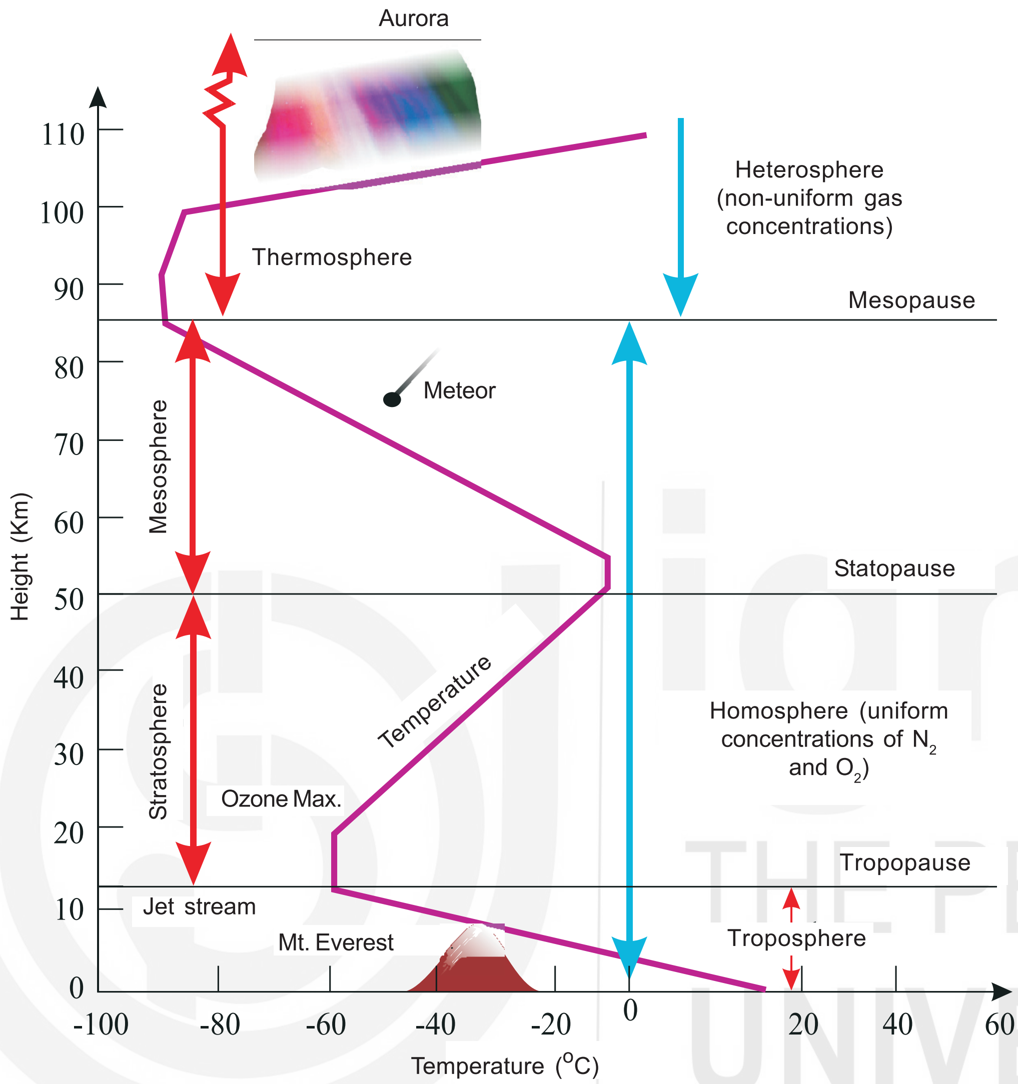

Fig. 11.8: Vertical Distribution of Temperature in the Atmosphere.

Now let us recapitulate what he have learnt in this unit.

11.10 SUMMARY

From the discussions made above, we could study that the incoming solar radiation reaching the earth surface undergo various physical processes and are responsible for heating of the earth and its atmosphere. The total incoming solar radiation is balanced by an equal amount of outgoing radiation, which has been exemplified through the concept of 'heat budget'. Latitude, altitude, distribution of land and water, ocean currents, winds, clouds and relief features are the factors which govern the horizontal distribution of temperature on the earth's surface. We have also studied that the changing pattern of global temperature is mainly due to the change in the apparent position of the sun and distribution of land and water. Vertical distribution of temperature varies in different layers of the atmosphere namely troposphere, stratosphere, mesosphere and thermosphere.

11.11 TERMINAL QUESTIONS

1. What is insolation? Explain the factors controlling insolation.
2. What is heat budget?
3. What are the factors influencing the horizontal distribution of temperature over the earth's surface?
4. What are isotherms? Explain distribution of isotherms during the month of January and July.

11.12 ANSWERS

Self-Assessment Questions

1. During dawn and dusk the sun is at the horizon and its rays have to travel a longer distance before reaching our eyes. So, much of sunlight is scattered along shorter wavelengths and only orange or red colour which is of higher wavelength is able to reach our eye. Contrary to this when the sun is overhead at noontime, the distance covered by Sun's rays is relatively less and so only one or two colours of light in shorter wavelengths gets scattered (like violet). The colour 'blue' which is also in shorter wavelengths reaches our eye. Thus the sky appears blue at noontime.
2. Using the formula C/5= (F-32)/9,

   C= [(104-32)/9]*5= 40°
3. Annual Temperature Range = Annual Maximum Temperature - Annual Minimum Temperature

   Annual Maximum Temperature= 38+4= 42°C

Terminal Questions

1. After defining and explaining insolation, list all the factors controlling insolation and describe them too. Refer to Sections 11.2 and 11.3 of this unit
2. First give the definition of heat budget and then describe how incoming solar radiation is equal to outgoing terrestrial radiation in terms of units. Support your answer with a figure as given in Sec.11.5 of this unit.
3. First list and describe all the factors related to horizontal distribution of temperature over earth. Refer to Section 11.7 of this unit.
4. First define and explain isotherm as is given in Sec. 11.6.3. Then explain the pattern of isotherms for the months of January and July as given in Sec.11.8 of this unit. You don't need to draw a world map for it. Just explain the pattern.

11.13 REFERENCES/FURTHER READING

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UNIT 12

GLOBAL DISTRIBUTION OF SURFACE PRESSURE SYSTEMS AND WINDS

Structure

12.1 INTRODUCTION

In the preceding units of this block, you were introduced to the composition and structure of the atmosphere and the processes related to heating of the atmosphere and earth. You now know that, atmosphere is held to earth by its gravitational force and rotates along with it. However atmosphere itself has certain complex internal motions which are related to air pressure. We will study about these in this unit.

Air pressure is an important element of weather which is introduced in Sec. 12.2. On a global perspective, it can be seen that different pressure systems are in existence. These global pressure systems have decisive roles in bringing about different climatic patterns on earth. This is explained in Sec. 12.3. Small changes in pressure, brings about noticeable changes in day-to-day weather. This is explained in the shifting of pressure belts in

Sec. 12.4. Differences in air pressure from one place to other gives rise to winds which are horizontal movement of air on the earth's surface. Winds are an essential part of the atmosphere and acts as a means of transporting heat, moisture and other properties from one place to the other. They play a great role in balancing out the uneven distribution of pressure over the globe. This forms the matter of study of Sec. 12.5.

So in this unit, you will study the global distribution of surface pressure systems and different types of winds and their mutual relations. In the next unit, you will study about atmospheric moisture.

Expected Learning Outcomes

After studying this unit, you should be able to:

- explain atmospheric pressure, pressure gradient and coriolis effect;
- describe the distribution of surface pressure systems and its shifting;
- correlate between atmospheric pressure and winds; and
- distinguish between planetary winds, seasonal winds, local winds and variable winds.

12.2 ATMOSPHERIC PRESSURE–MEANING AND DEFINITION

As air has weight, it follows that atmosphere exerts pressure on earth. The pressure at any point will depend upon the amount of air above a given point. Take for example, pressure on one square centimeter area of the surface of earth would be equal to the actual weight of the column of air above that area extending upwards to the outer limits of the atmosphere. So, atmospheric pressure is the force per unit area exerted by the weight of air above it. As air is compressible, so the air which lies in the lowest portion is greatly compressed and is therefore the densest whereas, as we move up, both density and pressure of air decreases.

You should also know that the amount of pressure exerted by air at a particular point is also determined by its temperature and density. A change either in temperature or density will cause a corresponding change in air pressure.

12.2.1 Measurement of Atmospheric Pressure

The air exerts a pressure of 1034 g/cm^2 at sea level. As one goes up from sea level to higher altitudes, air pressure decreases. You might notice that while travelling to high altitudes places, you experience mountain sickness in the form of nose bleeding, ear bleeding, nausea etc. Mountaineers face these difficulties because the higher we go, the thinner the atmosphere becomes and there is lesser air pressure and hence lesser oxygen. Bleeding of nose and similar ailments are related to higher pressure inside the body compared to lower external pressure due to which the thin nasal capillaries tend to bleed. At the height of Mt. Everest (8848m above mean sea level) the air pressure is about 2/3rd of what it is at the sea level.

The instrument to measure the atmospheric pressure is called Barometer. The type of Barometer devised by Evangelista Torricelli in 1643 is known as the Mercurial Barometer. It measures the atmospheric pressure. A glass tube of 1m long was taken which was completely filled with mercury. The open end was temporarily held closed and the tube was inverted and immersed into a dish of mercury through this end. When the opening was uncovered, the mercury in the tube fell a few centimeters but remained fixed at a level about 76 cm above the surface of mercury in the dish. Refer to Fig. 12.1 to get a clear picture of this. At this height atmospheric pressure is supposed to balance the weight of the mercury column. When air pressure increases or decreases, the mercury level rise or fall respectively. With various refinements

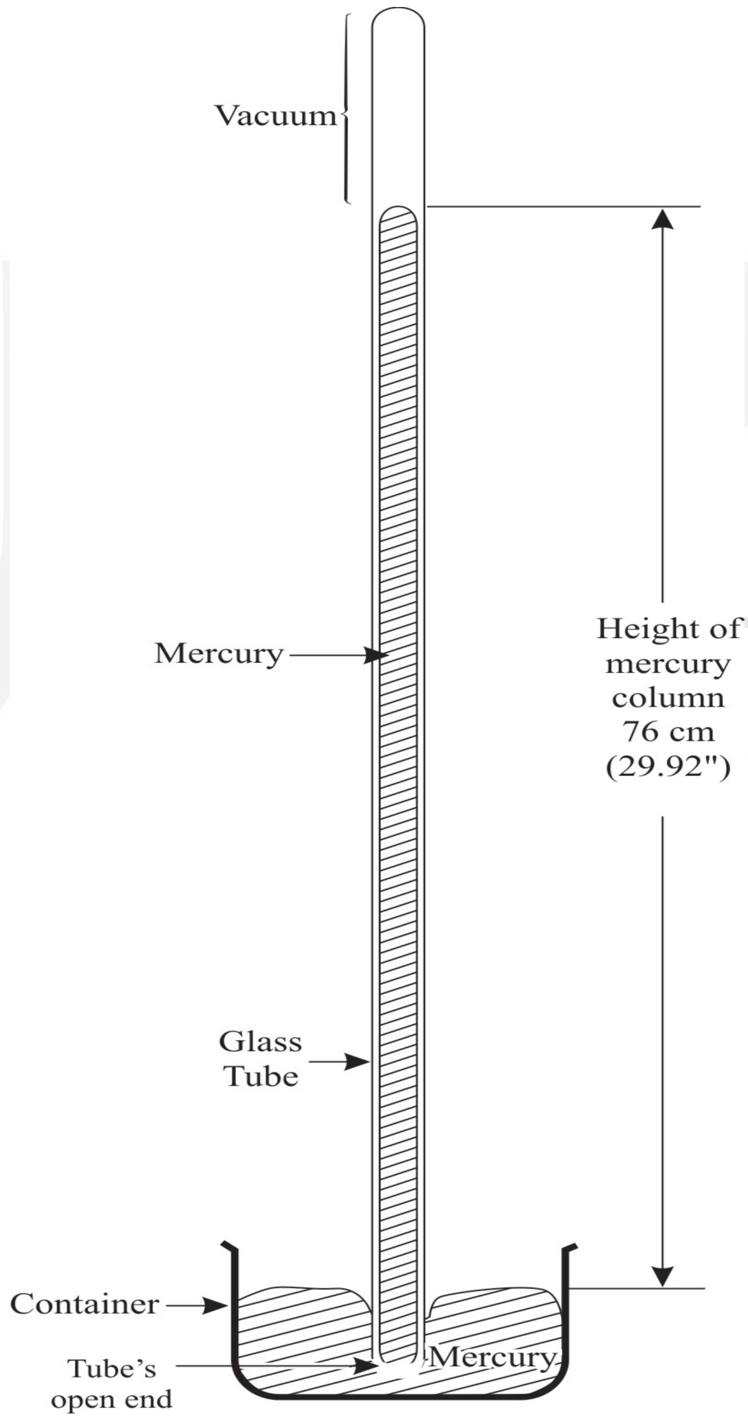

Fig. 12.1: Mercurial Barometer.

over the original simple device, it has become a standard instrument for measuring atmospheric pressure at a particular place.

Pressure is read in centimeters or inches of mercury, the true measure of the height of the mercury column. Standard sea level pressure is 76 cm (29.92Inches) on this scale. Since 1910, millibars have gradually come into use as convenient unit of atmospheric pressure. It represents a force of 1000 dynes acting on 1 cm^2. The SI unit of pressure is Pascal that is equivalent to a force of one Newton per square meter. The value of pressure at sea level is 1013.25 millibars (mb) at a temperature of 15^0C and latitude of 45^0. Thus 76 cm of mercurial column is equivalent to 1013.25 mb.

A dyne is a force, which acting on 1 gram mass at rest, imparts it an accleration of $1 cm/sec^2$

Besides Mercurial Barometer, other types of instruments such as Aneroid Barometer, Altimeter, Barograph, Micro Barograph and Micro Barovariograph are used for the measurement of atmospheric pressure.

In ***Aneroid Barometer***, there is a flexible diaphragm that moves up and down as the outer air pressure varies and these are recorded against a calibrated circular dial. The aneroid Barometer becomes an ***Altimeter*** when it is calibrated in terms of altitude rather than pressure. Hence it is carried in aircrafts. There are some other instruments which are also used for measuring the atmospheric pressure in different occasions. ***Barograph*** is like an aneroid barometer but does recording automatically. ***Microbarographs*** are high precision atmospheric pressure recording instruments that uses several siphon cells that records even the minute change in pressure. Now, have you ever thought how to show atmospheric pressure on a map? Let us learn in the coming sub-section.

12.2.2 Isobars

Isobars are imaginary lines drawn on a weather map connecting points of equal pressure. The isobars are generated from mean sea level pressure values which are given in millibars. Fig. 12.2 below depicts a pair of isobars. At every point along the first isobar, the pressure is 886 mb and at every point along the lower isobar the pressure is 900 mb.

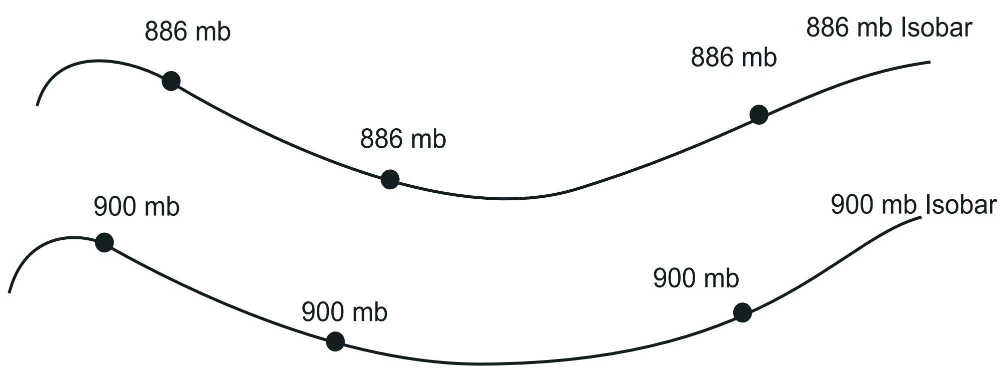

Fig. 12.2: Isobars of Different Pressures.

Any point in-between these two isobars will have a pressure somewhere between 886 mb and 900 mb. A map of isobars is useful for locating strong pressure gradients which are identified by a tight packing (close spacing) of the isobars. Stronger winds are associated with larger pressure gradients. Now let us understand what exactly a pressure gradient is.

12.2.3 Pressure Gradient

The change in pressure measured across a given distance is called "pressure gradient".

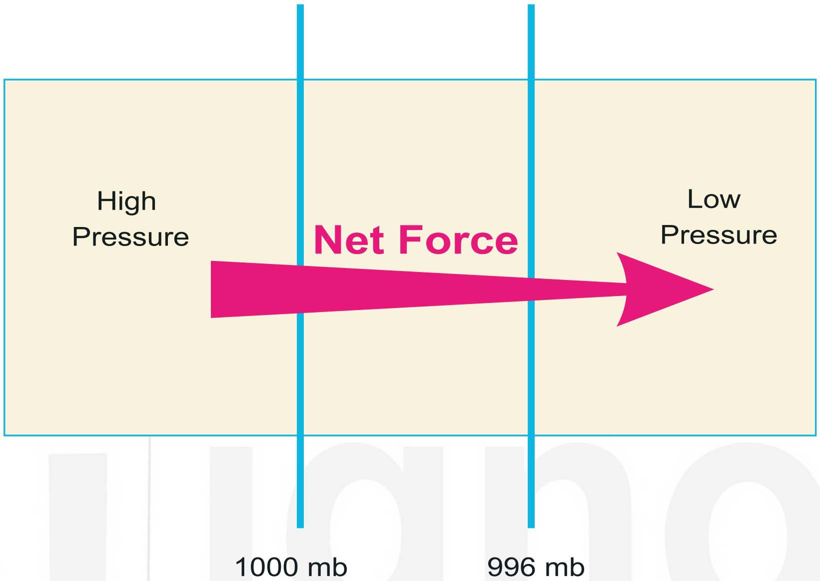

Fig. 12.3: Pressure Gradient

The pressure gradient results into a force that is directed from higher to lower pressure. This force is called the "pressure gradient force". It is responsible for triggering the initial movement of air which is directed from higher pressure to lower pressure area. Refer to Fig. 12.3 to understand this. Closely spaced isobars indicate a stronger pressure gradient and increased wind speeds.

12.2.4 Coriolis Force

The magnitude of coriolis deflection is related to the rotation speed between the start and end points. Between poles and 60° latitude the difference in rotation speed is 800 km/hr. Between equator and 30° latitude the difference is only 200 km/hr. Therefore the strength of coriolis effect is stronger near the poles and weaker at equator.

Once air has been set in motion by the pressure gradient force, it undergoes an apparent deflection from its path due to earth's rotation on its axis in counter-clockwise direction or from west to east. This apparent deflection is called the "Coriolis effect" or "Coriolis force".

Coriolis force tends to deflect the winds from their original direction. The direction of action of this turning effect is stated in Ferrel's law, which states that any object or fluid moving horizontally tends to be deflected to the right of its path of motion in northern hemisphere and towards the left of its path of motion in southern hemisphere. Due to this effect, winds, ocean currents etc. are deflected to the right in the northern hemisphere and to the left in the southern hemisphere.

The Coriolis force is zero at the equator but increases progressively towards the poles. The earth rotates faster at the equator than it does at the poles. As earth is wider at the equator, so to make one rotation in 24 hours, equatorial regions have high velocity, that is, about 1,674 km per hour (1,040 miles per hour). Near the poles, the earth rotates at a very low velocity, i.e. 0.00008 km per hour (0.00005 mph). Due to this, fluids like air currents, ocean currents undergo maximum deflection at poles and zero at equator. So the direction of surface winds is controlled by pressure gradient and coriolis effect.

Refer to Fig. 12.4 and Fig. 12.5 to get a clear picture of coriolis effect.

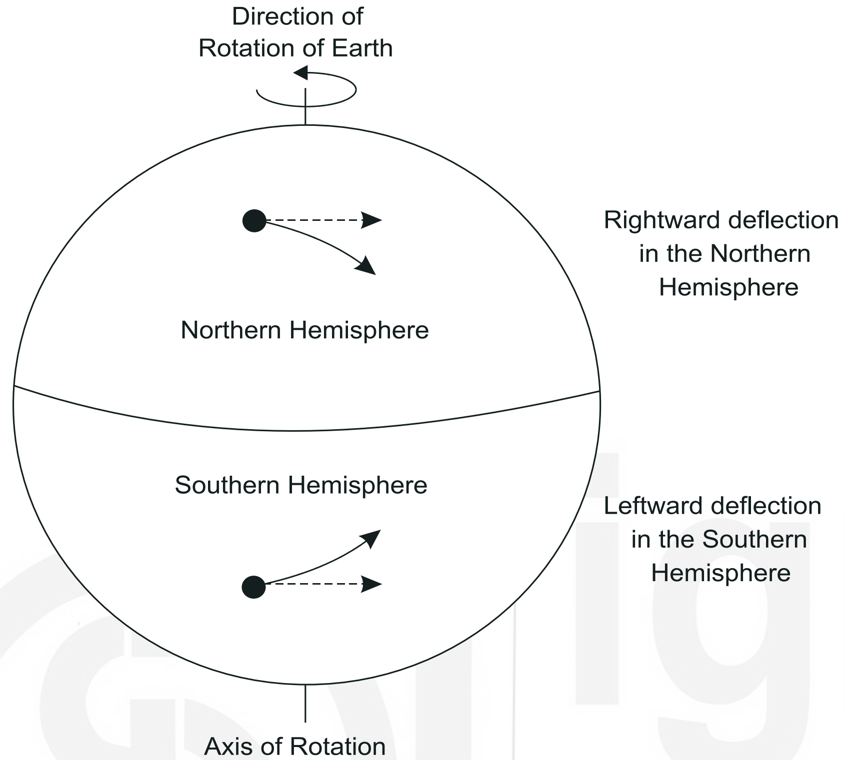

Fig. 12.4: Deflection of Path Due to Earth's Rotation

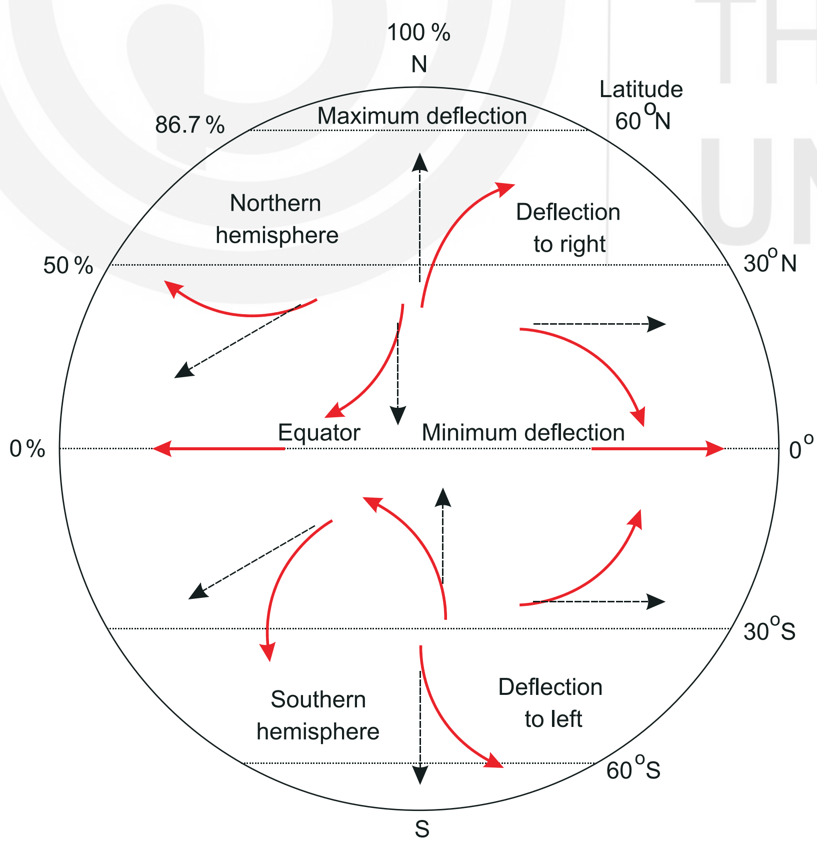

Fig. 12.5: Deflection Effect of Earth's Rotation on Different Latitudinal Circles

Now let us get acquainted with global pressure belts.

12.3 HORIZONTAL DISTRIBUTION OF ATMOSPHERIC PRESSURE–GLOBAL PRESSURE BELTS

The latitudinal distribution of atmospheric pressure is also known as its horizontal distribution. It is characterised by alternate low and high pressure belts. There are mainly seven pressure belts on the earth (refer to Fig. 12.6). The formation of these pressure belts are basically due to two factors, namely (1) Thermal factor and (2) Rotational factor. Thermal factor operates due to differential heating of the surface of the earth and atmosphere which results in the formation of pressure belts like the equatorial low pressure belt and polar high pressure belts. On the other hand, due to the effect of rotation of the earth, some pressure belts are dynamically induced e.g., sub-tropical high pressure belts and sub-polar low pressure belts. You would understand this by studying all the pressure belts in detail.

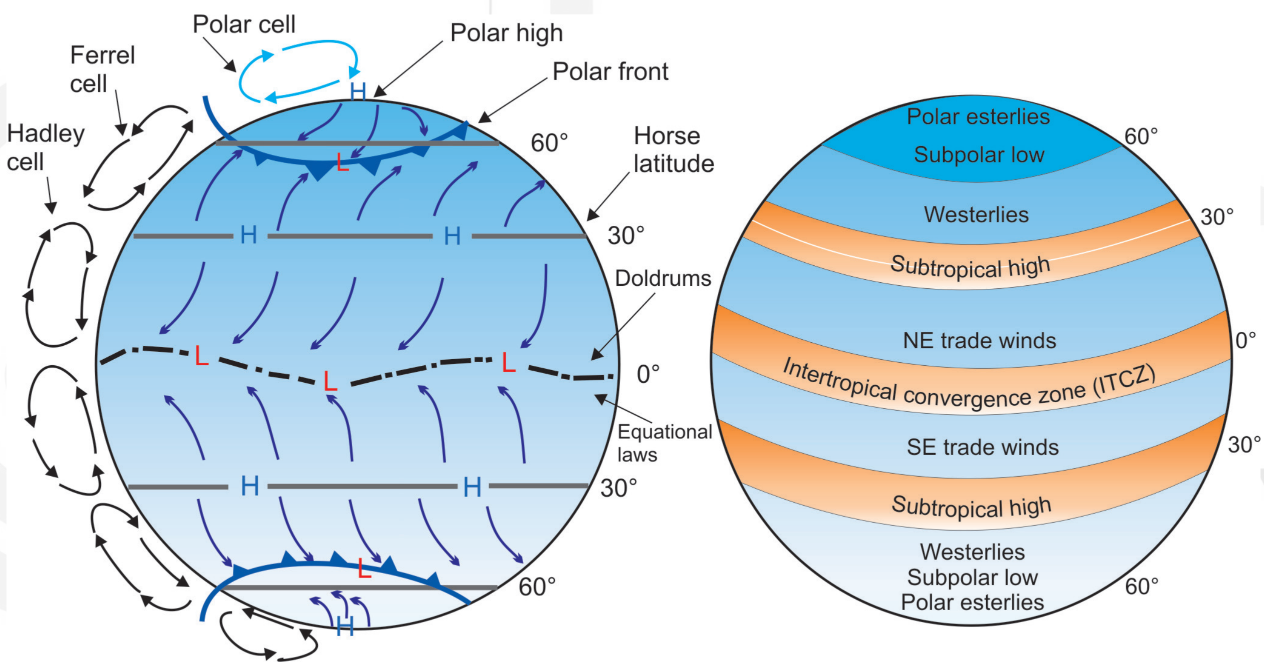

Fig. 12.6: Global Pressure Belts

There are seven alternate belts of low and high pressures on the earth's surface. They are listed below:

- Equatorial Low Pressure Belt
- Sub-Tropical High Pressure Belt (Northern hemisphere)
- Sub-Tropical High Pressure Belt (Southern hemisphere)
- Sub-Polar Low Pressure Belt (Northern hemisphere)
- Sub-Polar Low Pressure Belt (Southern hemisphere)
- Polar High Pressure Belt (Northern hemisphere), and
- Polar High Pressure Belt (Southern hemisphere)

Now let us know these pressure belts.

A. The Equatorial Low Pressure Belt

This pressure belt is located in the vicinity of the equator between 5° N and 5° S latitudes. The average pressure in this belt is less than 1013 millibars throughout. As these regions receive vertical rays of the sun throughout the year, temperatures are high. So the ground gets heated and as such the lower layers of air also get heated and expand and become light. Consequently they rise upwards creating a low pressure along the ground. That is why these belts are called the Doldrums. The equatorial trough of low pressure forms the zone of convergence of trade winds blowing from the sub-tropical high pressure belts of both the hemispheres towards the equator. Thus North-East trade winds and South-East trade winds converge here to form Inter Tropical Convergence Zone (ITCZ). The equatorial low pressure belt is tied with the sun. Therefore it shifts towards the north and south of the equator with the apparent movement of the sun.

B. The Sub-Tropical High Pressure Belt

Th sub-tropical high pressure belts are located between 25° to 35° latitudes in both the hemispheres. The most important feature of this pressure belt is that it is broken into a number of high pressure centres or cells. The high pressure belt in these latitudes is because of the settling down of winds that once arose in the equatorial region and got deflected towards poles due to the earth's rotation. So these sub-tropical high pressure belts are dynamically induced and not thermally induced in spite of the temperatures being fairly high in these regions for a greater time of the year. These belts have a convergence zone at higher altitudes which when subsides, causes piling up of air and reduction of its volume thus resulting into high pressure. Thus anticyclonic conditions develop which results in calm and arid weather. In olden days, vessels or ships with cargo of horses passing through these belts found difficulty in sailing under these calm conditions. Hence, they were forced to throw the horses into the sea in order to make their vessels lighter.Therefore these sub-tropical high pressure zones are also called as **horse latitudes**. As winds blow from these belts towards the equatorial and sub-polar low pressure belts, these are the regions of divergence of winds from the ground level.

C. The Sub-Polar Low Pressure Belts

Sub-polar low pressure belts are located between 60° to 70° latitudes in both the hemispheres. These low pressure belts are also dynamically induced in spite of the fact that these regions experience low temperatures throughout the year. Due to the rotation of the earth (Coriolis effect), the air here develops a tendency of being thrown outwards or spreading outwards. Winds from here are displaced towards sub-tropical high pressure and polar high pressure zones. As a result low pressure belt develops here. In the southern hemisphere, there is an uninterrupted belt of low pressure between latitudes 60° and 70°, as there is greater continuity of oceans there. This pressure belt is broken in the northern hemisphere due to dominance of landmasses in the northern hemisphere. However, there are well-defined low pressure cells over the northern oceans near Aleutian islands in the Pacific Ocean and between Greenland and Iceland in the Atlantic Ocean.

D. Polar High Pressure Belts or Polar Highs

The polar regions in both the hemisphere are characterised by extremely low temperatures throughout the year. Hence high pressure persists at the poles which overcomes even the high coriolis effect in these regions. Winds from these belts blow towards sub-polar low pressure belts in both the hemisphere.

12.4 SHIFTING OF PRESSURE BELTS

With the changing seasons, the position of the pressure belts also shifts to the north or south. On March 21 and September 23, the sun's rays fall vertically over equator. During these days, equatorial low pressure belts would be spread upto 5° on either side of the equator. Sub-tropical high pressure belts would be present around 30° latitudes in both the hemispheres.

After March 21 the sun's apparent movement is towards the northern hemisphere. On June 21 (summer solstice), the sun's rays fall vertically over the Tropic of Cancer. During this time all the pressure belts make a shift of 5° to 10° northwards from their original positions. After September 23, the sun's apparent movement is towards the southern hemisphere and on December 22 (winter solstice) the sun's rays fall vertically over the Tropic of Capricorn. In this period all the pressure belts move 5° to 10° southwards from their original positions. Please refer to Fig.12.7 which illustrates this.

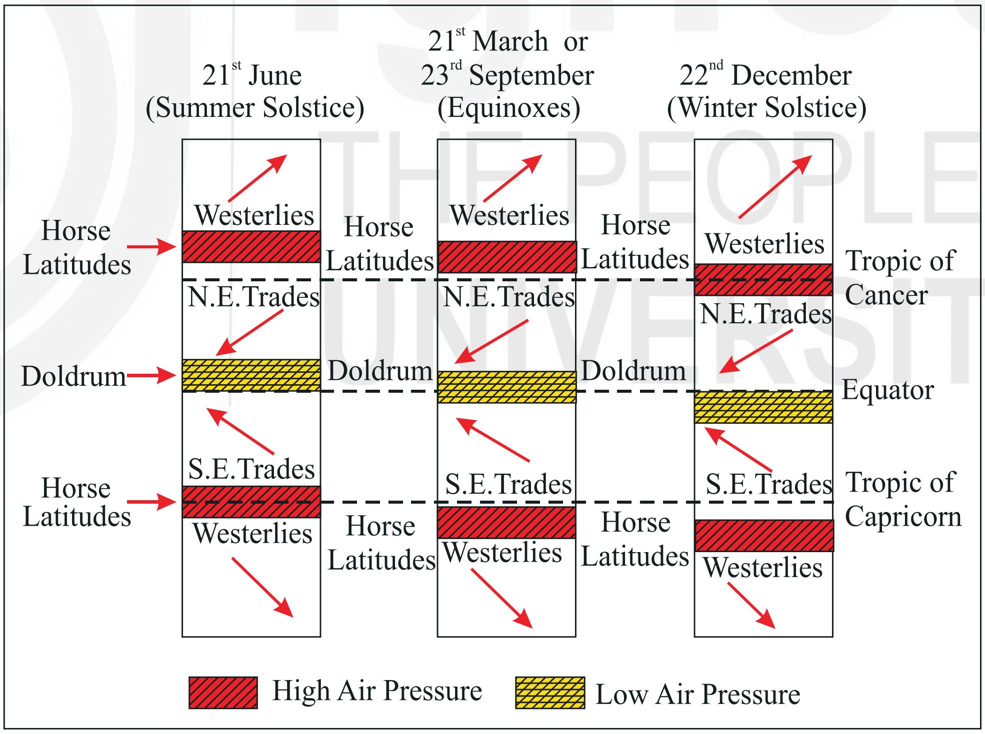

Fig. 12.7: Shifting of Pressure Belts

Now let us study the horizontal distribution of air pressure on a world map during summer and winter extremes. It is represented through isobars for the months of January and July as can be seen in Fig. 12.8 and Fig. 12.9 respectively. It can be seen from the figures that seasonal variations are minimal in lower latitudes because of lower temperature differences here compared to higher latitudes. In the northern hemisphere during January high pressure cells develop over land areas while low pressure cells develop over oceans (Aleutian and Icelandic Lows) as they are relatively warmer. Polar highs are well developed in northern hemisphere at this time due to southern shift of sun towards the Tropic of Capricorn. In the southern hemisphere, January isobars are broken into 3 cells in oceans because continents are relatively warmer and low pressure cells are found there (see Fig. 12.8).

July isobars show the effect of sun's apparent shift towards the tropic of Cancer. In the northern hemisphere sub-tropical highs are more developed along the oceans (Pacific high and Bermuda high). Polar high pressure weakens in northern hemisphere due to greater heating of this hemisphere at this time. Refer to Fig. 12.9 to understand better.

SAQ 1

Spend 5 min

Why low pressure belts are formed in the sub-polar regions ?

So far, you have learnt about atmospheric pressure, how it is measured and how different pressure belts are arranged on earth and how they are represented on a world map.

Now, let us study about winds in the next section.

12.5 ATMOSPHERIC PRESSURE AND WINDS

By now you must have understood that atmospheric pressure is not the same everywhere? Changes in atmospheric pressure causes movement of air in the atmosphere. Winds are horizontal movement of air from high pressure regions to low pressure regions. It would be interesting to note some of the general characteristics of winds. Winds are mostly named on the basis of the direction from which they blow. For example, the winds blowing from the land is called land breeze while those blowing from sea are called sea breeze. Winds blowing from south-easterly direction are called south-easterly winds. The winds blowing from the oceans are saturated with water vapour and hence they are able to bring rain while winds blowing from continents are relatively dry. Due to the rotation of earth on its axis from west to east, a change in the direction of winds occur which is due to coriolis effect as you have already read. Speed and direction of winds is also affected by pressure gradient force and friction.

Winds blowing on earth are of different types.They are classified as follows:

- Planetary Winds or Permanent Winds
- Periodic Winds or Seasonal Winds
- Local Winds
- Variable Winds.

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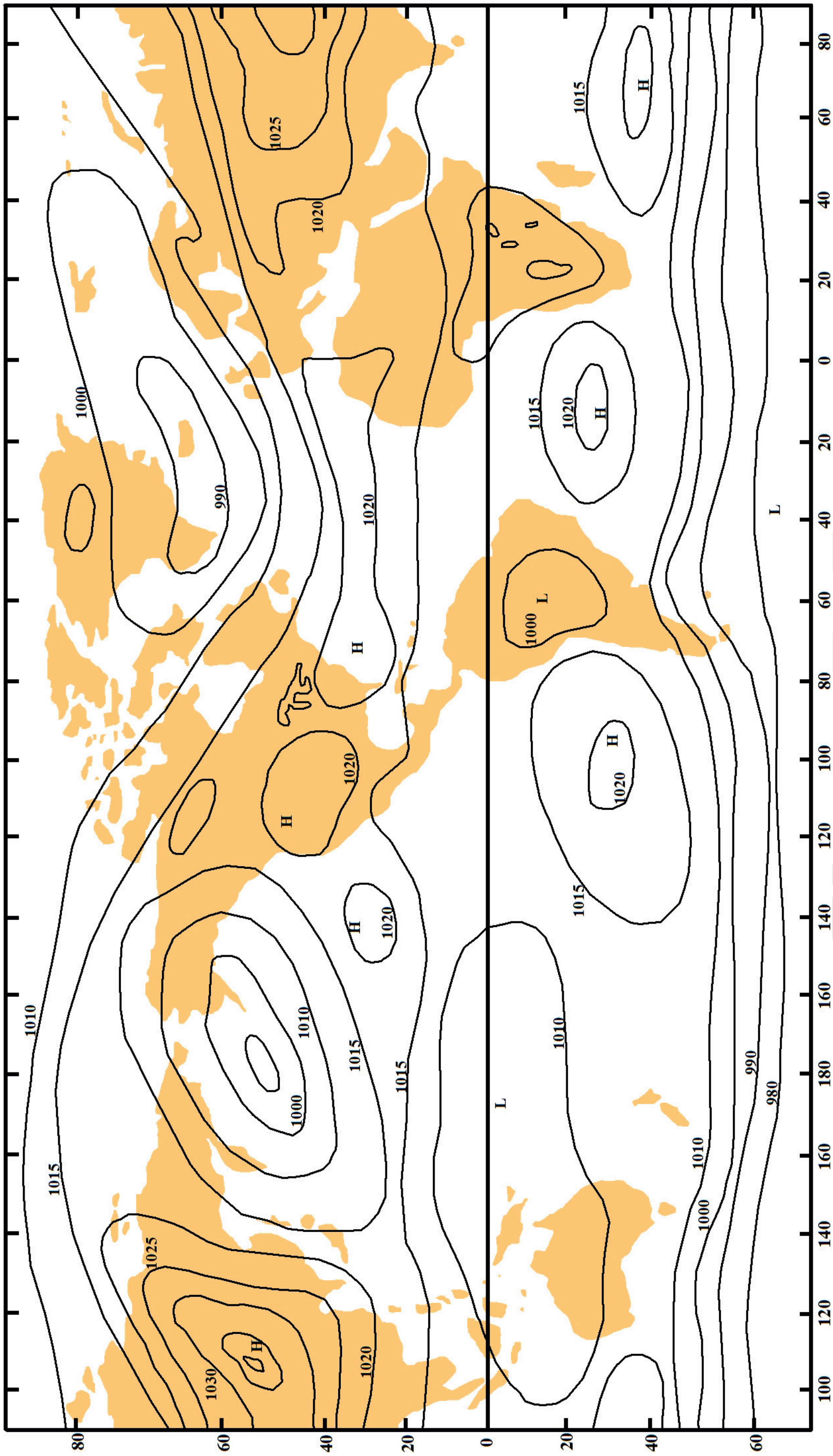


Fig. 12.8: Average Sea Level Pressure in January in Millibars.

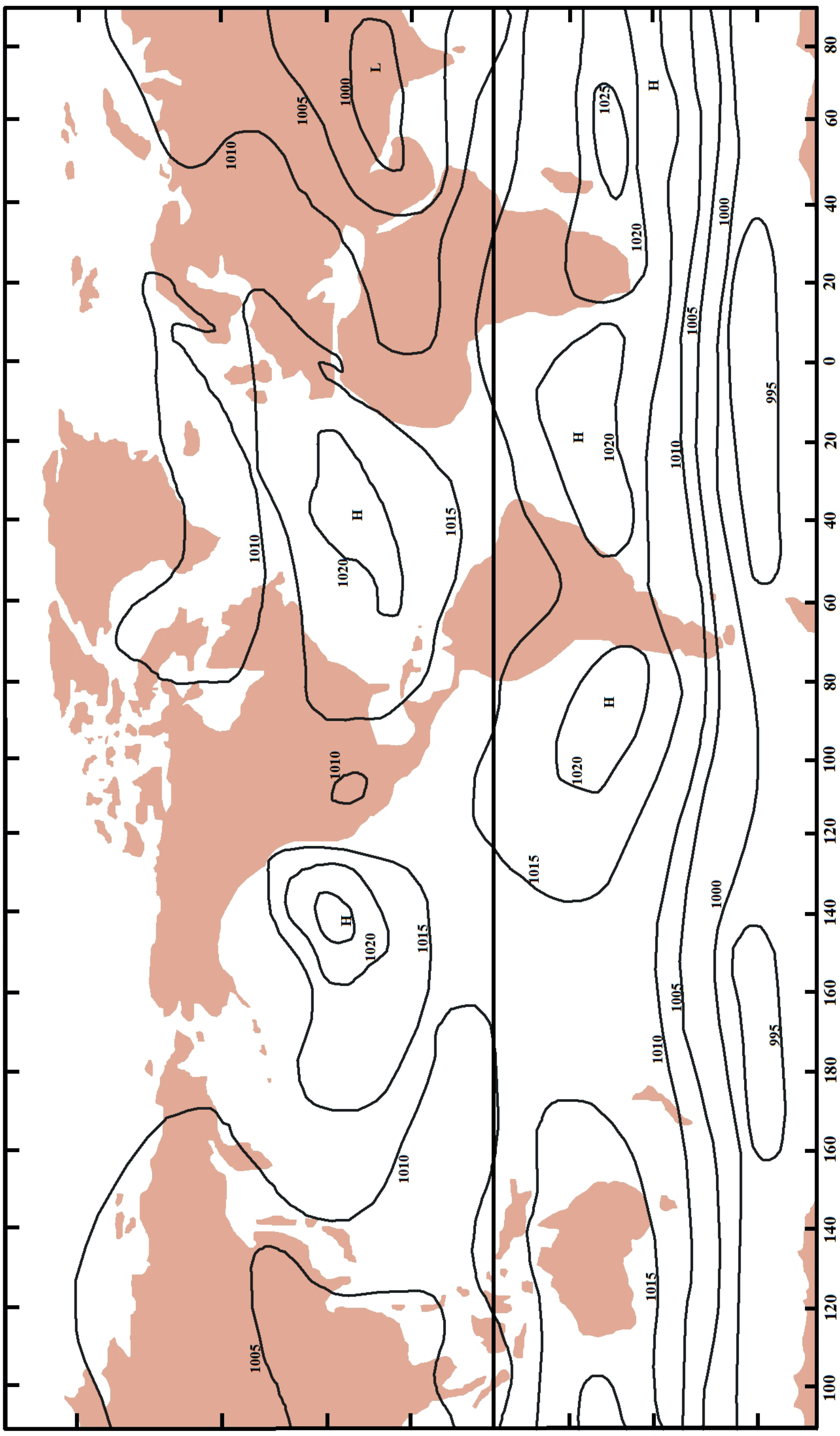


Fig. 12.9: Average Sea Level Pressure in July in Millibars.

Now let us see the explanation for each of these types of winds in the following sub-sections.

12.5.1 Planetary Winds

The winds blowing in a more or less similar direction throughout the year between the specific pressure belts are called ***Planetary winds*** or ***permanent winds***. For example, ***Trade winds***, ***Westerlies*** and ***Polar winds*** are planetary winds. Refer to Fig. 12.10 which show planetary winds and the pressure belts between which they blow.

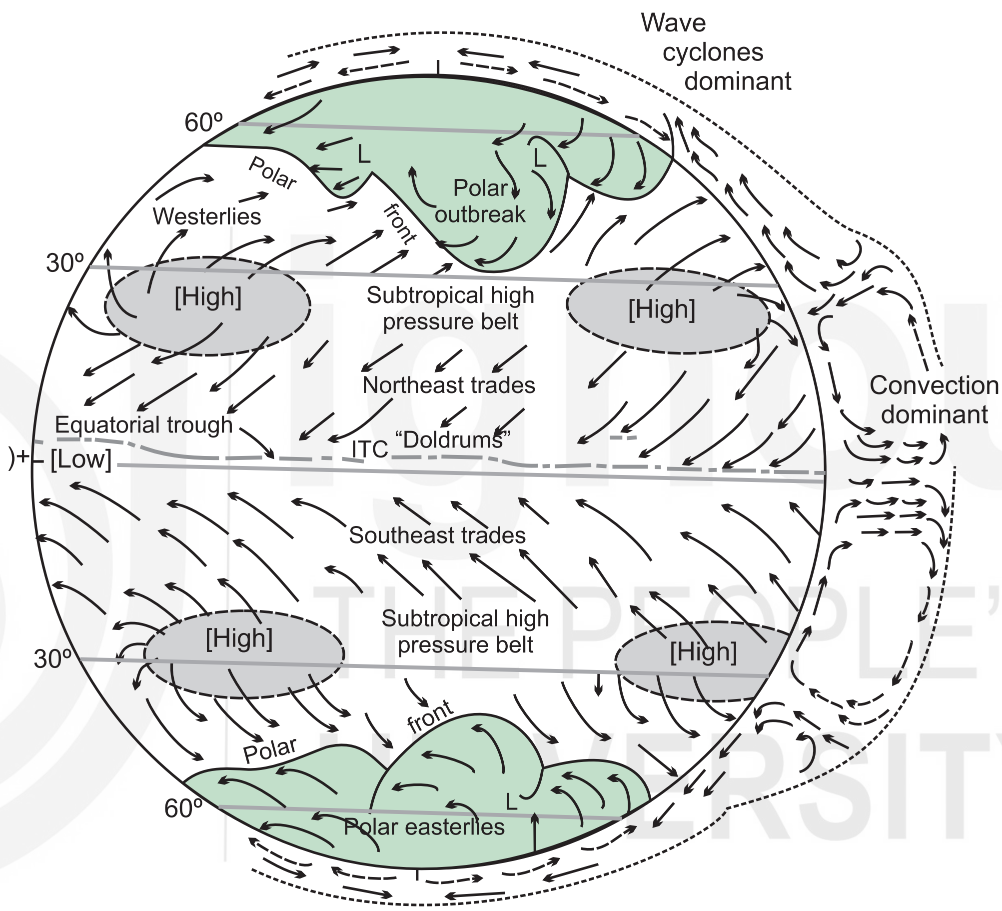


Fig. 12.10: Planetary Winds.

Trade Winds

Trade winds constantly blow from the sub-tropical high pressure belts to equatorial low pressure belts in the northern and southern hemispheres. The word 'Trade' has been derived from ***"tread"*** which means to follow a certain path carefully. On account of Coriolis force or Ferrel's law, they are deflected from their path (towards right in northern hemisphere and towards left in southern hemisphere) and blow from north-east direction in the northern hemisphere and from the south-east direction in the southern hemisphere. So they are called north-east trade winds and south-east trade winds respectively. These are the winds which blow in the same direction with the same strength throughout the year, especially over the oceanic regions. During the ancient times these winds helped traders to sail their ships in seas for business purposes for quite long distances. That has given the name ***"trade wind"*** to these steady winds.

Onshore trade winds carry moisture from the oceans and cause rainfall along the eastern coasts of the continents. As it moves towards the west it loses water vapour and hence doesn't cause any rainfall along the western coasts of the continents. Now you can reason out why the subtropical deserts are situated along the western parts of continents in the trade wind belt.

Westerly Winds

The planetary winds blowing from the sub-tropical high pressure belts towards the sub-polar low pressure in both the hemispheres are called ***Westerly winds*** or ***westerlies***. From Fig. 12.10, it can be understood that in the northern hemisphere the westerly winds blow from the south western direction to the north eastern direction. In the southern hemisphere they blow from the north western direction to the south eastern direction.Since they blow from the western direction, they are called the westerly winds. These winds are not as regular and strong as the trade winds. However, they are more pronounced, regular and strong in the southern hemisphere because of the predominance of oceans there. In the southern hemisphere between 40° to 60° south latitude, these westerly winds acquire more vigour and strength. Hence the ancient mariners called them as ***"Roaring Forties", "Furious Fifties"*** and ***"Screaming Sixties "*** according to their latitudinal positions.

Polar Winds

These winds blow from polar high pressure belts towards sub-polar low pressure belts in both the hemispheres between the poles and 60° latitude. The direction of the wind in the northern hemisphere is from north-east and in southern hemisphere is from south-east.These winds are also called ***Polar Easterlies***.These winds are more regular in the southern hemisphere than in northern hemisphere. As these winds come in contact with the ice sheets on their way, they are extremely cold and dry.

SAQ 2

How do the Mediterranean climatic regions in sub-tropical regions receive rainfall during winter season?

Spend 5 mins

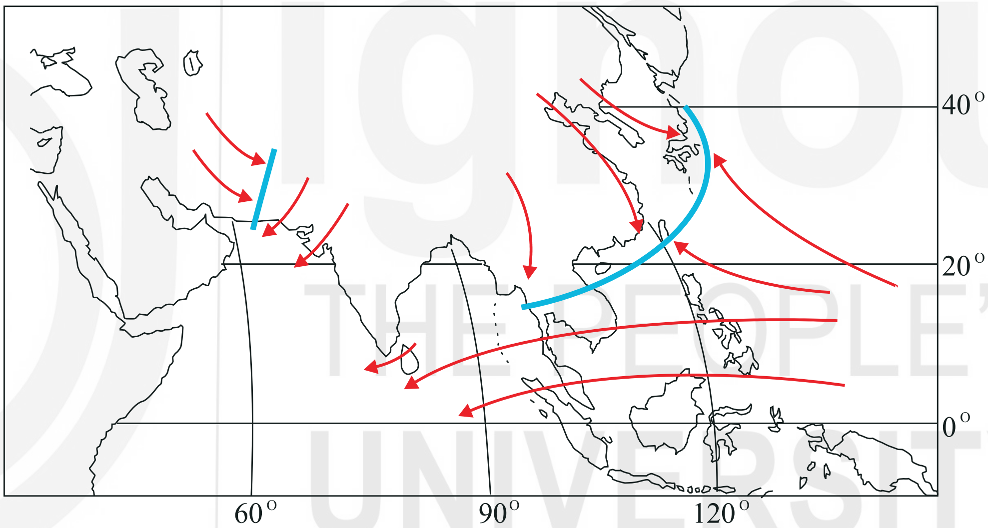
12.5.2 Seasonal Winds

Winds blowing in a particular direction over short periods or in particular seasons in particular regions are called ***seasonal winds*** or ***periodic winds***. These winds form because of heterogeneity of earth's surface which is composed of great landmasses and water bodies having unequal heating and cooling qualities. Seasonal differences in temperature often give rise to seasonal contrasts in pressure and contrasts in pressure causes changes in wind direction. Monsoon winds are the best examples for the seasonal reversal of the direction of flow. Let us study about these winds.

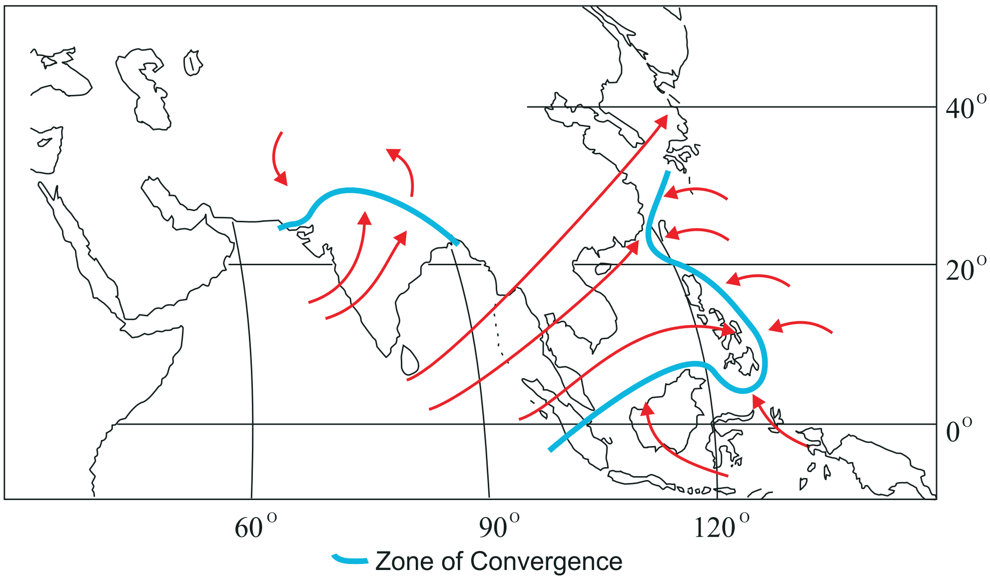
Monsoon Winds

The term ***'monsoon'*** has been derived from the Arabic word 'Mausim' meaning "seasons". Monsoon winds are more developed in the Indian sub-continent, South-East Asia, parts of China and Japan. Monsoon winds also blow in southern USA, northern Australia, and in western Africa. Monsoon winds have helped the merchants and travelers during medieval period who used to travel by their ships for long distances in the Indian Ocean.

During winter the interior of Asia becomes excessively cold, resulting in the development of a continental anticyclonic condition or high pressure area. At this time temperatures over the seas to the east and south of Asia, are relatively higher, and consequently pressure is lower. As a result of this arrangement of the pressure areas, the gradient is from the continent towards the ocean. Consequently, cold surface winds move out from Asia toward the surrounding seas. The winds blow from the north-east direction in southern Asia and hence called north-east monsoon and brings winter rain to the areas wherever they are onshore moisture laden winds. Refer to Fig. 12.11(a) to get a clear picture of it.



(a)



(b)

Fig. 12.11: a) Winter Monsoons; and b) Summer Monsoons

During summer, continental regions of Eurasia gets heated faster in comparison to the adjoining oceans. Hence low pressure develops over the continents in the southern and south-eastern Asia during summer. However, contrary to this, the oceanic areas are having higher pressure. This pressure difference causes winds to blow from Indian Ocean to the continent. The south-east trade winds blowing from south of equator crosses it and gets deflected to the right due to the Coriolis effect and becomes south -west winds which are moisture laden onshore winds blowing from the oceanic area. They are in fact the south-west monsoon rainfall bearing winds. Refer to Fig. 12.11(b) to understand better.

Now you must have understood that the seasonal changes cause complete reversal of monsoon winds. Just as monsoons which result due to seasonal temperature contrasts between land and water, there are also diurnal or 24 hourly reversal of winds resulting from similarly induced temperature contrasts. These are called land and sea breezes which have local effect.

12.5.3 Local Winds

Local winds are formed as a result of local differences in temperature and affect a relatively small area and are confined to lower levels of troposphere. They are known by different names in different areas. Let us study some of the local winds and their characteristics.

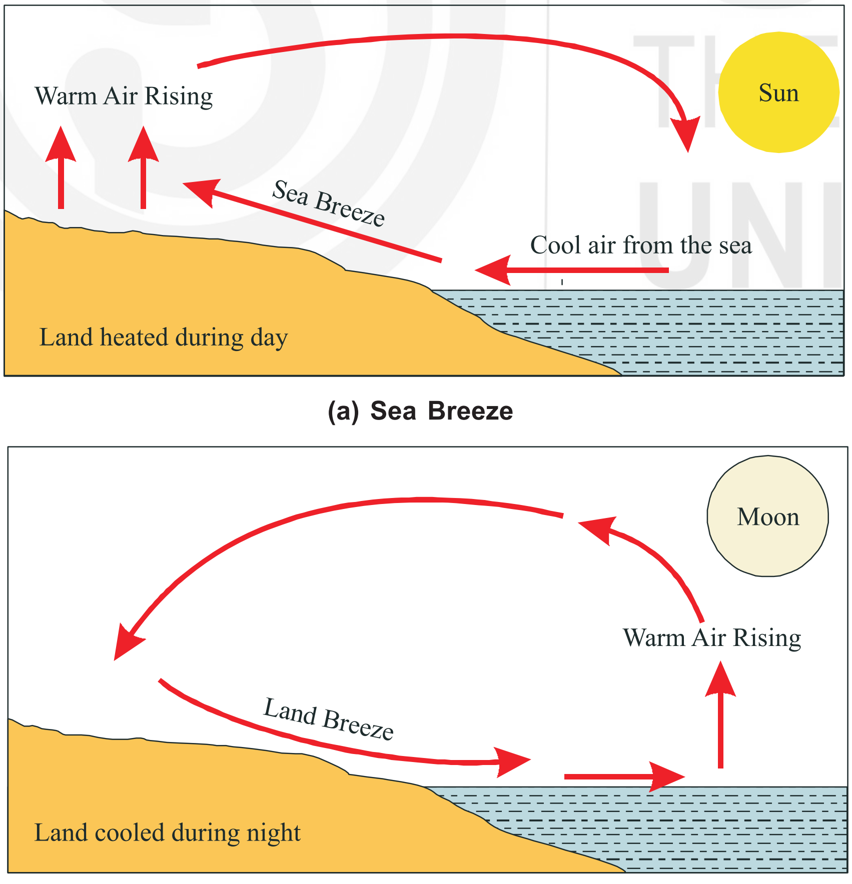


Fig. 12.12: Land and Sea Breezes.

Land Breeze and Sea Breeze

As you know, the land and the sea do not heat or cool in the same manner. During daytime land gets heated quickly and during night it cools faster. On the other hand, sea or water bodies gets heated and cooled very slowly. It is this uneven heating and cooling that causes the land and the sea breezes. This can be understood from Fig. 12.12. As the land gets heated quickly during daytime, the air in contact with the land also gets heated and expands and rises up creating a low pressure over the land. This low pressure attracts cool air from the sea and so during daytime sea breeze blow from sea towards the land. Contrary to this, during night the land gets cooled quickly and the temperature of air over the sea remains relatively higher. This causes low pressure over the sea which gets filled up by cool breeze blowing from the land. This is called land breeze. This is the way land and sea breeze blow and results in moderate temperature over the oceanic areas.

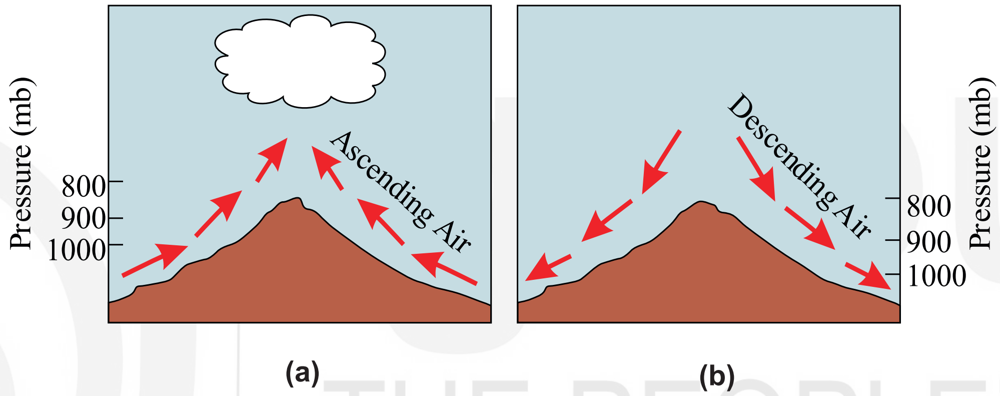


Fig. 12.13: a) Valley Breeze and b) Mountain Breeze.

Similar to land and sea breezes, mountain and valley breezes also blow with diurnal periodicity Refer to Fig. 12.13 to understand this. During day time, the slopes adjoining the valleys receive direct rays of the sun and becomes heated. Hence, the pressure is low over the slopes and relatively high in the valleys below. As a result, during daytime, winds start blowing from valley towards slopes and they are called valley breeze.

After sunset, the slopes cool rapidly and begin to cool the air adjacent to them. The cooler and heavier air starts slipping down the mountain sides to the valleys. This is a reversal of valley breeze and is known as the mountain breeze.

Now let us get familiar with some other local winds which as the name suggests are local in terms of their area of influence.

Chinook

These are hot and dry winds that blow down the eastern slopes of Rocky Mountains of North America. The literal meaning of chinook is ***"snow eater"*** as it helps in the melting the snow. This wind blows during the winter time and causes melting of snow in the Prairie region.

Foehn

These are hot dry winds similar to chinook that blow down the northern slopes of Alps. The temperature of these winds vary from 15° C to 20° C which also help in melting the snow, thus making pastures ready for animal grazing and also help the grapes to ripe early.

Loo

These are hot and dry winds that blow over the northern plains of India during the months of May and June. They usually occur during the afternoons and their direction is from west to east. Temperature of loo winds varies between 45° C to 50° C.

Mistral

These are cold and dry winds, that originates on the Alps and blows down the southern slopes of Alps towards France and Mediterranean Sea through Rhone valley. They lower temperature to below the freezing point in areas of their influence.

Bora

Bora is similar to minstral and is extremely cold and dry north-easterly wind in Adriatic Sea blowing with a velocity of 128 km/h to 196 km/h.

Sirocco

Sirocco is a warm, dry and dusty local wind, which blows in northerly direction from Sahara desert and after crossing the Mediterranean Sea, reaches even upto Italy and Spain. It becomes extremely warm and dry while descending through the northern slopes of the Atlas Mountain. It is known as Khamsin in Egypt, Gibli in Libya, Chili in Tunisia, Simoom in Arabian Desert, Blood Rain in South Italy, Leveche in Spain and Gharbi in the Adriatic and Aegean Sea.

Harmattan

They are warm and dry winds blowing from north-east and east to the west in Sahara desert. These are also called as ***"doctor"*** winds in Guinea Coast of western Africa. Similar winds are called as "Brickfielders" in Victoria (Australia), "Blackrollers" in the Great Plains of USA, "Shamal" in Iraq and Norwesters in New Zealand.

Blizzards

These are violent, stormy and extremely cold polar winds laden with dry snow and are prevalent in north and south Polar Regions, Siberia, Canada and some parts of USA.

SAQ 3

Why is harmattan also called as "doctor" winds?

Spend 5 mins

Lastly let us go through variable winds in brief.

12.5.4 Variable Winds

Variable winds, as the name suggests are those winds whose speed, direction and extent are of variable nature. They are distinctly different from the winds described above. Cyclones and anticyclones come under the category of variable winds.

We would study about the Origin and mechanism of cyclones and anticyclones in detail at higher levels.

Cyclones

The heating up of air of a region with respect to its surrounding regions causes sudden changes in the pressure. This pressure difference creates cyclones. Cyclones are characterized by low pressure in the center surrounded by high pressures. The isobars, as shown in climatic charts, are close together. Cyclones vary in its extent from 200 kms to more than 3000 kms.They remain quite stationary or move several thousand kilometers in a day. The approach of a cyclone is characterised by a fall in barometric reading, dull sky, oppressive air and strong winds, rain or snow falls and the weather is usually bad. In cyclones, winds blow inwards to the low pressure center, circulating in anti-clockwise direction in the northern hemisphere and in clockwise direction in the southern hemisphere (due to coriolis effect). Refer to Fig. 12.14 (a) for cyclones.

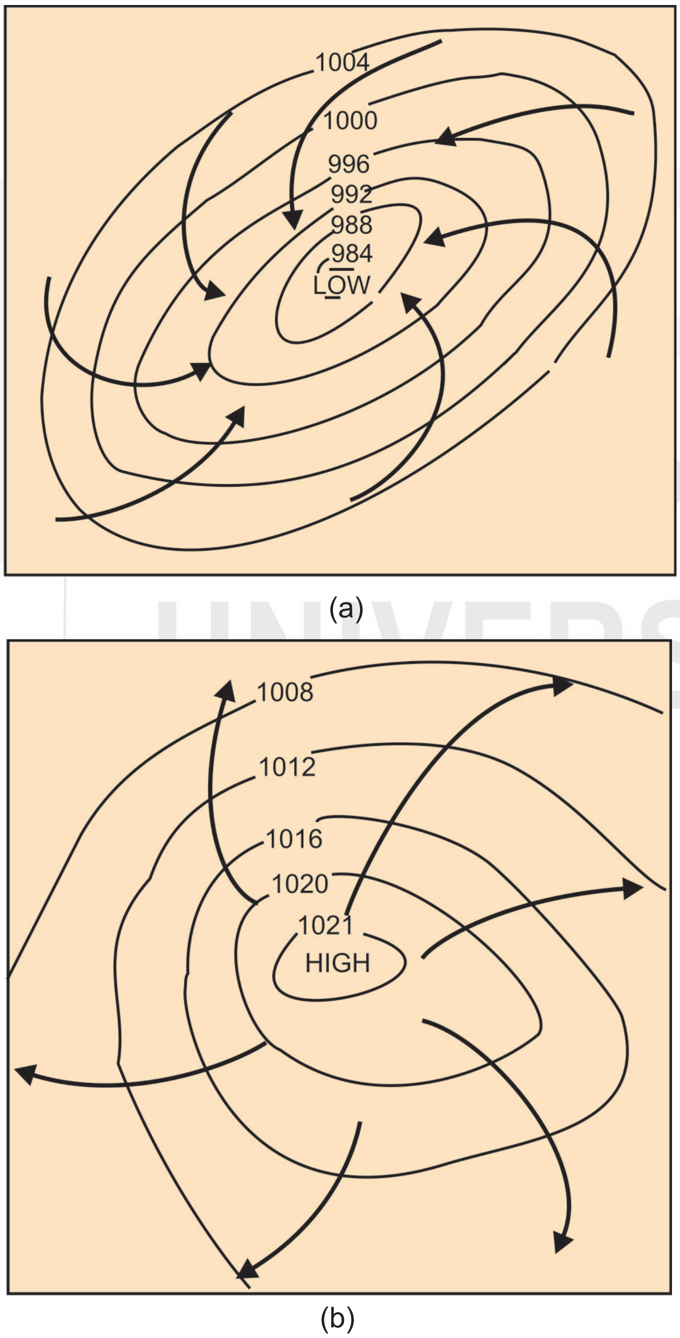


Fig. 12.14: a) Cyclone; b) Anticyclone of Northern Hemisphere.

Anticyclones

These are opposite to cyclones, with high pressure in the center and the isobars are far apart. The pressure gradient is gentle and winds are light. Anticyclones normally signify calm weather. Skies are clear, the air is calm and temperatures are high in summer but cold in winter. Anticyclones may last for days or weeks. Winds in anticyclones blow outwards and are also subject to deflection. Winds blow clockwise in northern hemisphere and anticlockwise in the southern hemisphere which is again due to coriolis effect. Refer to Fig. 12.14(b) for anticyclones.

12.6 SUMMARY

The weight of a column of air at a given place and time is called air pressure.

The horizontal distribution of atmospheric pressure is not uniform over the earth's surface. Global pressure belts are formed due to thermal and dynamic factors and there are seven alternate belts of low and high pressures on the earth's surface.

With the apparent movement of the sun during different seasons, the position of the pressure belts also shifts northwards or southwards. The difference in air pressure causes movement of air in horizontal direction, called winds. Winds are classified into planetary winds, seasonal winds, local winds and variable winds.

12.7 TERMINAL QUESTIONS

1. What do you mean by atmospheric pressure? How is it measured?
2. Give a description of the distribution of global pressure belts.
3. Explain the planetary winds on the earth.
4. How do monsoons occur?
5. Distinguish between cyclones and anti-cyclones.

12.8 ANSWERS

Self-Assesment Questions

1. Sub-Polar regions are low pressure belts in spite of the fact that these regions experience low-temperature throughout the year. This is due to the effect of rotation of earth or coriolis effect which increases from equator towards the poles. This is the reason why winds in sub-polar low pressure belts have a spreading or throwing-out tendency thus creating low pressure. The winds from here go to sub-tropical high pressure and polar high pressure belts.

2. Mediterranean regions are found on the western side of continents between 30° to 40° latitudes in both the hemispheres. During the winter season the apparent movement of the sun is towards the southern hemisphere which causes the southward shift of subtropical high

pressure belts. Due to the southward shift of the subtropical high pressure belt, the regions which were under the influence of trade winds come under the influence of westerlies. Along the western sides of continents, these winds have already passed over huge ocean masses and so are onshore or moisture laden winds. Hence they are able to provide rainfall to those areas where they blow. This is the reason why the Mediterranean regions get rainfall during winter season.

3. Harmattan winds are also called doctor winds along the Gulf of Guinea in West Africa because of its dryness compared with humid tropical air prevailing which is supposed to be good for health.

Terminal Questions

1. First define atmospheric pressure and then give a little bit of explanation. After that list the instruments used for measuring it and give their brief description. Refer to Sec. 12.2 and 12.2.1 of this unit.
2. Give a brief discussion of all the pressure belts. You can combine the similar belts in northern and southern hemisphere as given Sec. 12.3 of this unit. Support your answer with a figure.
3. Start your answer by definition of planetary winds and then list and describe them as given in Sec. 12.5.1 of this unit. You can support your answer with a figure.
4. First explain that monsoons are seasonal winds and describe briefly how they occur as in Sec. 12.5.2 of this unit. Also draw a figure to explain it.
5. Define cyclones and anti-cyclones with figures and bring out the difference between them as in Sec. 12.5.4 of this unit.

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UNIT 13

HUMIDITY AND PRECIPITATION

Structure

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13.1 INTRODUCTION

In the previous unit, we have discussed about global distribution of surface pressure systems and wind. So now you are aware how differences in air pressure causes movement of winds. You can also differentiate between prevailing winds, seasonal winds and local winds and explain their importance. You have also learnt how onshore winds bring rain to the areas they visit. Now in this unit, you will get acquainted with atmospheric moisture which has a tremendous bearing on the weather and climatic conditions of a place and which is an important determinant of humidity, cloudiness, precipitation and visibility.

Humidity refers to water vapour content of air at a particular time and place. Our planet earth is unique in the sense that water exists on it and that too in all the three phases, that is, solid, liquid and gas. An introduction to moisture in the atmosphere, process related to phase changes of water is discussed in Sec. 13.2. In Sec. 13.3, you will get a brief description of distribution of this moisture content. In Sec. 13.4 you will study about hydrological cycle and get acquainted how water in its different forms moves around the earth-atmosphere system through the process of evaporation, condensation, precipitation etc. Condensation and various forms of condensation is dealt with in Sec. 13.5 and 13.6 respectively. Lastly, Sec. 13.7 will acquaint you with different forms and types of precipitation.

In the next unit, you will learn about classification of climates by Koppen.

Expected Learning Outcomes

After studying this unit, you should be able to:

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

Now let us begin our study regarding moisture in the atmosphere.

13.2 MOISTURE IN THE ATMOSPHERE

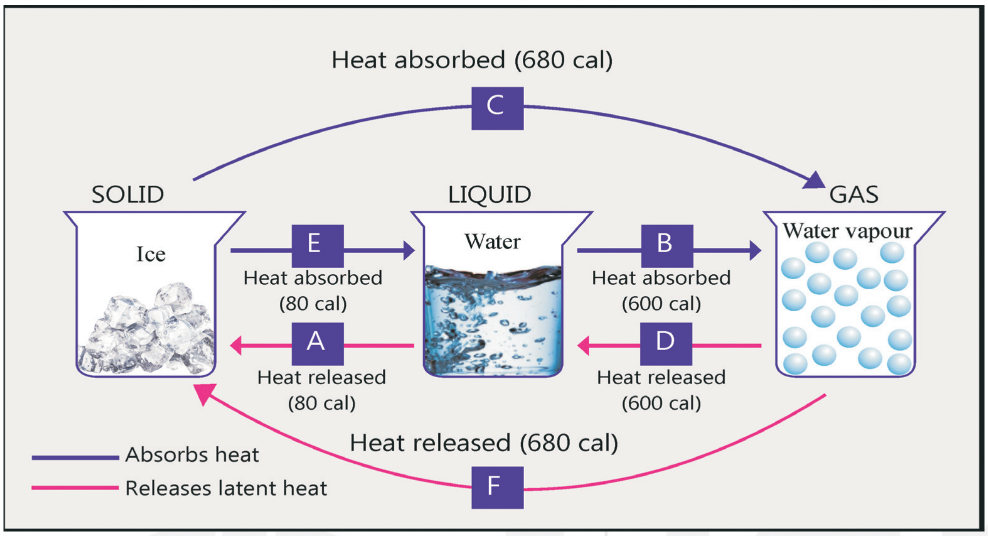
Significance of Moisture in the Atmosphere

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

Phase Changes of Water

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

Reverse of evaporation is called ***condensation*** that marks a change from gaseous to liquid state. Sometimes there is a direct change of state from solid ice to water vapour. This process is called ***sublimation***. Reverse of sublimation is called the ***deposition***. Further change of state from liquid to solid is called ***freezing***. **The processes of evaporation, sublimation and melting consume energy while condensation, deposition and freezing release energy.** Refer to Fig. 13.1 to get an idea of the entire process. This never ending release and consumption of energy drives the weather engine.



A- Freezing

B- Evaporation

C- Sublimation

D- Condensation

E- Melting

F- Deposition

Fig. 13.1: Phase Changes of Water

Vapour Pressure

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

Evaporation

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

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

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

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

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

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

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

The rate of evaporation depends on source of energy. Thus the potential for evaporation decreases from equator to the poles. But 'actual' evaporation also depends on the availability of water. For example, the Sahara desert has high potential for evaporation as it is in the subtropical region, but it is very low in actual evaporation due to little availability of water there. Therefore, actual evaporation is greater over oceans than over continents. Refer to Fig. 13.2 to understand better. More than two thirds of actual evaporation takes place in the region between 30^0 North and South latitudes. There is abundant supply of surface water in these regions, along with huge amount of evapotranspiration from equatorial rainforests. Refer to Table 13.1 to get a general picture of mean annual evaporation along different latitudinal zones.

Spend 5 mins

SAQ 1

What is evaporation and how does it occur?

Table 13.1: Zonal Distribution of Actual Mean Annual Evaporation in cm

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

Now let us get acquainted with some indices of moisture.

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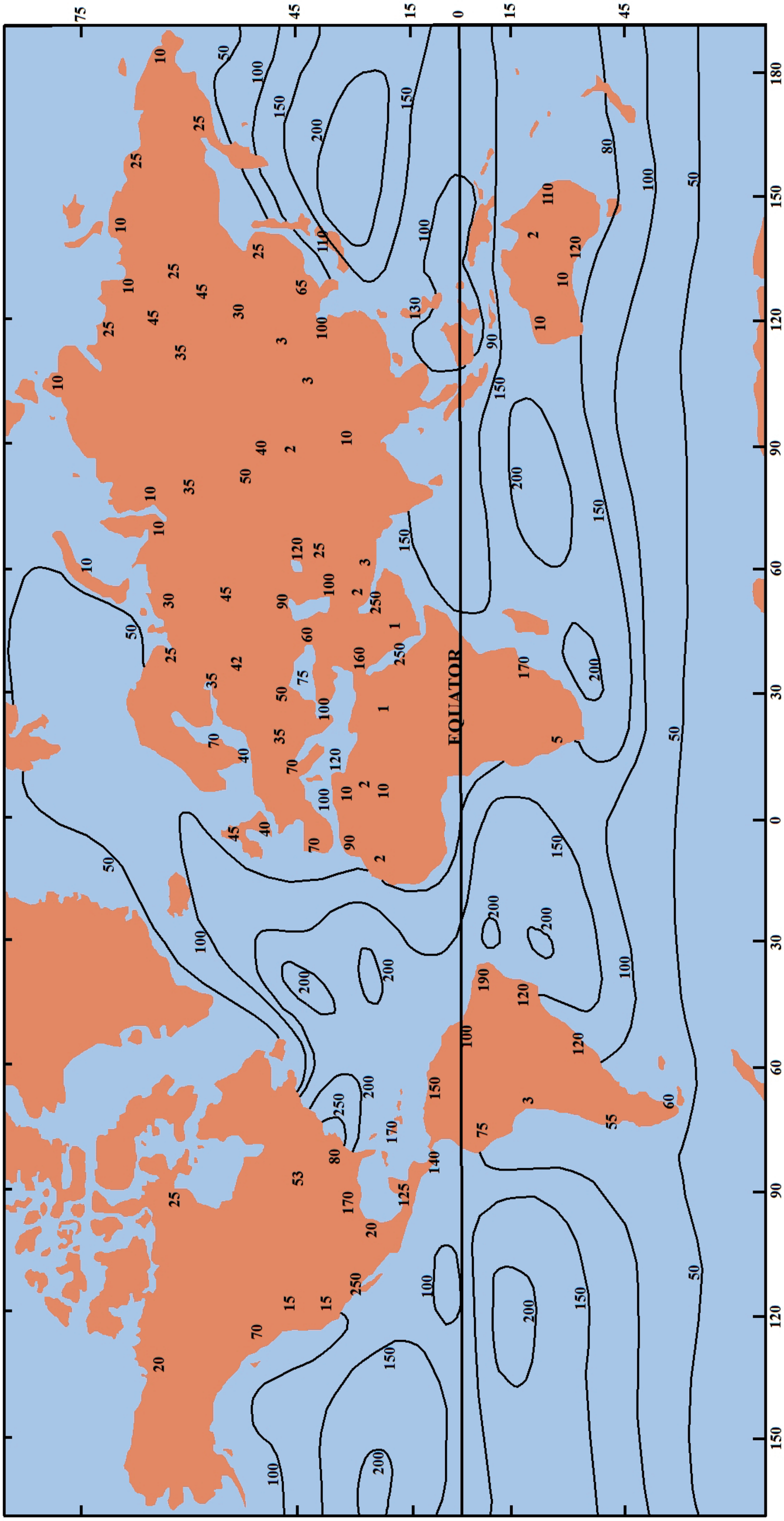

Fig.13.2: Global Distribution of Mean Annual Evaporation.

(Redrawn from Source: Brittanica.com)

Indices of Moisture

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

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

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

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

Relative humidity is highly variable, and changes with variations in temperature. Maximum relative humidity is reached during the morning hours and it decreases as the day proceeds. If the early morning relative humidity is about 100% then it may be 40-50 % in the afternoon. This is basically due to change in temperature, although the actual amount of water vapour in the air may or may not have increased or decreased. Refer to Fig. 13.3 to get a clear picture where the rightmost parcel of air shows 100% R.H. while in the second and third parcel from right, it is seen that though water vapour content is same but R.H. decreases with the increase in temperature. This is because, the parcels are not saturated and their water holding capacity is increased with the temperature increase.

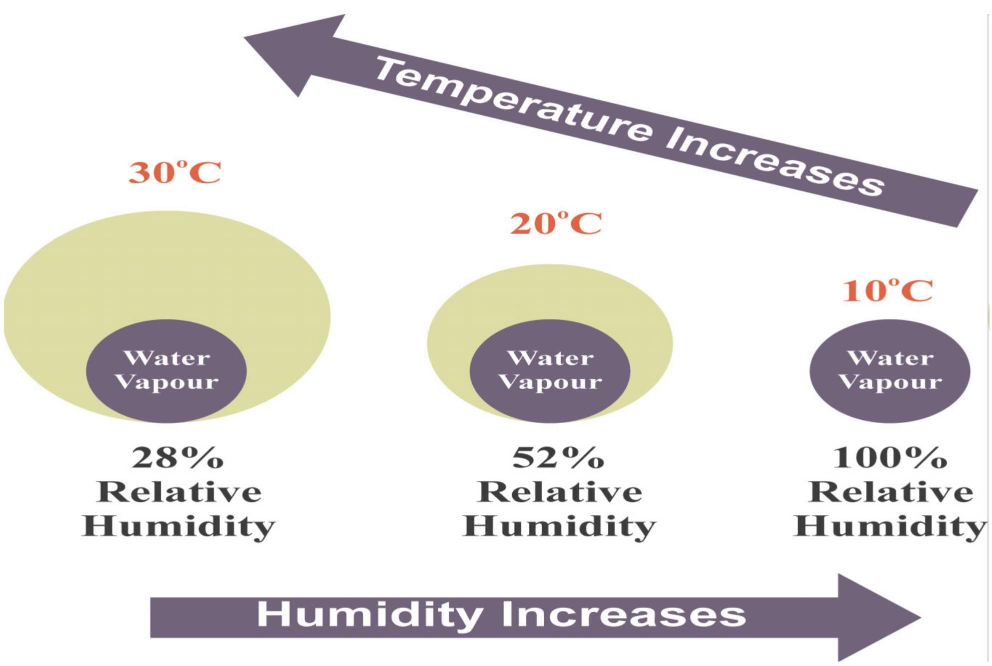

Fig. 13.3: Relative Humidity and Temperature

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

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

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

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

SAQ 2

Spend 5 mins

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

Measuring the Atmospheric Water Vapour

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

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

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

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

13.3 DISTRIBUTION OF WATER VAPOUR

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

A. Altitudinal Distribution

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

B. Latitudinal Distribution

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

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

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

13.4 HYDROLOGICAL CYCLE

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

Let us understand this from Fig 13.4. In strong sunlight, water evaporates from the oceans and other water bodies. This is taken to be the beginning of hydrologic cycle. Solar radiation also heats the surface of the earth. This in turn heats the air above it, which becomes lighter and rises. Air cools when it reaches the cooler layers of troposphere and its capacity to 'hold' moisture reduces. At one point the air is cooled enough to reach saturation. The water vapour in the air condenses to form clouds. Moisture in the form of clouds is then transported around the world until it returns to the earth's surface as precipitation. When water reaches the ground, some of it may evaporate back into the atmosphere or may go below the surface and become groundwater. Groundwater flows into the oceans, rivers, and streams, or it is goes back to the atmosphere through evaporation from soil and transpiration from vegetation. Some of the water remains on the earth's surface as runoff, which flows into lakes, rivers and streams and is carried back to the oceans, where the cycle begins again.

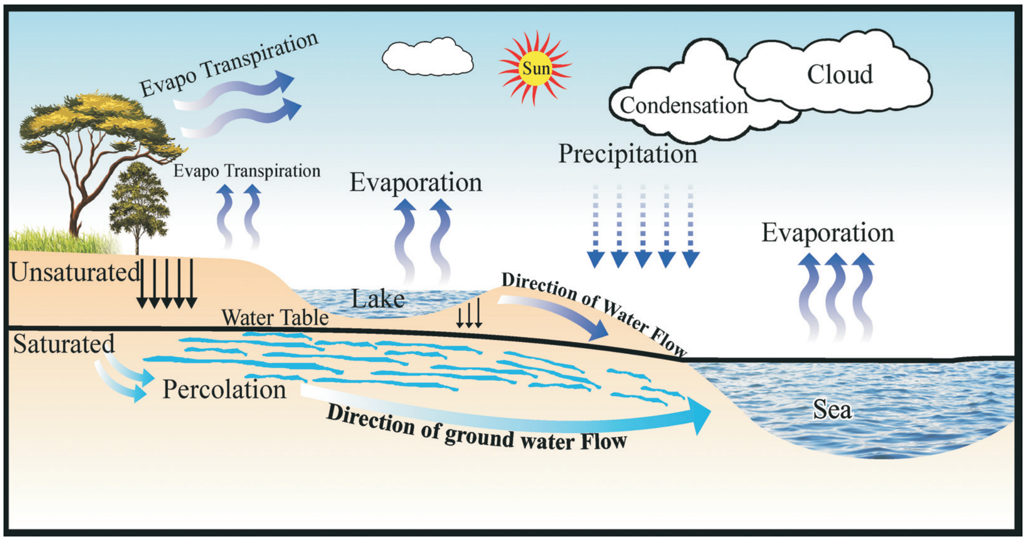

Fig.13.4: Hydrological Cycle.

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

13.5 CONDENSATION

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

- when relatively warm, moist air moves over a colder surface;
- when warm moist unsaturated air mixes with colder unsaturated air thus lowering the temperature of the air below its dew-point;
- during cold and long winter nights due to outgoing long wave terrestrial radiation which cools the land surface and also air in contact which becomes even colder than the air above it and condensation begins (fog, dew, rime may form in this way); and
- due to upward motion of air, its temperature can fall.

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

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

Hygroscopic Nuclei

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

Adiabatic Warming and Cooling

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

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

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

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

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

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

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

Stability and Instability of the Atmosphere

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

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

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

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

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

13.6 FORMS OF CONDENSATION

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

13.6.1 Fog and their Types

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

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

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

a) Radiation Fog

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

b) Valley Fog

This type of fog is very common in mountainous regions. The air along the ridge tops and upper slopes of mountains begins to cool after sunset, and becomes so dense and heavy that it descends into the valley floors. The descending cold air reduces the temperature of the valley floor where the air becomes saturated and fog forms (see Fig. 13 .5). Valley fog can be very dense at times and make driving very hazardous due to reduced visibility. However, it dissipates very quickly once the sun comes up and there is rise in air temperature.

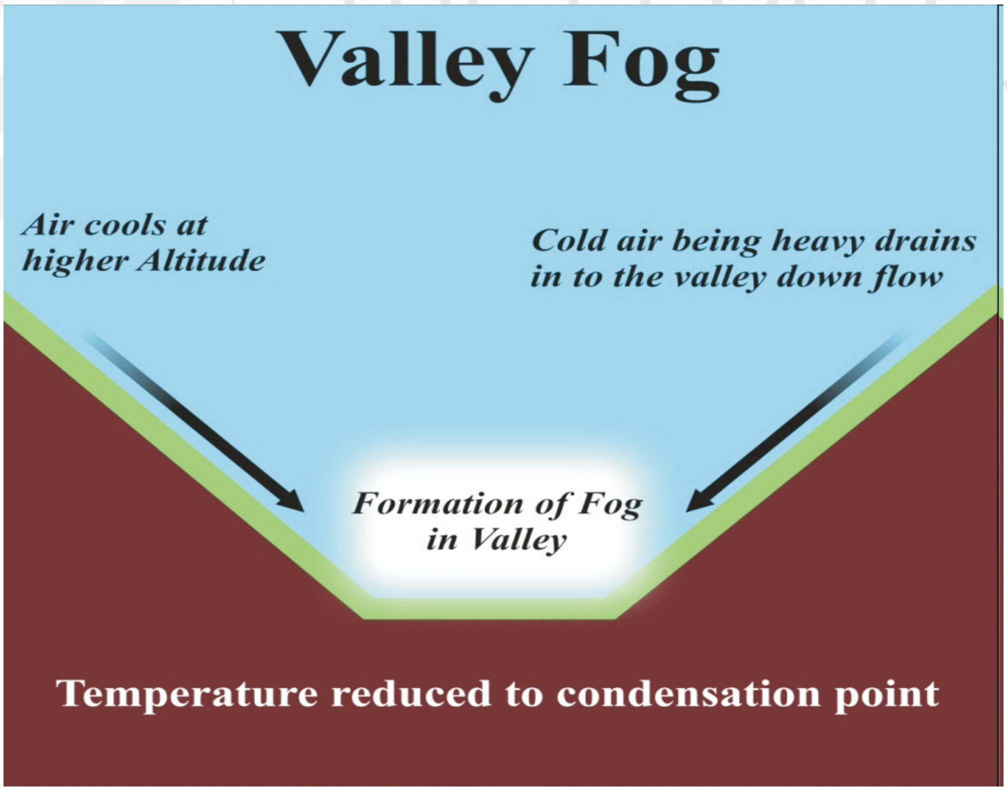

Fig. 13.5: Valley Fog.

c) Advection fog

Advection Fog is also like radiation fog. However, condensation in this case is caused not by a reduction in surface temperature but by horizontal movement of warm moist air over a cold surface. So, advection fog can also be distinguished from radiation fog by its horizontal motion along the ground (Refer Fig. 13 .6).

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

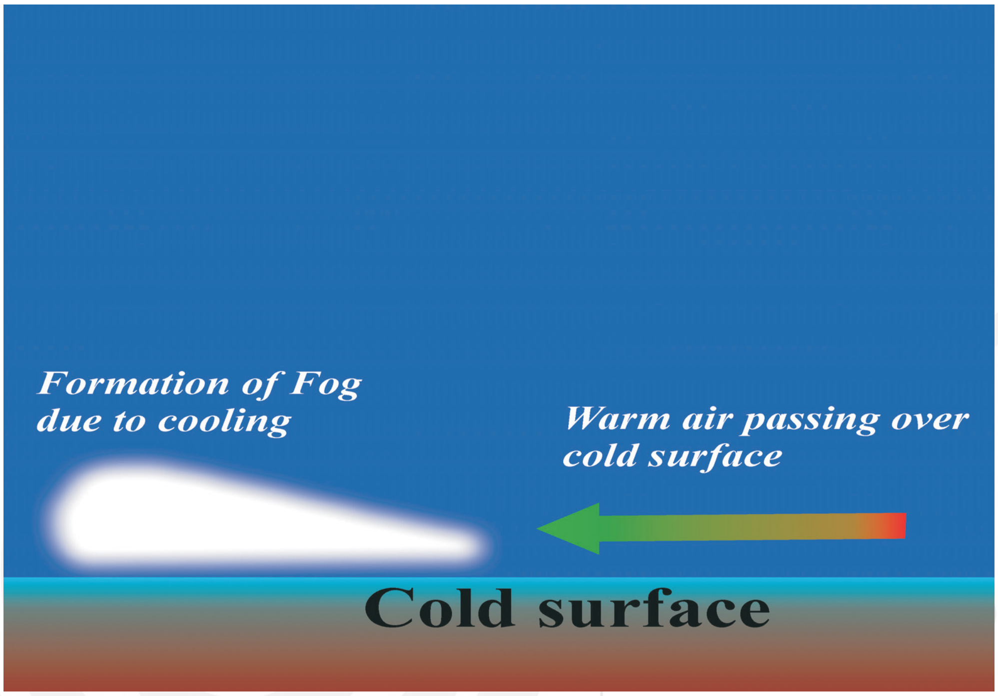

Fig.13.6: Advection Fog

d) Sea Fog

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

e) Upslope Fog

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

f) Ice Fog and Freezing Fog

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

13.6.2 Clouds and their Types

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

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

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

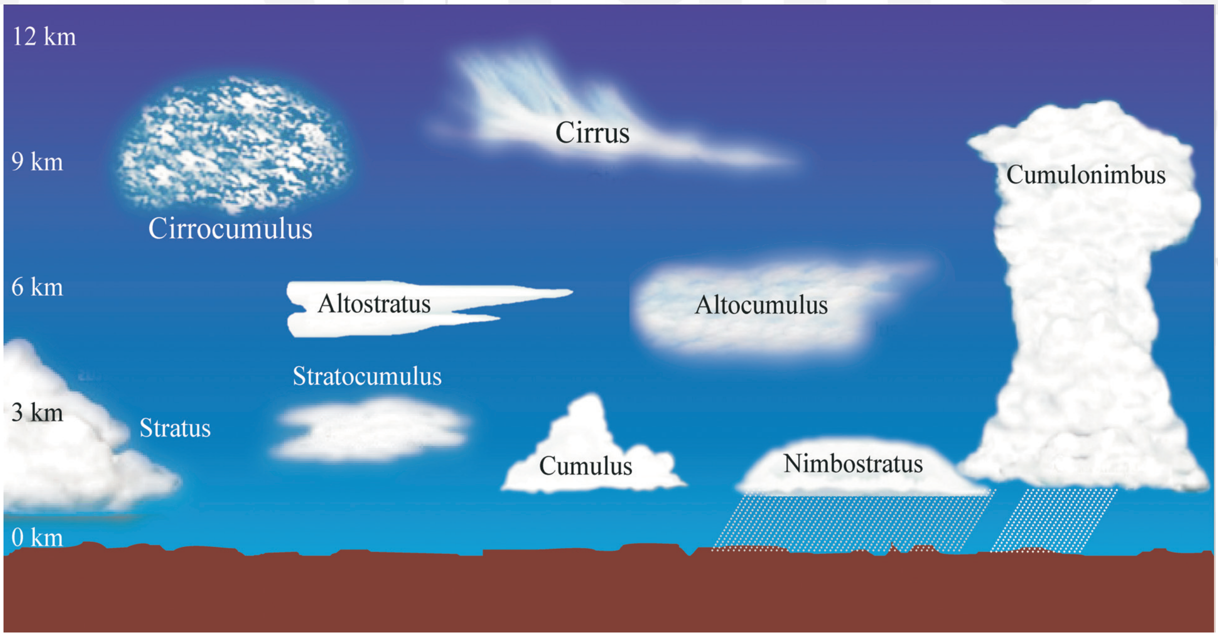

Fig. 13.7: Cloud Types.

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

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

Refer to Fig. 13.7 while studying different types of clouds.

[A] High Clouds

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

Cirrus (Ci)

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

Cirrostratus (Cs)

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

Cirrocumulus (Cc)

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

[B] Middle Clouds

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

Altostratus (As)

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

Altocumulus (Ac)

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

[C] Low clouds

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

Stratocumulus (Sc)

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

Stratus (St)

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

Nimbostratus (Ns)

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

[d] Clouds with Great Vertical Extent

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

Cumulus (Cu)

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

Cumulonimbus (Cb)

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

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

13.7 PRECIPITATION

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

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

13.7.1 Forms of Precipitation

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

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

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

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

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

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

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

13.7.2 Types of Precipitation

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

a) Orographic Precipitation

This occurs when moist air is blown over by the prevailing winds and is forced to rise up a mountain or plateau barriers obstructing it. As the rising air cools it condenses to form clouds and leads to precipitation. This type of rainfall is common in the Western Ghats and in the northeastern parts of our country. Refer to Fig. 13.8 for this type of rainfall. Most of the rain falls on the windward slope, while the other side of the slope, that is, the leeward slope is dry.

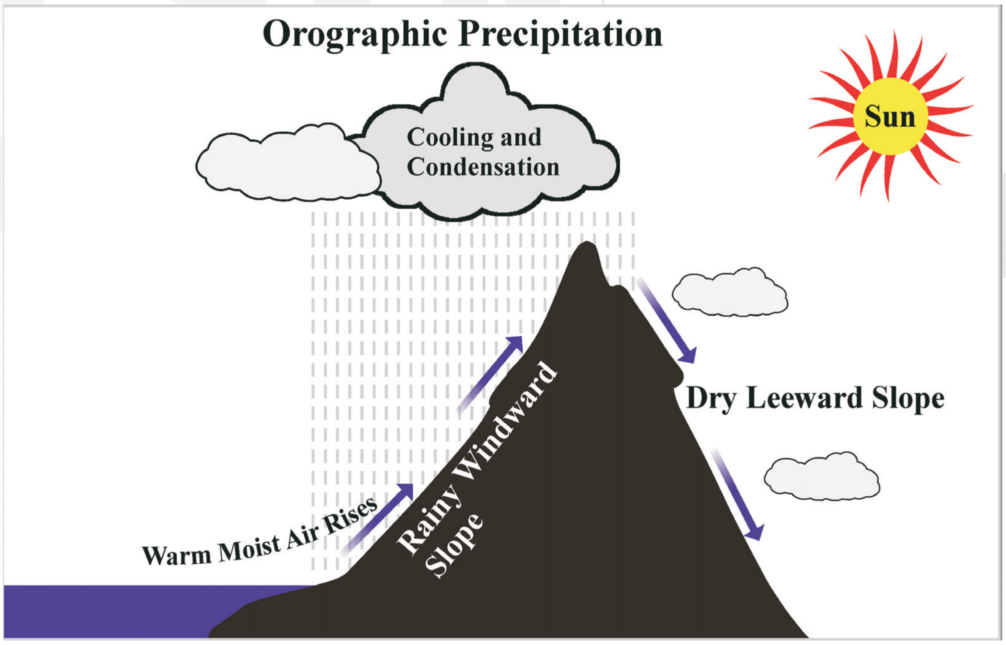

Fig. 13.8: Orographic Precipitation

b) Convective Precipitation

Convective precipitation occurs usually in equatorial regions which receives huge amount of insolation and has high humidity levels. Due to intense heating of the ground, the air in contact with the ground gets heated, expands and rises. This ascending air cools due to dry adiabatic lapse rate and at a point it becomes saturated. Cumulonimbus clouds form and results into heavy downpours accompanied by thunderstorms, especially in the afternoon. Please refer to Fig. 13.9 to understand better. Convective precipitation also occur in tropical, subtropical and temperate regions during summer. However, in temperate regions the rainfall is for a longer duration and is not that heavy.

c) Cyclonic Precipitation

Cyclonic precipitation is typically associated with frontal regions in the mid-latitudes. This happens when warm air is pushed up above a wedge of cooler air. It is a common occurrence when warm tropical air is undercut by cooler polar air. As rising warm air cools, clouds form and precipitation falls over a wide area. In India, the north-western region gets this kind of precipitation during winter, which is also known as 'western disturbance'. Refer to Fig. 13.10 to understand better.

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

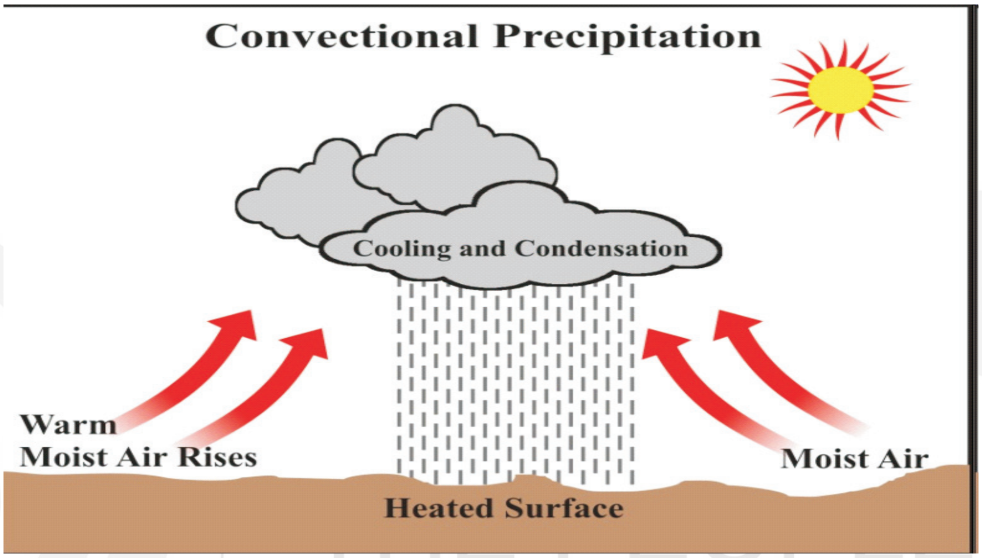

Fig. 13.9: Convective Precipitation

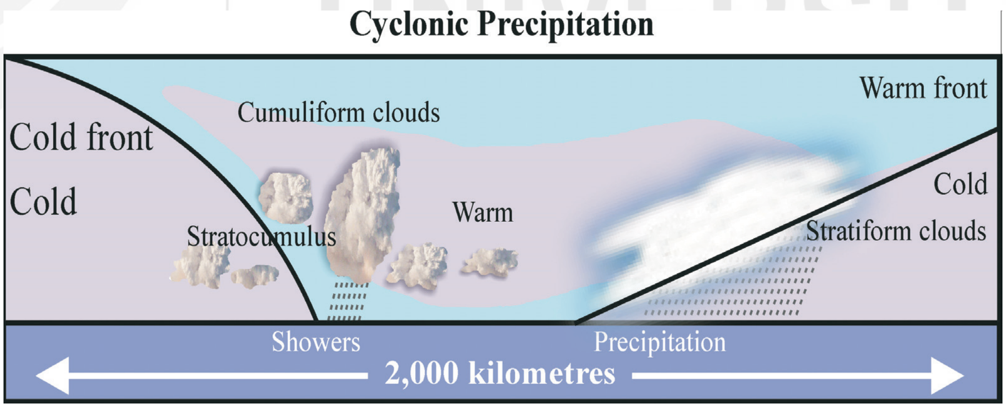

Fig. 13.10: Cyclonic Precipitation

Spend 5 mins

SAQ 3

i) How does Convective Precipitation occur?

ii) What is the difference between *halo* and *corona*?

13.8 SUMMARY

The presence of water in the atmosphere is a major determinant of weather. Its presence in all the three forms in the earth-atmosphere system drives the weather engine. There is constant consumption and release of energy as water changes its form from solid to liquid, to gas and vice versa.

Water is present in the form of water vapour, which ranges between zero percent, in the driest air, to only about three to four percent in moist air.

The content of water vapour in the atmosphere can be expressed in several ways, among which specific humidity, relative humidity are the variables of interest to the climatologist.

The hydrologic cycle defines how water in its three forms moves around in the earth-atmosphere system. Evaporation occurs from evaporating surfaces like oceans, rivers, lakes, ponds as well as soil and vegetation and changes water into gaseous form called water vapour. By the process of condensation, water vapour in the atmosphere changes to water droplets around hygroscopic nuclei. The water droplets aggregate to form fog, clouds and other condensation forms.

The clouds precipitate water droplets as well as snow or ice when the air is unable to 'hold' them any more as they may have grown in size and have become too heavy. The air that rises is labelled as unstable or stable depending on the way it goes up when it is forced to rise. The rising air will cool and condense to form clouds which would ultimately lead to precipitation.

To sum up, water or moisture in the atmosphere is the reason for all weather phenomena affecting the inhabitants of the earth's surface.

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13.9 TERMINAL QUESTIONS

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

13.10 ANSWERS

Self-Assesment Questions

1. Evaporation is the process by which liquid is transformed into gaseous or vapour form. When the liquid is heated, it absorbs heat and gets energy required to escape from the surface of the liquid and become gas. Heat absorbed in the process of evaporation is called the latent heat of vapourisation.
2. 8 g

   R.H.= (x/32)* 100; x=8g

3. i) Convective precipitation occurs usually in equatorial regions due to intense heating of the ground. The air in contact with the ground also gets heated, expands and rises. This ascending air cools due to dry adiabatic lapse rate and at a point it becomes saturated. Cumulonimbus clouds form and heavy downpours accompanied by thunderstorms occur especially in the afternoon.

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

Terminal Questions

1. Explain the concept of stable and unstable air giving examples as given in Sec. 13.5 of this unit.
2. First define clouds and then classify the clouds as per altitude. Then describe different types of clouds under each category as in 13.6.2 of this unit.
3. First define fog and describe different types of fog. Then explain why it is hazardous. Refer to section 13.6.1 of this unit.
4. First define precipitation and then go to describe their types with figures. Refer to section 13.7.2 of this unit.

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UNIT 14

CLIMATIC CLASSIFICATION

Structure

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14.1 INTRODUCTION

In previous units of this course, you have studied about the seasonal and spatial variations of the basic elements of climate. In this unit, you will study about the combined effects of these variations which are to be investigated, described and distinguished as different climatic classes. The basic goal of climatic classification is to bring order to a large and diverse information by organising similar entities together into groups that are different from other groups by specific attributes. In this way, an order is generated out of complexity. Climatic classification helps in comprehending the multiplicity of atmospheric conditions in meaningfully organised simple and general terms. It also helps in establishing an association of climate with other aspects of physical environment.

You will study about different approaches of climatic classification in Sec. 14.2 of this unit. You will get an overview of different bases of climatic classification and its significance in Sec. 14.3. Koeppen's classification of climates is discussed in detail in Sec. 14.4. Evaluation of his climatic classification is done in Sec. 14.5.

In the next block, you will study about hydrosphere and the related phenomenon.

Expected Learning Outcomes

After studying this unit, you should be able to:

- describe the goals of climatic classification;
- distinguish between different approaches and bases of climatic classification;
- summarise Koeppen's classification of climates;
- define and differentiate between various climatic classes; and
- evaluate Koeppen's classification of climates.

Before we start studying climatic classification, let us first get acquainted with different approaches towards climatic classification.

14.2 APPROCHES TO CLIMATIC CLASSIFICATION

Taking into consideration the objectives, different approaches have been adopted by geographers for climatic classification. There are, however, three broad approaches for the delineation of climatic regions of the world. These approaches are as follows:

i) Empirical Classification of Climate

ii) Genetic Classification of Climate

iii) Applied Classification of Climate

i) Empirical Classification of Climate

An empirical classification is based on the observable elements of climate which may be considered singly or in combination to frame criteria for climatic types. As this classification is based on statistics or data, it has well defined boundaries which brings more objectivity in the classification as compared to qualitative criteria. In general, temperature and precipitation have been taken into consideration in most of the empirical classifications of climate. The variants of temperature and precipitation such as precipitation effectiveness, thermal efficiency and evapotranspiration have also been frequently used. This approach helps in summarising enormous amount of information. Another advantage of this is that, quantitative criteria produce distinct boundaries for climatic classes.

ii) Genetic Classification of Climate

A classification based on genetic or causative factors of climate is known as genetic classification. It attempts to organise climates according to their causes. The bases of this kind of classification include latitude or angle of sun's rays, winds, pressure belts, air masses, topography and distribution of land and sea. The explanation of genetic classification is however, theoretical, incomplete and difficult to quantify. One such classification was proposed by

H. Flohn in 1950 based on wind regimes. Another simple but extremely effective, genetic classification of world climate based on air masses has been proposed by ***Strahler***.

iii) Applied Classification of Climate

In applied classification of climate the climatic regions are delineated in terms of effects of climate on other phenomena. It is, therefore, also known as functional classification of climate. A number of scholars have tried to identify the climatic factors which have deep impact on vegetation and numerous correlations between vegetation and heat and moisture have been established. The vegetation terms like rainforest, forest, savanna, steppe, desert and tundra have climatic connotations. Thornthwaite in 1948 used the concept of potential evapotranspiration in his applied classification of climate.

SAQ 1

Describe the goal and approaches for climatic classification?

Spend 5 mins

14.3 BASES AND SIGNIFICANCE OF CLIMATIC CLASSIFICATION

A. Bases of Climatic Classification

The major problem in the process of climatic classification is that climate is affected by so many elements such as insolation, temperature, atmospheric pressure, winds, air masses, precipitation, cyclones, fronts etc. Any classification based on a single climatic element would be a macro-level generalisation and it will have limited utility. However, climatic classification based on numerous elements would be so complex that it would lose simplicity, clarity and practical utility.

So,the most common elements which have been used for climatic classification are temperature, precipitation and vegetation. The ancient Greeks classified the world climate into three zones, that is, tropical (torrid), temperate and polar (frigid) on the basis of angle of sun's rays, latitude and temperature. On the basis of temperature, world can be delineated into 'hot', 'warm', 'cool', 'cold' and 'frigid' or 'permafrost' climates. The availability of data of daily minimum and maximum temperatures and monthly and annual means for many decades at thousands of observing stations located all over the world has been an important factor in favouring the use of temperature as criterion for climatic classification. A comparison of annual temperature cycles for different parts of the globe helps in the identification of a number of distinctive types, which can be called 'thermal regimes'. Thermal regimes can be used to classify climates. For instance, in the equatorial regime temperature remains around 27°C throughout the year but in the tropical continental regime it ranges from very hot summer season to mild winter season. The thermal regimes easily distinguish 'continental climate' from 'marine climate'.

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Like temperature, precipitation statistics are also abundantly available for long periods for thousands of observing stations widely distributed over the globe. That is why the monthly and annual precipitation data make the cornerstone of most of the widely used climatic classifications. Climates based on rainfall can be defined as 'wet', 'humid', 'sub-humid', 'semi-arid' and 'arid' climates. The annual precipitation is a useful variable in highlighting the characteristics of a climate type but it can be a misleading statistic because there are well established seasonal cycles of precipitation. The presence of dry and wet seasons instead of a uniform distribution of precipitation throughout the year has great impact on natural vegetation and crops. Further, it also matters whether the wet season coincides with a season of high temperature or with a season of lower temperature because vegetation needs both heat and moisture.

Thornthwaite in his climatic classification (1931) used the criteria of thermal efficiency and precipitation effectiveness. Keeping in view the significance of temperature in vegetation growth, Thornthwaite introduced an index of thermal efficiency. It is expressed by the positive departure of monthly mean temperature from the freezing point. Precipitation Effectiveness is the amount of precipitation which is actually available for the growth of natural vegetation. It is also known as precipitation efficiency. It is a function of precipitation and evaporation. In 1948, Thornthwaite proposed a new classification of climates with a number of modifications in criteria. In this classification, he developed and introduced the concept of potential evapotranspiration. Potential evapotranspiration is an index of thermal efficiency and water loss. It represents the amount of moisture that would be transferred to the atmosphere by evaporation of liquid or solid water plus transpiration from plants.

So it can be inferred from the above study that two main elements of climate viz. temperature and precipitation affect vegetation of a particular region. The vegetation is a true reflection of climate. Therefore by determining and identifying particular vegetation the type of climate can be inferred. In genetic climate classification, winds and air masses have also been used as bases of classification. Global patterns of precipitation are related to air mass source regions and prevailing movements of air masses.

B. Significance of Climatic Classifcation

Climatic classifications deal not only in describing the natural environment but also in framing land use planning. This role is particularly crucial in guiding the progress of developing nations as they seek to augment inadequate food resources and to achieve the goal of sustainable development. For instance, in India, the Planning Commission introduced the concept of Agro-climatic zones to achieve the goals of food security and sustainable development.

Climatic classification is a means to replace the multiplicity of atmospheric conditions over the globe in meaningfully organized units. As mentioned earlier, it helps in comprehending the diversity in the distribution of basic elements of climate over globe and also reflects their relationships with other aspects such as soils, landforms, plants and animals. This way climatic classification has significance not only for geographers but also for scientists and planners having research interests in physical environment, soils, plant and animals. It also enables the scholars to predict the climatic conditions of an area by correlating vegetation, soil, landform and animal life of the area with climatic elements.

So, no single classification scheme has been able to classify climates satisfactorily. As a result, different schemes have been developed. The most widely known scheme is the climatic classification of Koeppen which you will study in the next section.

SAQ 2

What are the most commonly used bases of climatic classification?

Spend 5 mins

14.4 KOEPPEN'S CLASSIFICATION OF CLIMATES

In 1900, German botanist and climatologist Wladimir Koppen (1846-1940) presented his first scheme of climatic classification which was based on the vegetation classification of a French plant physiologist A. deCandolle (1874). Koeppen revised his scheme in 1918 by giving more weightage to the monthly and annual averages of temperature and precipitation and their seasonal distribution. In 1931 Koeppen represented the world map of climatic classification. In 1936 Koeppen and his student Geiger published updated maps of world climate at continental levels. However, a further modified version of the classification was published in 1953 known as Koeppen-Geiger-Pohl classification of world climate.

Koeppen believed that vegetation type of an area is the best expression of totality of climate. His climatic classification is based on annual and monthly means of temperature and precipitation and also seasonal distribution of precipitation. He gave weightage to ratio of precipitation and temperature in a single formation i.e. application of the concept of precipitation effectiveness. It is quantitative as well as empirical classification of climate.

The Koeppen system recognised five major categories of climate and each category is designated by a capital letter as listed below in Table 14.1.

Table 14.1 Broad Climatic Types of Koeppen

Letter Symbol	Climate Type	Associated Vegetation
A –	Tropical Rainy Climates	Megatherms
B –	Dry Climates	Xerophytes
C –	Humid Mesothermal Climates or Warm Temperate Rainy Climates	Mesotherms
D –	Humid Microthermal Climates or Cold Forest Climates	Microtherms
E –	Polar Climates	Hekistotherms

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It is worth noting that four (A, C, D and E) of the above mentioned five groups are based on mean monthly temperature of warmest and coldest months, whereas B is based on precipitation-evaporation ratio. Koppen has further divided these 5 major climatic types into sub-types on the basis of seasonal distribution of precipitation, level of aridity and seasonal characteristics of temperature. Now let us get acquainted with these types and subtypes.

14.4.1 A-Tropical Rainy Climates

In tropical rainy climates the temperature of the coldest month is above 18° C. It means temperature remains above 18°C throughout the year. This climate type is associated with tropical rainforest or megatherms. Megatherms are plants which depend on high temperature and humidity throughout the year. The climate is humid because rainfall is always in excess of evaporation. On the basis of precipitation regime or seasonal distribution of precipitation this climate type has been further sub-divided into the following four types:

i) **Af**- This is the tropical wet or rainforest climate or tropical humid climate where precipitation in the driest month is 6 cm or more. The seasonal distribution of precipitation is almost uniform throughout the year. The annual and diurnal range of temperature is very low. There is no dry season.

ii) **Aw-** This is the tropical wet and dry climate also known as tropical savanna. It is characterised by wet summer and dry winter. Here the precipitation of at least one month is less than 6 cm. High temperature conditions prevail throughout the year.

iii) **Am-** This is the tropical monsoon climate and is supposed to be the intermediate between Af and Aw. It resembles Af in annual amount of precipitation and Aw in seasonal distribution of precipitation. Like Aw the precipitation of at least one month is less than 6 cm. This climate has short dry season but the total amount of precipitation is sufficient to support dense forests. The boundary between Aw and Am climates is demarcated on the basis of annual precipitation and precipitation of the driest month on the basis of the following formula:

$$a = 10 - R/25$$

Where, a = precipitation of the driest month

R = annual precipitation in cm

If the precipitation of the driest month is less than the value of a, it will be Aw climate, if it is equal or more than the value of a, it will be Am climate. For example, when the annual rainfall is 200 cm, then according to the above formula “a” is 2 cm. So if the precipitation of the driest month is less than 2 cm then it is Aw and equal or more than 2 cm it is Am climate. However, the precipitation of driest month should be less than 6 cm, otherwise it would be Af climate.

iv) **As**- This is the tropical dry summer climate, which is rarely found. However, in India it is present in coastal Tamil Nadu, where summers are dry and rainfall takes place mainly in winter.

Koeppen has further identified finer details in A climates by using the following lower case (small) letters with their meanings:

w' – maximum precipitation in autumn.

w'' – two seasons of maximum precipitation separated by two dry seasons.

s – dry summers.

i – range of temperature of coldest and warmest months less than 5°C.

g – Ganga type, where hottest month is preceding the summer rainy season.

14.4.2 B-Dry Climates

Dry climates are characterised by excess of evaporation over precipitation. In these climates precipitation is not sufficient to maintain permanent stable groundwater table. The boundary between the dry and humid climates is delineated on the basis of the following formulas:

a) $R < 2T + 28$, when 70 per cent or more of precipitation occurs in 6 warmer months.

b) $R < 2T$, when 70 per cent or more of precipitation occurs in 6 cooler months.

c) $R < 2T + 14$, when neither half year has 70 per cent or more of precipitation.

Where, R is average annual precipitation in cm and T is average annual temperature in °C.

This way, for dry climates Koeppen applied the criterion of precipitation effectiveness. The effectiveness of precipitation in providing moisture to the ground for plants depends not only on amount of precipitation but also on the rate of evaporation, which in turn varies directly with temperature. For instance, if 30 cm rainfall takes place in three summer months at one place and same amount in three winter months at another place, as evaporation will be higher in summer season the effectiveness of precipitation (availability of moisture for plant growth) will be higher at second location. To determine this, Koeppen used average annual precipitation, average annual temperature and seasonal distribution of precipitation as variables. For example, if a place X has average annual precipitation (R) 40 cm, average annual temperature (T) 15°C and 80 per cent of precipitation takes place in warmer six months, in this situation applying the formula $R < 2T + 28$, we get the value as $40 < 58$.

This means that precipitation is less than evaporation, that is the place X has B or Dry Climate.

On the basis of levels of aridity, Koeppen further sub-divided B climates into BW and BS. BW is arid climate and BS is semi-arid climate. When R (in the above equations) is less than half of upper limit for B, the climate is BW and when R is more than half of upper limit for B, the climate is BS. Let us understand this with the help of an example.

In the above example, the place X has B climate and it is B type till the precipitation is less than 58 cm. Therefore, in this example the upper limit for B is 58 and half of it is 29. As R (40) is more than half (29) of upper limit (58) for B, the climate of place X is BS i.e. semi-arid. If the R at this place would have been say 25 cm then it would have been BW or arid climate because R(25) in that case would be less than half (29) of upper limit for B which is 58.

For identifying further details in B climates Koeppen used following letters:

h (hiess or hot) = average annual temperature over 18°C.

k (kalt or cold) = average annual temperature below 18°C.

k' = temperature of the warmest month below 18°C.

s = summer drought, that is, at least three times as much rain in wettest winter month as in driest summer month.

w = winter drought, at least ten times as much rain in the wettest summer months as in the driest winter month.

n (nebel) = frequent fog.

Koeppen identified the following sub-divisions of B climates on the basis of criteria suggested above as:

i) BWh – Tropical Desert Climate.
ii) BSh – Tropical Steppe Climate.
iii) BWk – Mid-latitude Cold Desert Climate.
iv) BSk – Mid-latitude Cold Steppe Climate.
v) BWn and (vi) BSn climates are usually found along coastal lands associated with cold ocean currents.

14.4.3 C-Humid Mesothermal or Warm Temperate Rainy Climates

Here the average temperature of the coldest month is above - 3°C but below 18°C and average temperature of the warmest month is above 10°C. On the basis of seasonal distribution of rainfall, these climates are divided into three major climate types with the help of the following three letters:

- f = no dry season
- w = dry season in winter; and
- s = dry season in summer

Hence, the climate types for C are as follows:

i) **Cf-** This climate is characterised by precipitation throughout the year and driest month of summer season receives more than 3 cm rainfall. This climate represents the Western European type of climate. It is further divided into two second order sub-divisions as Cfa (Humid Subtropical) and Cfb (Marine West Coast type).

These minor details in C – climate were identified by Koeppen by using the following small explanatory letters:

a = Warm summer; average temperature of the warmest month > 22°C; at least four months above 10°C.

b = Cool summer, average temperature of the warmest month is < 22°C; at least four months above 10°C.

c = Cool short summer; average temperature of the warmest month < 22°C; at least one to three months above 10°C.

x = rainfall maximum in late spring or early summer, drier in late summer.

i, n, g = same meaning as in A and B climates.

ii) **Cw-** This climate is characterised by dry winter. The wettest month of summer season receives at least ten times as much rain as the driest month of winter season. Seventy per cent or more of the average annual precipitation is received in the six warmer months. This type of climate prevails in southern China.

iii) **Cs**- This is the warm temperate climate characterised by dry summer. It has three times more precipitation in the wettest month of winter season than the driest month of summer season. The driest month of summer season receives less than 3 cm rainfall. It represents Mediterranean type of climate.

14.4.4 D-Humid Microthermal or Cold Snow Forest or Humid Cold Climates

Here the average temperature of coldest month is below - 3°C and the warmest month average temperature is above 10°C. The ground surface remains covered with snow for several months of a year. This climate is divided into following two categories:

i) Df- This is the humid cold climate where there is no dry season. It is further divided in (a) Dfa - long warm summers, continental, (b) Dfb - short cool summer, subarctic.

ii) Dw- This is the humid cold climate with dry winters. It is further divided into (a) Dwa- continental climate with long cool summer, (b) Dwb- cool short summer (sub-arctic type), (c) Dwc- cold winters, and (d) Dwd- average temperature of the coldest month is below -38°C.

14.4.5 E–Polar Climates

The average temperature of the warmest month is less than 10°C. It is further divided into ET and EF:

i) ET – This is the tundra climate, where average temperature of the warmest month is below 10°C but above 0°C. The length of growing season is very short and vegetative cover is limited and scattered,

ii) EF – Perpetual Frost or Permafrost: the average temperature of the warmest month is below 0°C. It is represented by permanent ice caps without vegetation.

Now let us have a quick recap of Koppen's classification of climates with the help of Table 14.2.

Table 14.2: Koeppen's System of Climatic Classification

Letter Symbol			Precipitation and temperature
1st Order	**2nd Order**	**3rd Order**	
A			Average temperature of the coldest month is 18°C or above.
	f		Moist; Every month has 6 cm of precipitation or more; no dry season
	m		Short dry season in monsoon type of precipitation; driest month < than 6 cm but equal to or more than 10-R/25 (R is annual precipitation in cm)
	w		Well-defined winter dry season; precipitation in driest month < than 10-R/25.
	s		Well-defined summer dry season(rare distribution)
B			Potential evaporation exceeds precipitation. It is identified on the basis of average annual precipitation (R), average annual temperature (T) and seasonal distribution of precipitation in following manner:(i) R<2T+28, when 70 % or more of precipitation occurs in 6 warmer months.(ii) R<2T, when 70 % or more of precipitation occurs in 6 cooler months.(iii) R<2T+14, when neither half year has 70 % or more of precipitation.
	S		When R is more than ½ of the upper limit for B.
	W		When R is less than ½ of the upper limit for B.
		h	Average annual temperature is 18°C or above.
		k	Average annual temperature is less than 18°C.
C			Average temperature of the coldest month is < than 18°C and above -3°C; average temperature of the warmest month is greater than 10°C.
	w		At least ten times as much rain in the wettest month as in the driest winter month; precipitation in driest summer month < than 4 cm.
	s		At least three times as much rain in wettest winter month as in the driest summer months; precipitation in driest summer month < than 3 cm.
	f		Precipitation throughout the year and no dry season. Difference between the rainiest and driest months is less than that for w and s and the driest month of summer receives > 3 cm rainfall.

Letter Symbol			Precipitation and temperature
1st Order	2nd Order	3rd Order	
		a	Hot summer; average temperature of the warmest month > 22°C; at least four months above 10°C.
		b	Cool summer; average temperature of the warmest month < 22°C; at least four months above 10°C.
		c	Cool short summer; average temperature of the warmest month < 22°C; at least one to three months above 10°C.
D			Average temperature of coldest month is – 3°C or below; average temperature of warmest month is greater than 10°C.
	s,w,f		Same as under C.
		a,b,c,d	Same as under C.
E			Average temperature of the coldest month is – 38°C or below. Average temperature of warmest month is below 10°C.
	T		Average temperature of warmest month is between 0°C and 10°C.
	F		Average temperature of warmest month is 0°C or below.

Now let us assess the Koeppen's climatic classification in the next section.

14.5 EVALUATION OF KOEPPEN'S CLIMATIC CLASSIFICATION

Koppen's classification of climates is most widely and frequently used classification system. It is based on temperature and precipitation statistics which are measurable and most effective in determining climate. As it is based on statistical parameters the climatic regions have precise boundaries. In determining the B or dry climates Koeppen applied the concept of precipitation effectiveness by establishing relationship between heat and moisture. It is more appealing to geographers because due consideration has been given to interrelationship that exists between vegetation and climate.

As Koeppen's climatic classification is based on vegetation classification of A. de Candolle, the climatic boundaries match with vegetation boundaries. For instance, the 18°C average temperature of the coldest month separates A-Climates from C-Climates. This value is selected because certain sensitive tropical plants do not survive when the monthly temperature is below 18°C. The megatherms realm of plants is associated with high temperature and high precipitation. Likewise, the 10°C isotherm for the warmest month not only shows the southern boundary of the Tundra region but it also represents the northward or poleward limit of tree growth. As this classification shows well established association of vegetation with climate it becomes more appealing to geographers.

The Koeppen's classification of climates is very useful for geographers because it is descriptive and generalised. As it is based on shorthand code of letters for the climate types, the repetition of descriptive terms is easily avoided. The use of symbols and representation of climatic types on map further increases its utility for geographers. This classification is so simple and detailed that it is most frequently used at all educational levels i.e. from school to research levels.

Despite many revisions and modifications there are certain limitations of this classification. As it is based on mean monthly temperature and precipitation values it fails to highlight the variations over time in one locality or region and makes comparison of one locality with another difficult. Further, Koeppen ignored the role of weather elements such as winds, atmospheric pressure, cloudiness, air masses and cyclones etc. This way it is empirical but not genetic classification as causative factors were ignored totally.

Koeppen applied the same formula for highlands and lowlands. As a result many errors surfaced in his classification of climates. Though he believed that vegetation is the true reflection of climate but in his scheme it is difficult to analyse and explain the presence of different types of vegetation in the same climatic region and same type of vegetation in different climatic regions. However, in-spite of drawbacks and limitations of classification of climates propounded by Koeppen, this scheme is still held in high esteem and widely used.

Spend 5 mins

SAQ 3

What are the criteria and classes of Koppen's Dry climates?

14.6 SUMMARY

A climatic class or region represents a homogenous set of climatic conditions. Climatic classification is essential for identification, mapping and description of climatic classes or regions. Climatic classification helps in generalisation and simplification of diverse atmospheric conditions prevailing in different parts of the earth surface. The major challenge in the process of climatic classification is that climate is a complex of elements such as insolation, temperature, precipitation, winds and pressure belts, cloud cover, fronts and cyclones etc. Therefore, any classification based on limited elements would fail to represent the reality. Also the inclusion of a large number of dynamic elements would make it too complex. The most commonly used criteria for climatic classification are temperature, precipitation and vegetation.

Koeppen used mean monthly temperature of the warmest and coldest months, mean annual temperature, mean annual precipitation, seasonal distribution of precipitation and precipitation-evaporation ratio for climatic classification. Koeppen's climatic classification is quantitative and generalised. It is very popular in geography due to its simplicity, clarity and practical utility. Koeppen's climatic classification is preferred for macro level understanding and comparisons. His classification system tries to identify the major types of climates prevailing on the earth's surface. It establishes relationships among the various climate types present in the classification. It provides a hierarchical framework from marco to micro levels.

14.7 TERMINAL QUESTIONS

1. Discuss the significance of classification of climates?
2. Discuss Koppen's climatic classification?
3. Critically evaluate the Koppen's classification of climates?

14.8 ANSWERS

Self-Assesment Questions

1. The goal of climatic classification is to bring order to large and diverse information. By organising similar entities together into groups that are different from other groups by specific attributes an order is generated out of complexity. The different approaches for classification are – empirical, genetic and applied. The empirical approach of climatic classification is based on observed data of climatic elements like temperature, precipitation, humidity and response of vegetation, soil formation etc. Genetic approach emphasises on the causative factors–like insolation, winds, atmospheric pressure, fronts, jet streams, cyclones and air masses. Applied approach is also known as technical or functional approach. It is based on the functional impact of climate on other phenomena like correlation of vegetation with temperature, precipitation and moisture.

2. The most commonly used bases for climatic classification are temperature, precipitation and vegetation. The ancient Greeks classified the world climates into three zones, that is, tropical (torrid), temperate and polar (frigid) zones on the basis of angle of sun's rays or latitude and temperature. On the basis of temperature, world can be delineated into 'hot', 'warm', 'cool', 'cold' and 'frigid' or 'permafrost' climates. The annual precipitation is a useful variable in highlighting the characteristics of a climate type. Climates based on rainfall can be defined as 'wet', 'humid', 'sub-humid', 'semi-arid' and 'arid' climates.

   These two elements of climate viz. temperature and precipitation affect vegetation of a particular region. The vegetation is a true reflection of climate. Therefore by determining and identifying particular vegetation the type of climate can be inferred. In genetic climate classification winds and air masses have also been used as bases of classification. Global patterns of precipitation are related to air mass source regions and prevailing movements of air masses.

3. According to Koeppen, dry climates are characterised by excess of evaporation over precipitation. The criteria he adopted for dry climates was of precipitation effectiveness which depends not only on precipitation but also on the rate of evaporation which is directly associated with temperature. He used the criteria of average annual precipitation, average annual temperature and seasonal distribution of precipitation to identify dry climates. On the basis of levels of aridity, Koppen further sub-divided B climates into BW and BS. BW is arid climate and BS is semi-arid climate. The B or dry climates were further subdivided on the basis of average annual temperature into hot (*h*) and cold (*k*) climates.

Terminal Questions

1. Bring out the significance of climatic classification in terms of land use planning or how it could serve in implementation of governmental plans as given in Sec. 14.3 B of this unit.
2. Discuss the five major categories of climates as given by Koeppen. It is a long answer so you must also describe the sub-divisions of all the categories as in Sec. 14.4 of this unit.
3. Start your answer by giving the merits of Koeppen's climate and then discus some limitations of the classification as in Sec. 14.5 of this unit.

14.9 REFERENCES/FURTHER READING

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GLOSSARY

Advection : Transfer of heat from a locality to another by winds.

Aerosols : Solid or liquid particles suspended or dispersed in a gas.

Albedo : Reflecting power of a surface.

Diurnal Range of Temperature : Difference between maximum and minimum temperature of a day.

Doldrums and ITCZ : The Inter Tropical Convergence Zone (ITCZ) is also called doldrums, a low pressure area extending around the equator. Here North East trade winds and South East trade winds coming from subtropical high pressure belts converge. This convergence causes lifting up of air due to convective impact. However the entire volume is not uplifted. Some winds converge to form equatorial westerlies which blow from west to east along ITCZ.

Dry climate : It represents the condition where evaporation exceeds precipitation.

Evapotrans-piration : It is the combined loss through evaporation from the soil surface and transpiration from plants.

Genetic classification : It is a classification based on causative factors.

Heat Budget : The balance between the amount of insolation and outgoing terrestrial radiation.

Heterosphere : The atmosphere above 90km where its composition is not uniform and is rarefied and different gases are arranged in concentric layers on the basis of their atomic weights.

Homosphere : The atmosphere upto about 90km in which the proportionality of the principal gaseous constituents such as oxygen and nitrogen is constant because of thorough mixing.

Horse Latitudes : Horse latitudes are sub-tropical highs or the zone of calms falling between 30°and 35° north and south of Equator. Cargoes carrying horses during olden times found it difficult to sail through this zone. Hence they used to throw their horses into the ocean to make the vessel lighter and able to sail.

Isobar : An imaginary line on a map connecting places of equal atmospheric pressure reduced to sea level.

Isotherm : An imaginary line on a map joining places having equal temperature, reduced to mean sea-level.

Mean Daily Temperature : An average of highest and lowest temperatures recorded during 24 hours.

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Meteorology	:	Meteorology is the study dealing with the physical phenomena of the atmosphere at lower reaches and is concerned with day-to- day atmospheric conditions and their causes.
Normal Lapse Rate	:	It is related to the decrease in temperature in troposphere at a uniform rate of 6.5°C for every 1 km of ascent.
Photochemical Smog	:	Emission from cars, industrial emissions, domestic fossil fuel burning, reacts in the atmosphere with sunlight. It combines with other emissions to form photochemical smog. This is a type of air pollution.
Precipitation effectiveness	:	It is the amount of precipitation which is really available for plant growth. It is a function of precipitation and evaporation.
Thermal Equator	:	Imaginary line drawn on a map by connecting places that have the highest mean temperature for any particular period.
Thermal efficiency	:	It is function of temperature and is expressed by positive departure of monthly mean temperatures from the freezing point.