UNIT 1 ATMOSPHERIC STRUCTURE AND COMPOSITION

Structure

1.1 INTRODUCTION

Weather and climate have a profound influence on life on earth. They affect landforms, soil types and vegetation. They are part of the daily experience of human beings and are essential for their health, food production and wellbeing. The mental alertness, physical characteristics and even social differences, when closely examined, have at least some relationship with climate. There are many causes of climate change. Many are natural and involve processes which influence the flows of energy into, out of and within the climate system. However, concern has grown that man's activities may be affecting these processes, thus also affecting climate. If one wishes to understand, detect and eventually predict the human influence on climate, one needs to understand the system that determines the climate of the earth and the processes that lead to climate change. Through this unit, we would be discussing the difference between weather and climate; composition of the atmosphere. This unit will give you an overview of vertical structure of the atmosphere.

1.2 OBJECTIVES

After studying this unit, you should be able to:

- Identify the difference between weather and climate;

- Explain the composition of the atmosphere;
- Explain the vertical structure of the atmosphere.

1.3 WEATHER AND CLIMATE

The term "climate" should not be confused with "weather". We don't hear people saying that the climate of the day is warm or cold, but we do talk of warm weather, a cold morning, a sunny afternoon, a rainy day or a chilly night.

Weather comprises the day to day conditions of the atmosphere at any place as regards temperature, rainfall, winds, humidity, sunshine, cloudiness and such other elements. It is never static and thus cannot be generalized. It may be sunny in one part of the district, but raining heavily a few miles away. It is important to realize that any place can be subjected to haphazard changes in weather at any time.

Climate is generally defined as the average state of the weather patterns over an area. The elements to be considered are the same while studying the climate or weather conditions of a place, but climate considers these over a longer period of time. Weather records of a minimum period of 35 years are needed to obtain reliable averages.

Both weather and climate are affected by such things as directness of the sun's rays, length of day, altitude, distribution of land and water bodies, direction of mountain ranges, air pressure, winds and ocean currents.

1.4 CLIMATE

1.4.1 Elements of Climate

The main elements of climate are temperature; pressure; winds; and rainfall. All these elements are highly variable and constitute the weather or climate. They are closely interrelated and a change in one of these elements generally brings about changes in the others. The different climates on earth are produced by different combinations of these four elements. The variations in climate are largely the result of variations in the amount, intensity and distribution of these elements over the earth. In the study of climate, the main consideration is with the average occurrence of the various elements, their interrelationships and how they affect the environment.

1.4.2 Climate Controls

The variations of the weather or climate elements are both temporal and spatial. The important climatic controls are latitude, distribution of land and water, altitude, semi-permanent high and low pressure systems, winds and air masses, atmospheric disturbances or storms, ocean currents and mountain barriers. Further, there are certain other climatic factors such as distance from the sea, relief, type and colour of soil and natural vegetation, which affect the climate in no less significant way.

1.4.3 Climate Components

Our earth is habitable and hospitable due to the favourable climatic condition brought about by the interaction among different components of climate system. The United Nation Framework Convention on Climate Change (UNFCCC)

defined the climate system as the totality of the atmosphere, hydrosphere, biosphere and geosphere and their interactions. The earth's atmosphere is a gaseous blanket held by the earth due to its gravitational attraction. The atmosphere has evolved since the formation of earth and now it is nitrogen and oxygen rich gaseous blanket. The water vapour, trace gases and particulates present in the atmosphere are primarily responsible for the weather phenomena that are observed in the troposphere. In the troposphere, the various atmospheric properties are subject to large-scale turbulence and mixing. The atmospheric phenomena occurring in the troposphere of the atmosphere primarily influence many of the human activities.

1.5 CLIMATE - GLOBAL, REGIONAL AND LOCAL

(a) Global Climate

The term "Global Climate" is used to refer to the general state of the world's climate. For specific purposes, such as investigating the evidence for climate change, climatologists like to study the general climate of the whole earth. Global climate is fundamentally influenced by the amount of energy, the earth receives from the sun. It also influences how that energy is stored and redistributed through the world's atmosphere and oceans. The position of the world's continents and large mountain ranges also affect global climate. Greenhouse gases in the atmosphere trap a lot of heat which would otherwise escape to space, keeping the earth warmer than it would otherwise be.

Today, the global average surface temperature is about 15^{o}C. During the ice age, global average surface temperature was 5^{o}C lower than the present global average surface temperature. "*Human activities are estimated to have caused approximately 1.0°C of global warming above pre-industrial levels, with a likely range of 0.8°C to 1.2°C. Global warming is likely to reach 1.5°C between 2030 and 2052 if it continues to increase at the current rate. Warming from anthropogenic emissions from the pre-industrial period to the present will persist for centuries to millennia and will continue to cause further long-term changes in the climate system, such as sea level rise, with associated impacts*" (IPCC 2018)**.** It is reported that "*the risks related to droughts are indeed higher at 2°C compared to 1.5°C of global warming in some regions of the world. As regards the rainfall, the heavy precipitation when aggregated at global scale is projected to be higher at 2°C than at 1.5°C of global warming. As a consequence of heavy precipitation, the fraction of the global land area affected by flood hazards is projected to be larger at 2°C compared to 1.5°C of global warming*" (IPCC 2018). It is alarming that it is projected to rise a further 2 to 3^{o}C by the end of the 21st century.

(b) Regional Climates

Regional climates are patterns of weather that affect a significant geographical area. They indeed influence much greater area than that of local climatic effects such as sea breezes but much smaller than the global climate of the whole earth. Sometimes, regional climates may be identified on account of special features which distinguish them from other patterns of climate.

The Indian Monsoon is an example of a distinctive regional climate. Dry for much of the year, when northeast trade winds blow, airflow reverses in the summer and the South westerly monsoon brings months of prolonged rain to India and South East Asia. Much further to the north, far from the influence of the Indian Ocean, the air becomes much drier.

Some countries are large enough to experience a full range of regional climatic patterns. Australia for example has a tropical north and North-west and a sub-tropical desert interior. Mediterranean climate is experienced in the southeastern part of the country with warm summers but fairly chilly winters.

(c) Local Climate

Local climate describe those climate which have influence over a very small geographical area. This might only be a few miles or tens of miles across. Under certain conditions, local climatic effects influence the general pattern of regional climate. Examples of local climate include land and sea breezes, the orographic effects of mountains and "heat island" effect of cities.

Cities contain a lot of concrete structure, like buildings, which soak up sunlight during the day. At night they release this heat, which warms urban areas several degrees Celsius above the nearby rural areas. This phenomenon is called the urban heat island effect.

Check Your Progress 1

Note: 1) Use the space given below for your answers.
2) Check your answers with those given at the end of this unit.

1. What are the differences between weather and climate?

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2. What are the elements of climate? What are the factors that control climate and how?

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3. Explain global, regional and local climate.

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1.6 THE ATMOSPHERE

The atmosphere is as much a part of the earth as land or water, although we may not feel it, except where it moves as wind. It is not as dense as either land or water but it has weight and exerts pressure. The atmosphere is mobile, elastic and both compressible and expansible. Held to the earth by gravitational attraction, this envelope is densest at sea level and thins rapidly as we move upward.

Box 1.1 : Nature of Atmosphere

The earth's atmosphere is the most critical component of climate system. The atmosphere is a mixture of gases held to the earth due to gravitational attraction. The atmospheric composition is not absolutely constant, as it varies in time and space. The main component gases of dry air by volume are nitrogen (78.01%), oxygen (20.9%), Argon (0.93%) and carbon dioxide (0.04%). Less than 1% of air consisting of carbon dioxide, methane, nitrous oxide, ozone, particulate matter is responsible for global climate change and stratospheric ozone depletion. The lower atmosphere where the chemical composition of atmosphere is uniform is called homosphere. In the lower atmosphere, due to constant mixing and turbulence, the lighter gases are unable to separate to form individual layers. On the other hand, at heights more than 100 km (heterosphere), due to the absence of mixing and turbulence, the atmospheric gases separate to form concentric layers like nitrogen layer (100 - 200 km), oxygen layer (200 - 1100 km) and helium layer (1100 - 3500 km). The atmosphere of the earth helps in the existence of life on earth by obstructing the harmful ultra-violet radiation, providing oxygen and carbon dioxide for the living organisms and livable environment. The earth's surface temperature of about 15^0C is due to the presence of radiatively active gases in the atmosphere.

Source: Oliver and Hidore, 2011

1.6.1 Composition of the Atmosphere

The atmosphere is a mixture of many gases. It also contains a large number of solids and liquid particles, collectively called aerosols. Some of the gases, which may be regarded as permanent components of the atmosphere, are present in a fixed proportion to the total gas volume. Other constituents vary in quantity from place to place and from time to time.

Table 1.1: Principal gases comprising dry air in the lower atmosphere

Constituent	Per cent by volume	Constituent	Per cent by volume
Nitrogen (N_2)	78.008	Ozone (O_2)	0.00006
Oxygen (O_2)	20.94	Hydrogen (H_2)	0.00005
Argon (Ar)	0.93	Krypton (Kr)	Trace
Carbon dioxide (CO_2)	0.03	Xenon (X_2)	Trace
Neon (Ne)	0.0018	Methane (Me)	Trace
Helium (He)	0.00015		

As shown in the table 1.1, two gases nitrogen and oxygen make up about 99 percent of the clean dry air. The remaining gases are mostly inert and constitute about 1 percent of the atmosphere. About 21 percent of it consists of oxygen which helps in burning and heating and without which we cannot live. The bulk of the atmosphere is made up of an inert gas, nitrogen which dilutes the oxygen and slows down the process of oxidation.

There is a small amount of carbon dioxide which the plants utilize during the process of photosynthesis. It is transparent to the incoming solar radiation but opaque to the outgoing terrestrial radiation. It absorbs a part of terrestrial radiation and reflects back some part of it towards the earth's surface. It is largely responsible for the greenhouse effect. This gas absorbs heat and thus allows the lower atmosphere to be warmed by heat radiation coming from the sun and from the earth's surface. It is heaviest of all the gases of atmosphere; therefore the lower layer of atmosphere contains much more CO_2 than the upper layers.

Ozone is another important gaseous component of the atmosphere found between 10 and 50 km above the earth's surface. It acts as a filter and absorbs the ultra-violet rays radiating from the sun and prevents them from reaching the surface of earth.

There are also traces of argon, ammonia and water vapour. The percentage of these gases varies slightly in different parts of the earth. For example, the variable water content of the atmosphere in different areas ensures that we have such great contrasts in weather and climate over different parts of the world. Dust particles are generally concentrated in the lower layers of the atmosphere. Dust and salt particles act as hygroscopic nuclei around which water vapour condenses to produce clouds.

The properties of the air that is important in climatology are pressure, temperature, and volume or density. Pressure (p) of the atmosphere at any level is defined as the "weight of the overlying column of air per unit area of the surface at that level". It varies across the earth's surface and also with altitude. Further, in the tropical regions, there occurs a distinct diurnal and seasonal variation of pressure. The density of the air is deûned as "it's mass per unit volume and expressed in units of grams per cubic centimetre or kilograms per cubic metre". Like barometric pressure, temperature and density of the air varies in time and space.

1.6.2 Structure of the Atmosphere

The vertical structure of the atmosphere encompasses different layers with different atmospheric characteristics particularly with respect to the climate variables like temperature and density. Density of the air is indeed highest near the surface of the earth and it gradually decreases with increasing height. In other words, the air is rarefied in higher altitudes. Further, the atmospheric column can be studied by dividing it into different layers based on the temperature characteristics. The vertical structure of the atmosphere is divided into layers namely troposphere, stratosphere, mesosphere, thermosphere and exosphere.

The lowermost layer of the atmosphere is called as troposphere. The average height of the troposphere is about 13 km, varying from 18 km at the equator and 8 km at the poles. This layer contains about 75 per cent of the mass

of the atmosphere. Further, the phenomena of weather and climate occur in this layer. The atmospheric temperature in this layer decreases at the rate of 1ºC for every 165m of height. This decrease in air temperature with altitude is because air is compressible and the density of the air decreases with altitude. Further, it must be noted that the atmosphere is heated due to the turbulent heat transfer from the earth's surface. Perhaps, this layer is important from the perspective of biological life and activity. The zone between the troposphere and the stratosphere is called as the tropopause, wherein the air temperature is about minus 45ºC over the poles. The air temperature in the tropopause is nearly constant. The tropopause is essentially an inversion level.

The stratosphere indeed extends upward from the tropopause. It extends up to a height of 50 km. It accounts for about 10 percent of the total molecular mass of the atmosphere. Interestingly, stratosphere contains most of the total atmospheric ozone and the maximum temperature, however, occurs at the stratopause, which lies between the stratosphere and the mesosphere. One important feature of the stratosphere is that it contains the ozone layer. This layer absorbs harmful ultra-violet radiation from the Sun and shields life on the earth from intense and harmful forms of energy from the Sun. In the stratosphere, the density of the air is lower as compared to the air density in the troposphere layer. Because of the lower air density, even limited absorption leads to high temperature rise. As regards the stratosphere layer, the occurrence of the polar stratospheric clouds in the circumpolar low-pressure vortex at the poles are significant from the perspective of stratospheric ozone depletion. Nevertheless, to what extent the events and atmospheric processes occurring in the stratosphere are linked with the surface air temperature and turbulence in the troposphere falls under the emerging research areas.

The mesosphere layer extends above the stratosphere and the average temperature in this layer decreases with height. Lowest temperature of minus 130 ºC is observed at a height of 90 km above the earth surface. The pressure of the air in the mesosphere layer is low and it is about 0.01mb at 90 km. Just above 80 km, average air temperature start decreasing due to the presence of molecular oxygen and ozone, which absorbs heat. This zone is called mesopause. In this region, during the summer nights over high latitudes, noctilucent clouds are observed.

The thermosphere layer extends above the mesopause and the density of the air in this layer is extremely low. The lower portion of this layer is predominantly composed of nitrogen, molecular oxygen and atomic oxygen. Nevertheless, above 200 km, the atomic oxygen is more prevalent than the molecular and atomic nitrogen. The average air temperature rise with height in this layer, mainly due to the absorption of ultra-violet radiation by the molecular oxygen and atomic oxygen. Above 100 km from the earth's surface, the short wave radiation from the Sun causes ionization. For this reason, the ionosphere is the term normally applied to the layer above 80 km. This layer is known for the Aurora Borealis and Aurora Australis.

Further, the layer called exosphere lies between 500 km and 750 km. This layer is known for the presence of oxygen, hydrogen and helium atoms. The neutral helium and hydrogen atoms due to their low atomic weight escapes into the outer space. The frequency of the ionized particles indeed increase in the exosphere and in fact beyond 200 km, in the layer called magnetosphere, the occurrence of electrons and protons are more common.

1.7 CLIMATE CHANGE AND CLIMATE VARIABILITY

Climate change is referred to as a "*change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use*". Nevertheless, United Nations Framework Convention on Climate Change (UNFCCC), in its Article 1, defines climate change as "*a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods*". On the other hand, climate variability refers to "*variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events*". Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability). In fact, the UNFCCC makes a distinction between climate change attributable to human activities altering the atmospheric composition, and climate variability attributable to natural causes.

Check Your Progress 2

Note: 1) Use the space given below for your answers.
2) Check your answers with those given at the end of this unit.

1. What do you know about the vertical structure of the atmosphere?

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2. What are the differences between climate change and climate variability?

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1.8 LET US SUM UP

We have seen that climate is a complex system. It has various components which interact in multiple ways to produce the different climate zones of the world. These are again subject to influences at the regional and local

level. The earth maintains a constant temperature by a system of radiation balance whereby the energy received from the sun is balanced by heat reflected by earth. The atmosphere, hydrosphere and biosphere all play a crucial role in this process. It is an accepted fact that the earth's temperature is rising and the global climate seems to be showing some changes. The crucial question is why this is happening. Is this part of long term climate change or is it induced by human activities? It is believed that man is hastening this process and we need to understand the scope of these changes better. We have discussed in this unit about the differences between weather and climate; gaseous composition of the atmosphere; and vertical structure of the atmosphere.

1.9 KEYWORDS

Climate : Climate in a narrow sense is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years.

Climate System : The climate system is the highly complex system consisting of five major components: the atmosphere, the hydrosphere, the cryosphere, the lithosphere and the biosphere, and the interactions between them. The climate system evolves in time under the influence of its own internal dynamics and because of external forcings such as volcanic eruptions, solar variations and anthropogenic forcings such as the changing composition of the atmosphere and land use change.

Atmosphere : The gaseous envelope surrounding the earth. The dry atmosphere consists almost entirely of nitrogen (78.1% volume mixing ratio) and oxygen (20.9% volume mixing ratio), and a number of trace gases, such as argon (0.93% volume mixing ratio), helium and radiatively active greenhouse gases such as carbon dioxide and ozone.

Troposphere : The lowest part of the atmosphere, from the surface to about 10 km in altitude at mid-latitudes (ranging from 9 km at high latitudes to 16 km in the tropics on average), where clouds and weather phenomena occur. In the troposphere, temperatures generally decrease with height.

Stratosphere : The highly stratified region of the atmosphere above the troposphere extending from about 10 km (ranging from 9 km at high latitudes to 16 km in the tropics on average) to about 50 km altitude.

Climate Change : Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended

period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use.

Climate Variability : Climate variability refers to variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, etc.) of the climate on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).

1.10 SUGGESTED FURTHER READING/ REFERENCES

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Web Links

http://www.ipcc.ch/report/ar5/wg1/

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http://www.ipcc.ch/report/ar5/syr/

https://www.ipcc.ch/sr15/

https://www.globalchange.gov/climate-change/glossary

https://health2016.globalchange.gov/glossary-and-acronyms

1.11 ANSWERS TO CHECK YOUR PROGRESS

Check Your Progress 1

1. Weather and climate are different from the perspective of space and time.
    - Weather involves day to day conditions and it reflects the state of atmosphere on a small area.
    - Climate involves averages over a long period of time. It gives the conditions prevalent in that area.
2. The elements of climate are temperature, pressure, winds and rainfall.

- Variations of these four elements give rise to different kinds of climate.
- Other factors have a controlling effect- latitude, altitude, distribution of land and water, distance from the sea, ocean currents, high and low pressure systems that influence the direction and force of winds, mountain barriers that determine whether an area gets rain or remains in rain shadow.

3. Global climate is the climate prevalent in areas of the earth as a whole.
   - It is due to the directness of the sun's rays, the earth's rotation, and tilt of the earth's axis. It gives rise to equatorial, tropical and sub-tropical climatic zones
   - Regional climates are prevalent over large areas. They are due to regional factors such as development of high and low pressure zones, which gives rise to the Indian Monsoons, or nearness to the sea which gives rise to the Mediterranean climate
   - Local climates are prevalent over very limited areas. Urban heat island effect, or small areas with high temperature, is produced due to proximity to cities

Check Your Progress 2

1. The vertical structure of the atmosphere includes different layers with different atmospheric characteristics particularly with respect to the climate variables like temperature and density. The atmospheric column can be studied by dividing it into different layers based on the temperature characteristics. The vertical structure of the atmosphere is divided into layers namely troposphere, stratosphere, mesosphere, thermosphere and exosphere.

   The lowermost layer of the atmosphere is called as troposphere. The average height of the troposphere is about 13 km, varying from 18 km at the equator and 8 km at the poles. This layer contains about 75 per cent of the mass of the atmosphere. The atmospheric temperature in this layer decreases at the rate of 1ºC for every 165m of height. The atmosphere is heated due to the turbulent heat transfer from the earth's surface. The zone between the troposphere and the stratosphere is called as the tropopause, wherein the air temperature is about minus 45ºC over the poles. The tropopause is an inversion level. The air temperature in the tropopause is nearly constant.

   The stratosphere extends up to a height of 50 km. It accounts for about 10 percent of the total molecular mass of the atmosphere. It contains most of the total atmospheric ozone and the maximum temperature, nevertheless, occurs at the stratopause, which lies between the stratosphere and the mesosphere. Ozonosphere absorbs harmful ultra-violet radiation from the Sun and shields life on the earth from intense and harmful forms of energy from the Sun. The occurrence of the polar stratospheric clouds in the circumpolar low-pressure vortex at the poles in the stratosphere are important with respect to the depletion of stratospheric ozone.

   The mesosphere layer extends above the stratosphere and the average temperature in this layer decreases with height. Lowest temperature

of minus 130 ºC is observed at a height of 90 km above the earth surface. The pressure of the air in the mesosphere layer is about 0.01mb at 90 km. Just above 80 km, average air temperature start decreasing due to the presence of molecular oxygen and ozone, which absorbs heat. This zone is called mesopause.

The thermosphere layer which extends above the mesopause, is predominantly composed of nitrogen, molecular oxygen and atomic oxygen. The average air temperature rise with height in this layer, mainly due to the absorption of ultra-violet radiation by the molecular oxygen and atomic oxygen. Above 100 km from the earth's surface, the short wave radiation from the Sun causes ionization. Exosphere lies between 500 km and 750 km. This layer is predominantly composed of oxygen, hydrogen and helium atoms.

2. Climate change is referred to as a "change in the state of the climate that can be identified by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use". Climate variability refers to variations in the mean state and other statistics of the climate on all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).