MGG 005
CLIMATOLOGY

Indira Gandhi National Open University
School of Sciences

BLOCK
5

CONTEMPORARY ISSUES

BLOCK 5: CONTEMPORARY ISSUES

In the realm of contemporary issues Block 5 delves into pressing concerns demanding our attention and understanding. With a focus on Climate Change this block encompasses various facets crucial for comprehending and addressing this global challenge.

Unit 16 navigates through the Climate Change and Variability, exploring Climate Chronology, Evidences, and Theories.

Unit 17 scrutinises Human-Induced Climate Change, dissecting Atmospheric Pollution, Global Warming, and its myriad impacts while also delving into the crucial topic of Climate Change Adaptation and Mitigation Measures.

Unit 18 sheds light on Weather Forecasting, unravelling its Procedures, Tools, Methods, and its specific application in the context of India.

Unit 19 expands the horizon with Applied Climatology, examining the intricate relationships between Climate and Natural Systems such as Water and Biodiversity, as well as its profound impacts on Societal Systems encompassing Agriculture, Tourism, Housing, and Health.

After studying this block, you should be able to:

- analyse the historical chronology of climate change, evaluate various evidences supporting climate change theories, and articulate the complexities surrounding climate variability;
- identify different forms of atmospheric pollution contributing to climate change, understanding the mechanisms and impacts of global warming, and proposing effective adaptation and mitigation measures to address human-induced climate change;
- interpret weather forecasting procedures, utilise relevant tools and methods for predicting weather patterns, and apply weather forecasting techniques specifically in the context of India; and
- demonstrate an understanding of the interrelationships between climate and natural systems like water and biodiversity, as well as the implications of climate change on societal systems including agriculture, tourism, housing, and public health.

Our best wishes are with you in this endeavour.

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

MGG 005 CLIMATOLOGY

UNIT 16

CLIMATE CHANGE AND VARIABILITY

Structure

16.1 INTRODUCTION

In previous unit i.e., unit-15, you have learnt about climatic regions of the world. Now in Block 5 i.e. contemporary issues, you are going to study about climate change and its variability. Under this unit, we are going to discuss the topics chronology of climate end nous and theories of Climate Change in detail. Here, you are going to learn one of the special features of climatology. You all are acquainted with the term climate chronology and climate change. Have you ever been gone through this? How climate changes occur? What are the evidences? This and many more questions will haunt your mind. Therefore, in this unit you are going to acquaint with climate chronology and evidences and theories of climate change. These are the two basic and unique aspects of applied climatology. So, as a student of climatology it is compulsory to know about climate chronology and evidences and theories of climate change under climate change and variability.

Expected Learning Outcomes

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

- explain about climate chronology;
- discuss the causes and consequences of climate chronology;
- deal and explain about climate change;
- summarise about evidences of climate change; and
- describe theories regarding climate change.

Sanjay Kumar

16.2 CLIMATE CHRONOLOGY

Chronology term refers to the regular division of time. Here you are going to learn the chronology of climate through geological age. Geologist suggests that Azoic is the oldest and longest stage of the earth. The Greek word 'Azoic' itself means devoid of life. The temperature was very high during this period to sustain any life. The sun rays directly affected the earth/ mass. Therefore, its temperature enormously increased. Volcanic activity was very frequent, which emitted poisonous gasses and formed large clouds. There was no water. Over the time, situation changed due to formation and presence of water vapour. The water vapour is converted into water. After condensation, it was deposited as liquid water on the surface of the earth. The presence of hydrogen and oxygen in the water, combined with methane gas and the different gases emitted by volcanic lava, transformed the earth's original atmosphere of azoic era.

After Azoic, Paleozoic era started. The era was marked with drastic fluctuation in temperature. The earth crust fractured as continents broke apart and collided with each other. Volcanic activity has changed the composition of atmosphere. Temperatures rose to the beginning of the life rebounded with the start of Silurian period. Coral reefs and fish appeared in warm, shallow seas. Temperatures rose, creating varied climatic zones. The first land plants appeared in Ordovician period. During Devonian period (416 million years ago) temperatures again warmed and wetlands became drier so trees grew on land, while variety of fishes developed in the seas. Toward the end of the period (359 million years ago), ice built up over the southern polar region, causing sea levels to fall. This phenomenon was followed by the extinction of nearly 70 percent of marine life. On the other hand, temperature rose in northern hemisphere. At the initial phase of the Permian period marine habitats decreased, and the climate became dry as the two major continental masses moved closer and seas between them closed. According to the scientists, during formation of Appalachians and Ural Mountains (299 million years ago), volcanic eruption created huge mass of ash into the atmosphere. That condition blocked the sunlight and therefore, oxygen level and temperature fell down. Scientists said that, by 251 million years ago, the earth's ozone layer was destroyed very much and 90 to 95 % of life was extinct.

The Mesozoic era started after Paleozoic era. It stretched from 248 to 65 million years ago. It is further sub divided into the three time periods- the Triassic, Jurassic and Cretaceous, during which the dinosaurs lived. About 200 million years ago, over half of all species on earth vanished forever. Jurassic period is characterised by the breaking up of Pangaea. It gave rise the formation of mountains from the ocean floor pushing sea levels up. This made the previously hot and dry climate fairly humid. During Cretaceous, the increasing expanses of ocean caused the climate to become more moist and cool.

Cenozoic Era: The Cenozoic era means recent life divided into Tertiary and Quaternary. The Quaternary Period is also sub divided into "Pleistocene" and the "Holocene." Climatically, the Pleistocene epoch was characterised by the series of ice ages, while the Holocene epoch has had a warmer climate, so far. The climate during the Paleocene (first Epochs sub division of tertiary) was much warmer and more uniform than today. At the end of the Paleocene there was a sudden global warming. Thus, the beginning of the Cenozoic Era was much warmer than the present time. During the Eocene, temperatures were warmer than during any other time in the Cenozoic. The exact cause for this temperature increase is unknown but may be related to the release of carbon dioxide (CO_2) and methane (CH_4) into the oceans and atmosphere. There was a lot of rainfall but no seasonal variations, no glaciers, and temperatures were uniform throughout most part of the globe. It is said that by the end of the Eocene, temperatures had dropped drastically. Near the end of the Oligocene, savannas (grasslands with scattered trees) and seasonality had returned. This had profound effects on the flora and fauna. Cool, dry, and seasons became the unique climatic features of Oligocene. Antarctica was covered extensively with glaciers, which lowered the sea level. And further north, temperate forests replaced subtropical forests. Near the end of the Oligocene, savannas (grasslands with scattered trees) appeared. There were warmer conditions in the first half of the Miocene. The increasing mountain building mechanism, changing oceanic currents and increase in polar ice on Antarctica has led to the decreased in temperature and rainfall. This process has led to the shrinking of forest area and extension in grassland. About Pliocene epoch, Scientists have the opinion that the first of it will be was warmer then today and the sea level was also higher than today. During the last half, temperatures dropped drastically, which led to the increase in the ice cap of Antarctica and in Arctic as well. Ultimately, this situation has led to the ice age of Pleistocene. Pleistocene is characterised by the global cooling and warming situations popularly known as Pleistocene ice age with interglacial periods of Gunj, Mindal, Riss and Wurm. Scientists are of the views that during this period, the ice was 13,000 feet thick and the sea level dropped about 430 feet.

16.3 CLIMATE CHANGE

You have read the geological record of global temperature variations. Humans begin to replace wood and other biomass fuels with readily available fossil fuels. Oil and gas join the arsenal of high-energy fossil fuels, spurring rapid global land, sea, and air transport; total energy consumption worldwide experiences unprecedented growth. French mathematician and physicist Jean Baptiste Joseph Fourier first hypothesised that the atmosphere plays a significant role in mediating temperature on earth.

Status of Past 200 Years: Some literature describes that the moisture level was high indicating more rainfall condition between 1st to 4th centuries. After that aridity started after this period and continued till 950 AD. During 950 AD to 1250AD, temperature was so suitable that people started inhabiting in Greenland. The period of 1450 to 1880 AD, temperature was much cooler than present time. Temperature recorded little increase by 0.2^0C to 0.4^0C during 1880 to 1920 AD. The temperature regularly increased during 1921 to 1945. After 1945 rapid increased in temperature has been observed in northern hemisphere in comparison to southern hemisphere. The change in climate has affected the four aspects of natural environment. They are:

a. Change in sea level
b. Increase in the storms and cyclonic activities
c. Increase in extreme heat condition
d. d-Increase in events of heavy precipitation
e. shrinking glaciers and icebergs rise in sea level

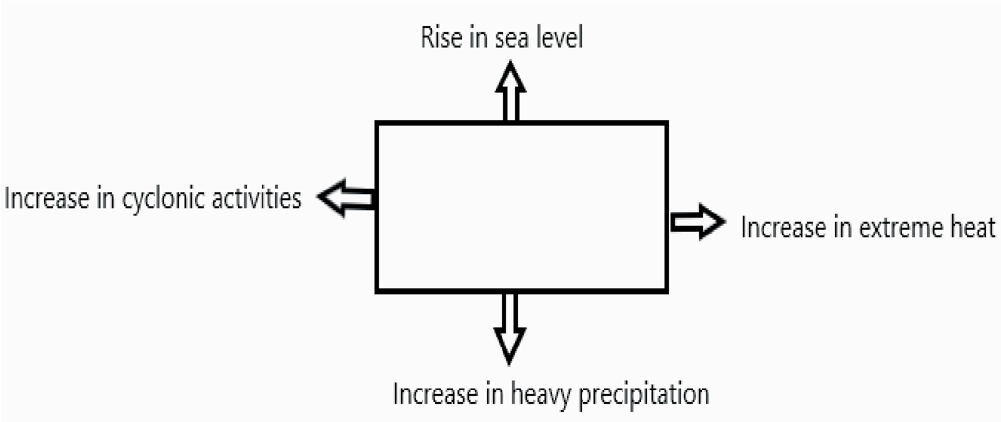

Fig. 16.1: Major Impacts of Climate Change.

At global level, some element of climate has been changing. Sometime scientists say that we are going towards global warming and sometimes they say that we are marching towards global cooling. These are two extreme conditions but where we are marching is still unknown. But it is the fact that the climatic conditions are changing at present. Urbanisation, industrialisation, deforestation, and misuse of resources are responsible for present different type of environmental problems. Deforestation has manifold negative impact over the global environment. In fact, Climate Change refers to the change in the climatic elements over a long period. Favourable climate is essential for the plants, animals and human existence. These days, we are facing some consequences of climate change not only at global level but at local level too.

- It has threatened the safety and well-beings, economy and heritages too.
- Climate helps in shaping and maintaining the ecosystem. When climate changes, the whole ecosystem changes as well.
- Rising temperature creates a warmer ocean which generates warmer and wetter ocean breezes. These factors give rise to frequent tropical storms and destructive cyclones.
- India herself has witnessed several cyclones during last five years. As per Indian Meteorological Department (IMD) India could witness many other pre-monsoon cyclones in the coming years.
- March 2022 making the hottest month in 122 years since record began.
- According to scientists, accumulation of green-house gases in atmosphere is contributing temperature rise.
- Scientists have forecasted that temperature may approach national records in India for the month of April 2022 also.
- Maximiliano Herrera, an expert on world weather extremes said that the highest reliable April temperature in India is 48.3^{0}C, set in Barmer in NW India in 1958. Nawab Shah, Pakistan, about 125 miles inland from the

Arabian Sea, hit 50.2^{0}C four years ago. This record, possibly the highest temperature ever recorded worldwide in April.

- Heat waves are more common in States of northern India.
- At least one person died of heat-stroke in March in Maharashtra, India.
- New Delhi is running about 4.8^{0}C above average for the month of April.
- In 2020, the IMD's Ministry of Earth Sciences published a report citing a 1.3^{0}C rise in temperature across India as a whole between1901-2018.
- India emits about 3 Giga tons CO_2 of greenhouse gases each year. It means 2.5 tons per person, which is less than the world's average.
- India rank third in the emission of greenhouse gases.
- The increasing temperature will ultimately increase the sea level and causes the submergence of much of Bangladesh and parts of India that border and may lose vast tracts of coastal land.
- Some tracts of low lying Sundarbans has already submerged.
- The interference of human activities into nature has led to its destruction.
- Rivers do extinct due to excess sedimentation and dryness of climate. Ghaghar river of Rajasthan is such type of river. Now-a-days, River Ganges is changing her course near Patna and shifting towards north. In future, it will certainly become serious threat to the Patna and its environs.
- Climate change is occurring at unprecedented rate because huge quantities of CO_2, methane, and other greenhouse gases are being releasing/ emitting into the atmosphere.
- The 20th century has been the warmest century in the past 600 years and 14 of the warmest years since the 1860's occurred in the 1980s and 1990s. Temperature in 1998 was higher than the mean temperature for the 118 years on record.
- Since 1980s, the winter temperature of sea water north of 45^0 latitude has risen by 0.5^{0}C.
- The sea ice in the Grand Bank Shipping lane has declined and in 1999 for the first time since the sinking of the Titanic in 1912, the International Ice Patrol did not report any single iceberg south of 48^{0}N latitude.
- The concentration of CO_2 in the atmosphere has risen from 280 ppm in 1760 to 360 ppm in 1990 and is expected to reach 600 ppm in 2100.
- The islands of Kiribati, a nation of atoll spread over two million sq. miles in the Pacific Ocean have submerged. These islands are the first victims of global warming.
- It was estimated that by 2025 about 900 million people in about 100 countries are affected by desertification and drought problem. This number will be double and 25 per cent of the earth's land area will be degraded. Land degradation has manifold impact over settlement.
- Landslides are common due to unscientific cutting of vegetation cover resultant into increase in wasteland area.

- Bird species and mammal species are threatened with extinction all over the globe.
- Climate change or global warming has affected all the human economic activities.
- Water crisis & health risk are increasing.

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

SAQ I

a. In which age, Savannah grassland was originated?
b. In which age, Pangaea was broken into two halves?
c. When the first land plants appeared on the earth?

16.4 EVIDENCES AND THEORIES OF CLIMATE CHANGE

It is a matter of great concern to think over the climate and associated feature, climate change. As a student of climatology, we are aware about the change in seasons in India. But as a whole, there are several evidences and examples suggest that local and global climate has been changed several times on the earth. The region which was hot and dry in the past are now enjoying humid climate. Similarly, snowy regions of the past are now covered with green vegetation. Some vice–versa conditions also happened. These are long term changes.

16.4.1 Theories of Climate Change

Several scientists have put forward their theories regarding climate change. Some of them are as follows:

A. Croll's Theory
B. Sun-Spot Theory
C. Carbon dioxide theory
D. Continental Drift Theory

Now we will learn about these theories one by one.

A. Croll's Theory

James Croll, A Scottish scientist has developed a theory of climate change which was based on variations in the earth's orbit. Croll was the leading proponent of an astronomical theory of climate change during the 19^{th} century. Taking into account the precession of the equinoxes, variations in the eccentricity of the orbit, and tilt of the axis, Croll proposed that climate change must be the result of the relation of the earth to the sun. He further stated that- "Geological and comical phenomena are physically related by a bond of causation." However, his theory has often been criticised. It influenced the work of Milutin Milankovic and provided important insights into the interplay of astronomical and geological elements. His paper published in Philosophical Magazine in 1864 on "On the Physical Cause of the Change of Climate through Geological Epochs," In this paper, Croll introduced changes in the earth's orbital elements as periodic and extra-terrestrial mechanisms responsible for the beginning of multiple glacial epochs. Croll argued that the eccentricity of the earth's orbit was sufficiently great to explain every extreme of climatic change evidenced by geology. His theory of ice ages was built on the precession of the equinoxes and variations in the shape of the earth's orbit. It forecast that one of the two hemispheres would experience an ice age whenever two conditions occur simultaneously: a markedly elongate orbit, and a winter solstice that occurs far from the Sun. In 1875, Croll published his book, Climate and Time widely admired when it published. The publication of this book led to his election as a Fellow of the Royal Society. The astronomical theory of climate change emerged 1864-90 thanks to the work of James Croll. However, because of uncertainties in the timing of ice ages and in the stratigraphic record, and because Croll's theory envisaged glaciation in only one hemisphere, the theory was criticised and largely dismissed for at least three decades.

B. Sunspot Theory

Sunspots are storms on the sun's surface that are marked by intense magnetic activity and play host to solar flares and hot gassy ejections from the sun's corona. Scientists believe that the number of spots on the sun cycles over time, reaching a peak—the so-called Solar Maximum—every 11 years or so. Some studies indicate that sunspot activity overall has doubled in the last century. The apparent result down here on earth is that the sun glows brighter by about 0.1 per cent now than it did 100 years ago. Solar wind, according to NASA's Marshall Space Flight Centre, consists of magnetised plasma flares and in some cases is linked to sunspots. It emanates from the sun and influences galactic rays that may in turn affect atmospheric phenomena on earth, such as cloud cover. But scientists are the first to admit that they have a lot to learn about phenomena like sunspots and solar wind, some of which is visible to humans on earth in the form of Aurora Borealis and other far flung interplanetary light shows. More recently it was discovered that the sunspot number during 1861-1989 shows a remarkable parallelism with the simultaneous variation in northern hemisphere mean temperatures. There is an even better correlation with the length of the solar cycle, between years of the highest numbers of sunspots.

C. Carbon Dioxide Theory

The most recent calculations of the infra-red flux in the region of the 15 micron CO_2 band show that the average surface temperature of the earth increases 3.6° C if the CO_2 concentration in the atmosphere is doubled and decreases 3.8° C if the CO_2 amount is halved, provided that no other factors change which influence the radiation balance. Variations in CO_2 amount of this magnitude must have occurred during geological history; the resulting temperature changes were sufficiently large to influence the climate. The CO_2 balance is discussed. The CO_2 equilibrium between atmosphere and oceans is calculated with and without CaCO3 equilibrium, assuming that the average temperature changes with the CO_2 concentration by the amount predicted by the CO_2 theory. When the total CO_2 is reduced below a critical value, it is found that the climate continuously oscillates between a glacial and an interglacial stage with a period of tens of thousands of years; there is no possible stable state for the climate. Simple explanations are provided by the CO_2 theory for the increased precipitation at the onset of a glacial period, the time lag of millions of years between periods of mountain building and the ensuing glaciation, and the severe glaciation at the end of the Carboniferous. The extra CO_2 released into the atmosphere by industrial processes and other human activities may have caused the temperature rise during the present century. In contrast with other theories of climate, the CO_2 theory predicts that this warming trend will continue, at least for several centuries. These temperature changes are sufficiently large to have an appreciable influence on the climate.

D. Continental Drift Theory

Continental drift theory was proposed by Alfred Wegener in 1912 According to Wegener's Continental drift theory, all the continents were one single continental mass (called a Super Continent) – Pangaea and a Mega Ocean surrounded this supercontinent. The Mega Ocean is known by the name Panthalasa. According to this theory, the supercontinent, Pangaea, began to split around two hundred million years back. Pangaea first split into 2 big continental masses known as Gondwanaland and Laurasia forming the southern and northern modules respectively. Later, Gondwanaland and Laurasia continued to break into several smaller continents that exist today. The Matching of Continents (Jig-Saw-Fit) indicates that the coastlines of South America and Africa western portion have a remarkable Jig saw fit. In 1964, Bullard created a map using a computer program to find the right fit of the continental margin. Rocks of the same age across the Oceans, The radiometric dating methods have helped in correlating the formation of rocks present in different continents across the ocean. The ancient rocks belts on the coast of Brazil match with those found in Western Africa. The old marine deposits found in the coasts of South America and Africa belongs to the Jurassic Age. This implies that the ocean never existed before that time. Tillite is the sedimentary rock made from glacier deposits. The Gondawana system of sediments from India is recognised as having its counterparts in 6 different landmasses in the Southern Hemisphere. Counterparts of this series are found in Madagascar, Africa, Antarctica, Falkland Island, and in Australia. At the base, the system has thick Tillite signifying widespread and sustained glaciation. Generally, the similarity of the Gondawana type sediments shows that these landmasses had exceptionally similar origins. The glacial Tillite gives clear evidence for Paleo-climates and the drifting of continents. The presence of abundant placer deposits of gold along the Ghana coast and the complete lack of its source rocks in the area is a phenomenal fact. The gold-bearing veins are present in Brazil and it is evident that the gold deposits of Ghana in Africa are obtained from the Brazil plateau from the time when the two continents were beside each other. The widespread distribution of Permo-Carboniferous glacial sediments in South America, Africa, Madagascar, Arabia, India, Antarctica, and Australia was one of the major pieces of evidence for the theory of continental drift. The continuity of glaciers, inferred from oriented glacial striations and deposits called Tillite, suggested the existence of the supercontinent of Gondawana, which became a central element of the concept of continental drift. The interpretations that Lemurs occur in India, Africa, and Madagascar led to the theory of a landmass named

"Lemuria" connecting these 3 landmasses. Mesosaurus was a tiny reptile adapted to shallow brackish water. The skeletons of these creatures are found in the Traver formations of Brazil and Southern Cape Province of South Africa.

Take rest here so that you can answer some SAQ.

SAQ 2

a. Who developed the theory of climate change based on variations in the earth's orbit?
b. Who has put forwarded continental drift theory?

16.4.2 Evidences of Climate Change

We have discussed some of the theories regarding climate change, but none of them is able to explain it clearly and effectively. Whatever be the reason of climate change, it is clear that climate change have been happening on the earth. There are lots of evidences available for climate change. This evidence of climatic change can be divided into four parts.

A. Geological Evidences
B. Historical Evidences
C. Biological Evidences
D. Modern Evidences

The geological history of the earth especially paleontologists have suggested that each era of geological history had different types of climate. From Azoic to Paleozoic, Mesozoic and Cenozoic; climatic condition never remains the same.

A. Geological Evidences

The geological evidences are associated with the thickness, structure, nature, age and forms of rocks. Some of these evidences are as follows:

Coal Reserves

The formation of coal on this earth is said to be the age of Carboniferous of Paleozoic era, nearly 150 million years ago. The formation of coal refers to hot and humid tropical climate. But today, most of the coal reserves are found in temperate region countries like U.S.A, Canada, England, Germany, Russia, China and Japan. Besides this, some coal reserves are also found in South Africa, India and under the ice cap of Antarctica. It proves that all these regions and countries have gone through the process of climate change.

Carboniferous Age Rocks

In India, we found the deposits/ layers of three types of rocks under Carboniferous age rocks. It includes- Glacial agglomerates, coal deposits and sand stone.

Gondawana System of India

Gondawana system of India is very popular amongst geologists, Paleo-botanists and climatologists as it presents the evidence of climatic change for shorter period of time at local level.

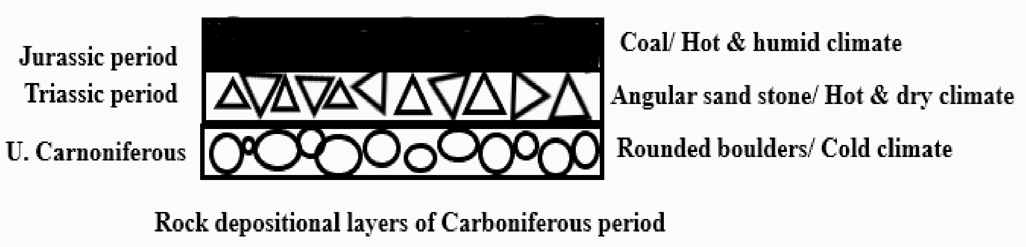

Fig. 16.2: Evidence of Short Period Climate Change at Local Level.

The Gondawana System of India especially Damodar valley region has such evidences where three types of deposits are found. Here, rounded boulder bed of Upper Carboniferous period is found in the lowest layer which represents the cold climate like situation. Above this, angular sand stone rocks are found representing the age of Triassic with hot and dry climate. Above all, Coal seems are found here in abundance which represents the age of Jurassic period when hot and humid climate was prevailing.

Therefore, the Damodar basin of Gondawana system in India gives the evidences of successive climate change for three (3) times at local level at short interval of time.

Alternate Layer of Gypsum and Salt

In the state of Rajasthan, India the alternate layer of gypsum and salt are found. These alternate layers of gypsum and salt represent the evidences of climate change .The deposition of gypsum are possible only in hot climatic condition whereas salt deposition is possible in only tropical condition. These deposition or layers clearly indicates that the sea water become hot and cold successively

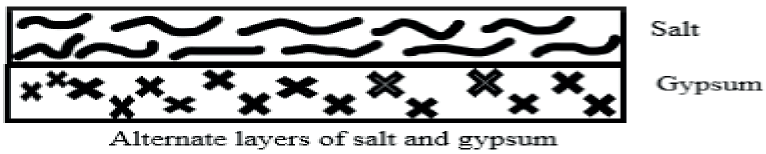

Fig. 16.3: Alternate Layers of Salt and Gypsum found in Rajasthan.

Deposit of Boulder Clay and Conglomerate

India is famous for its geological formations. Boulder clay is found in Damodar Basin region of India while you can found conglomerate in Rajasthan. Here, boulder clay represents glacial climate while conglomerate represents hot and humid climate. The presence of these layers clearly indicates that the climate has changed within Indian region.

Sedimentary Deposits in Africa

In the lakes of Africa, different colour sedimentary layers are found. Some layers are of deep colour whereas some others are of light colour. Deep colour deposits represent cold climate whereas light colour deposits represent warm climate. Silt of light colour and clay of deep colour sediments are found.

In north Nigeria, sand dunes are found in savannah belt. Savannah belt is famous for its farming. The presence of sand dunes in savannah belt shows that once the region was under hot and dry climate where sand dunes formed as arid topography but the region is now under cultivation. This gives the evidence that the present savannah belt was once under deserted condition.

Change in Sea Level

According to Daly, about 150 m change in sea level occurred due to eustatic change. It means that sea level reduces due to large scale glaciation (cool climate) and results into formation of coastal plain. After sometime, continental selves formed as sea level rises due to warm or hot climate. The example gives the evidences of global climate change.

Pleistocene Glaciation

Pleistocene glaciation comes to an end near about 15000 years ago. Pleistocene glaciation proves that during this age, whole earth's climate became very cool but some warm periods also came during such said period, popularly known as 'Interglacial period'. Such warm period were known as Gunj, Mindal, Riss and Wurm.

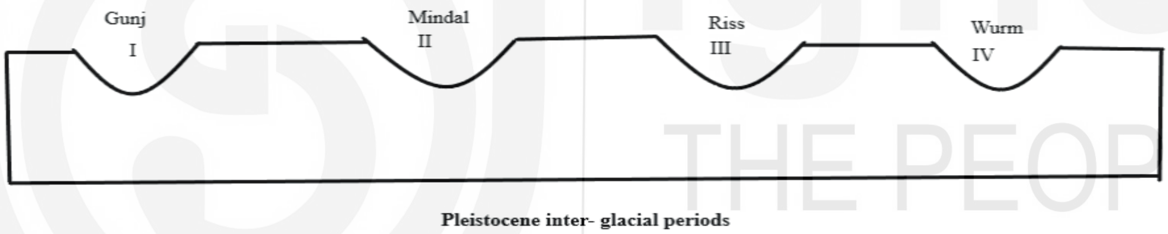

Fig. 16.4: Change in Sea – Level during Pleistocene Glaciations.

Glacial Periods

The geological history of the earth suggests that the climate of the earth never remains the same but, it changes with time. Some evidences are there which shows that glacial period occurs every 215 million years. The first glacial period on the earth occurred/ recorded in Proterozoic era nearly 750 million years ago. After that evidences indicates that the second glacial period was during lower Cambrian era, nearly 500 million years go. The third glacial period occurred in Permo-Carboniferous nearly 260 million years ago and the last known glacial period was in Pleistocene era, nearly 15000 years ago. These evidences show the changes in earth's climate at every 200 million years.

Answer some SAQ before we proceed ahead.

SAQ 3

a. How Gondawana System of India gives evidence of climate change?
b. Mention interglacial periods of Pleistocene age.
c. According to Daly what was the reason of sea level change.

B. Historical Evidences

Human history is merely of 10,000 years. This short span of human civilisation has seen some revolutionary changes. These changes give or show the evidences of climate change for smaller region. Some notable examples associated with historical evidences are as follows:

i. The relict of Mohan-Jo-Daro reveals that several other civilisations might have been flourished in humid climate by that time. At present the region is under hot and dry climate, indicates change of climate.

ii. Most of the civilisations like Sumerian, Babylonian, Aryan and such others were flourished for long time due to support of favourable climatic conditions. The Pyramids of Egypt are presently found in a dry region. But it is the fact that they were built there, when there were supporting climate like humid climate. It means climate must have changed.

iii. From the historical references, you would come to know that the people / population from Middle East or West Asia have migrated to the different parts of the world from their native places. This might have happened due to the increasing temperature and dryness of the climate.

iv. The settlements found in Middle East or West Asia exhibits that there must have moist and humid climate which have favoured the farming also. In Syria, several towns were flourished along water bodies but today it is rare to provide water to any single city or town here.

v. In Rajasthan province of India, several large settlements have been excavated during Rajasthan Canal digging. These settlements were developed along mighty river Saraswati. As the river dried up, and climate become warmer; the settlements could have ended as well respectively.

vi. Some countries like Russia keeps the record of opening and closing of northern Siberian ports to find out the length of winter season and their onset and offset. China has kept its climate record for last 1400 years. In Europe too, the record of sowing and ripening of crops are kept to find out the onset and offset of winter season and their length. India has also kept its climate record for the last 1.5 century. In Bible, there is a story of 7 years of abundance and 7 years of scarcity.

vii. During excavation in Greenland, the remains of Nordic peoples have been found. The presence of Nordic people in Greenland means that the region was under warm and moist climate favourable for settlement. Once that area was suitable for human settlement but now it is covered with thick layer of ice.

viii. All the above said historical evidences exhibits that the change in rainfall and temperature becomes gradually scares or vice versa which have changed the existing climate to a new one.

Stop here to check your understanding by answer some SAQ.

SAQ 4

Along which river old settlements are found in Rajasthan?

C. Biological Evidences

The distribution of flora and fauna at global level depends mainly on the distribution of temperature and rainfall or on climate. Fossils found in different rocks, structures and systems represent a special type of climate. Reptile fossils are found in Jurassic period rocks. Those reptiles survive in very hot and humid climate which was prevailed during Jurassic period. After that, during Cretaceous period, dry conditions prevailed. Such other evidences are found from other system of rocks. Some worthy biological examples are:

i. Remains of Glossopteris found in Paleozoic rocks. Its life is possible only in glacial climate whereas today it is found in rocks of erstwhile Jammu and Kashmir State.

ii. The skeleton of elephant and rhinoceros are found in tundra region and skeleton of polar beer in Africa clearly gives the evidence of climate change.

iii. Coconut tree mainly grow in warm coastal regions. Today we find the remains of coconut trees in the coastal areas of temperate region. Like this some Peat bogs and dead forest developed in humid climate are today found in temperate region of Ireland and dry regions respectively suggests that the region has experienced climate change.

iv. The concentration of Isotope 180 and 160 in deep sea also suggests that they were deposited during glacial and interglacial period respectively.

v. The development of circular rings in a tree is associated with the growth of that particular tree. These circular rings are of deep and light colours .The deep colour represents drought condition as their growth becomes slow due to lack of water or moisture. On the other hand, light colour rings represent heavy rain. Due to heavy precipitation, trees have tendencies to develop with faster growth.

vi. The 500 years old Red wood tree and Sequoya trees found in California, U.S.A. has deep and light colour rings in their stems. It suggests that during the growth of these trees some time warm dry climate prevailed and sometime humid condition prevailed. In other words- during last 500 years, climate of California has changed drastically.

D. Some Modern Evidences

All the above said evidences of climate change represent the evidences of past time. In modern era too, we have some evidences of climate change. Some of the major signs/ evidences are here been simply described as follows:

i. Scientists have suggested that the temperature of the earth is increasing. This phenomenon is called Global Warming. The main reason behind this is the increasing concentration of carbon dioxide in the atmosphere. According to a study, in 1760 the concentration of CO_2 in atmosphere was 280 ppm (part per million) which became 360 ppm in 1990. In 2020 it is measured ppm.

ii. Due to global warming, earth temperature has risen by 1^0C since the late 19th century. Most of the warming occurred in the past 40 years. The year 2018 and 2021 are tied for the warmest year on record.

iii. The temperature of the earth's atmosphere is increasing. It has resultant into melting of glacier /ice sheet and increase in sea level. Some islands have gone under water and some are under threat. Kiribati an atoll island situated in Pacific Ocean has already gone under sea water. Some islands in Western Atlantic have also loss their existence.

iv. During Antarctica survey in1987, it has been found that the ice of 175 km long, 40 km wide and 230 m thick melted during recent past.

v. Due to change in climate, about 30% of the earth's fauna species have become extinct. Global warming has caused damage to colours of some historical buildings and monuments.

vi. About 900 million populations of 100 countries are affected by desertification and drought problem.

vii. Strontium is a natural and commonly occurring element. Rocks, soil, dust, coal, oil, surface and underground water, air, plants, and animals all contain varying amounts of strontium. Strontium compounds, such as strontium carbonate, are used in making ceramics and glass products, pyrotechnics, paint pigments, fluorescent lights, medicines, and other products. Stable and radioactive strontium compounds in the air are present as dust. Increasing strontium in human body by breathing, eating, or drinking the substance, or by skin contact.

viii. The group of scientists has suggested that the temperature has raised 5.8^0C in 20th century which may cause on increase of sea level by 8.8 cm by 2100.

ix. The climate change has increased the problem of stone cancer in human beings.

x. The depletion ozone of is directly associated with climate change.

xi. No iceberg has seen south of 48^0N latitude after 1912. It is another evidence of climate change.

Several other evidences are being coming in front of us regarding global climate change.

16.5 SUMMARY

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

According to the available literature and records, it is evident that climate was changing through geological past from Azoic to Cenozoic period. Some scientists have put forwarded the theories regarding climate change. Among them Croll's theory, Sun-Spot theory, Carbon dioxide theory, Continental Drift theory are important. Whatever be the reason of climate change, it is clear that climate change have been happening on the earth. There are lots of evidences available regarding climate change. These evidences of climatic change can be divided into four categories such as - Geological evidences, Historical evidences, Biological evidences, and Modern evidences.

16.6 TERMINAL QUESTIONS

1. Explain any two theories regarding climate change.
2. Discuss some historical and biological evidences of climate change.
3. Describe the evidences of climate change in detail.

16.7 ANSWERS

Self-Assessment Question (SAQ)

1. a) Near the end of the Oligocene age, Savannah grasslands originated.

   b) The breaking up of Pangaea took place in the Jurassic period.

   c) The first land plants appeared in the Ordovician period.

2. a) Croll developed the theory of climate change based on variations in the earth's orbit.

   b) Alfred Wegner gave the given continental drift theory.

3. a) The presence of sand stone, coal and boulder bed in Gondawana system representing different types of climate and gives the evidences of climate change.

   b) Gunj, Mindal, Riss and Wurm were the names of interglacial period of Pleistocene age.

   c) According to Daly eustatic change was the reason of sea level change.

4. Along mighty river Saraswati, old settlements are found in Rajasthan.

Terminal Questions

1. Start the answer by stating that there are different theories put forward regarding climate change. Among them some theories are discussed here as Croll's theory, Sunspot theory, CO2 theory and Continental drift theory. Now explain any two theories one by one.
2. Describe the answer explaining some historical and biological evidences of climate change from the unit.
3. Describe all the evidences of climate change in detail as discussed in the unit.

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UNIT 17

HUMAN-INDUCED CLIMATE CHANGE

Structure

17.1 INTRODUCTION

In the last unit on climate change and variability, you have learned about the chronology, theories, and evidence of climate change. As you know climate is dynamic and change is also natural in geological time. In the present unit, you will learn about the anthropogenic interventions leading to imbalances and distortions in environmental settings.

Sec 17.2 will give you an idea of atmospheric pollution. This section enlists natural as well as anthropogenic sources of pollution. It also classifies the different types of pollution in detail. In the end, this section brings forth the effects of pollution.

Sec. 17.3 is about global warming and its impact. You have an idea of climate change after studying the previous unit, one aspect of climate change i.e. global warming and its effects is explained in brief for your benefit.

Sec. 17.4 we know that climate change is a reality now. This section of the unit enlists the adaptation and mitigation measures taken all over the world to climate change.

Expected Learning Outcomes

On the completion of the present unit, you will be able to

- define atmospheric pollution;
- identify the causes of pollution and suggest measures to check the pollution;

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- categorise the Sources of the Atmospheric Pollution;
- describe global warming and weigh its widespread impacts; and
- explain climate change and summarise the adaptation and mitigation measures.

17.2 ATMOSPHERIC POLLUTION

Atmospheric Pollution although interchangeably used with environmental degradation is different from the latter. Pollution means lowering of environmental/ atmospheric (as the case may be since atmosphere and environment are not the same) quality at the local scale/ level caused exclusively by human activities whereas environmental degradation is the lowering of environmental quality at local, regional, and at global level by both natural processes and human activities. However, it can be safely argued that the breach of the threshold of environmental degradation is pollution. In other words, the upper limit of the degradation is pollution.

There are classifications based on types of pollutants, location of pollution, and the medium of pollution, however, we restrict ourselves to the atmospheric pollution.

Atmospheric pollution more commonly known as Air Pollution is among the most dangerous forms of pollution. According to the World Health Organisation (WHO), air pollution is defined as limited to the situation in which the outdoor ambient atmosphere contains materials in concentrations, which are harmful to humans and their surrounding environment.

Air pollution is the contamination of the indoor or outdoor environment by any chemical, physical or biological agent that modifies the natural characteristics of the atmosphere. Household combustion devices, motor vehicles, industrial facilities, and forest fires are common sources of air pollution. Because of Natural and anthropogenic activities, gases such as CO_2, SO_2, H_2S, and oxides of Nitrogen, mist particulates, and aerosol are continuously being injected into the atmosphere, and get dispersed in the air through the wind currents. These gases can be found even up to 2000 ft above the mean sea level. This disturbs the dynamic equilibrium of the atmosphere and causes health hazards for all organisms.

17.2.1 Sources and Types of Air Pollution

a) Natural Sources of Pollution

Natural Sources of Pollution include volcanic eruptions, deflation of sands and dust, wildfires etc. Industries, urban centres, automobiles, aircraft, agricultural practices, thermal power plants, etc are some of the anthropogenic sources of pollution.

b) Anthropogenic Sources

Pollution from anthropogenic sources is the main cause of concern. Human-made sources can be further sub-divided into gaseous from industries, burning of the fossil fuels, incineration, etc. and particulate matters from vehicular emissions, thermal power plants, industries, urban centres, etc., and radioactive substances from nuclear plants and heat from the industries

(i) **Burning of the Fossil Fuels and Fires:** Fossils fuels which include coal, petroleum, and natural gas on burning produce poisonous gaseous by-products such as Carbon dioxide, Carbon monoxide, Methane, Sulfur Dioxide, and Oxides of Nitrogen these gases are pollutants, concentration and quality of which depend on the type of fuel used. Sulfur and Nitrogen from the chimneys of factories and dust from anthropogenic activities, burn in the atmosphere to produce their oxides. The oxide of sulphur and nitrogen are highly soluble in water in the form of sulphuric, sulphurous, and nitric acid respectively. These acids reach the earth in the form of acid rain causing widespread destruction to the crops, flora and corrosion to the buildings and man-made structures.

(ii) **Vehicular Exhausts:** 75 per cent of air pollution in urban areas is caused by automobile emissions. Vehicles use either petrol or diesel, however, Compressed Natural Gas (CNG) fitted vehicles are also plying nowadays. The air is polluted not only with exhaust gases but also with microscopic bits of lead from tetraethyl lead that is present in gasoline. Due to incomplete/ partial combustion, a mixture of carbon monoxide (77%), oxides of nitrogen (about 8.4%), Hydrocarbon (about 14%), and Leaded Gas along with some particulate of lead are released into the atmosphere. These gases react with oxides of nitrogen in the presence of sunlight to produce highly toxic photochemical smog.

(iii) **Industrialisation:** Industries are responsible for 20% of air pollution through the discharge of gaseous, liquid and particulate pollutants which includes CO_2, CO, No, NO_2, SO_2, and H_2S.

(iv) **Agricultural Activity:** Use of insecticides, pesticides, and herbicides indiscriminately inject harmful chemicals into the air, hazardous to both human and animal health.

Other sources of air pollution are modern warfare, smoking, domestic fuel consumption, construction (building and road) etc.

Common air pollutants, their sources and their effect on human beings

Pollutant	Source	Pathological Effects on Human Beings
Sulphur dioxide	Combustion of Coal and oil	Causes chest constriction, Headache, vomiting, and ultimately, death due to respiratory ailments.
Nitrogen oxide	Burning of Soft coal, automobile exhaust	Inhibits cilia action of the nose so that soot and dust directly enter into the lungs.
Hydrogen sulphide	Refineries, chemical industries and bituminous fuels	Causes nausea, and irritation of the eyes and throat.
Carbon monoxide	Burning of coal, gasoline motor	Reduce the oxygen-carrying capacity of the blood.

	exhaust	
Hydrogen cyanides	Blast furnaces, fumigation, chemical plants	Interferes with the nerve cells, causes dry throat, indistinct vision, and headache.
Ammonia	Explosives, dyes-making, fertilizer plants and lacquers	Inflames upper respiratory passage.
Phosgene	Chemical and dye-making industry	Induces cough, irritation and fatal pulmonary oedema.
Aldehydes	Thermal decompositions of oils, fats and glycerol	Irritates nasal and respiratory tracts.
Arsenic	The process involving metal or acid-containing arsenic soldering	Damages red blood cells, kidneys and cause jaundice.
Suspended particles (ash, soot, smoke, etc.)	Incinerator and almost every manufacturing process	Causes emphysema, irritation in the eyes and possibly cancer.

(Source: Taken from “environmental studies” book by Planisamy and Basak)

17.2.2 Adverse Effects of Air Pollution

Effects on Weather and Climate

Air Pollution modifies weather and climate at local, regional, and global levels. Following are the climatological effects of air pollution-

1. **Ozone layer Depletion:**This is caused by chlorofluorocarbons (CFCs) emitted from air conditions, Hair Driers, Foam Plastics, Spary Cane Dispensers, and Fire extinguishers, etc., and Nitrogen Oxide released by supersonic Jets. Ozone depletion increases the ultraviolet solar radiation reaching the earth's surface and therefore, rises air temperature. Increased ultraviolet radiation is responsible for thinning of the ozone layer which in turn causes skin cancer, particularly among the white population. It also affects the soil moisture negatively leading to crop failure.
2. **Excessive Concentration of Carbon Dioxide and Other Green House Gases:** This intensifies the greenhouse effect which could increase the global temperature. This section is further elaborated under the global warming section later in this unit.
3. **Smog:** It is the combination of smoke and fog that generally occur over the cities and industrial regions. SO_2 readily reacts with O_2 and water films and suspended particulate matter (SPM) to produce sulphuric acid (H_2SO_4). Smog along with H_2SO_4 and Nitric Acid (HNO_3) becomes toxicand is trapped in a shallow layer over cities due to inversion of temperature. A toxic fog causes respiratory disorders and may result in death. The famous

London smog in 1952, the Meus Valley of Belgium, 1930 and Pennsylvania, 1948 are some such cases.

4. **Acid Rains:** The chemical reaction between Sulphur dioxide and Nitrogen oxide results in acid rain. Acid rains are also called lake killers for it causes the destruction and death of aquatic lifein the ponds, lakes, and rivers. Acid rain lowers the productivity of the soils also. Acid rain causes extensive damage to buildings, marble sculptures, limestone and slate. Acid rain may cause neurological problems in human beings.

17.2.3 Type of Air Pollutants

Primary Pollutants

(i) Oxides of Carbon
(ii) Nitrogen Oxides (NO)
(iii) Hydrocarbons (HC)
(iv) Sulphur Oxides (SO)
(v) Particulate Matter

(i) Oxides of Carbon: CO_2, and CO are important oxides of carbon injected into the atmosphere from the burning of fossil fuels, emissions from vehicles, and other anthropogenic and natural sources. 80% of CO is produced by automobile exhaust; it is produced by the oxidation of methane by anaerobic decomposition of organic matters and is also found in small amounts in the volcanic eruptions, forest fires, and incomplete combustion of fuels. Inhalation of CO displaces oxygen from haemoglobin, to produce carboxyl haemoglobin (CoHb) which reduces the oxygen-carrying capacity of the blood. Carboxyl Haemoglobin in the blood can be fataland may result in impairment of central nervous system, cardiac and pulmonary and respiratory. The increased concentration of CO_2 causes global warming, acid rain and the greenhouse effect.

(ii) Nitrogen Oxides (NO): These are mixture of gases that are composed of Nitrogen and Oxygen. 90% of NO is produced by diesel from electric power plants and industry. Once the NO released into the atmosphere, it forms into NO_2 combining with oxygen. Breathing nitrous oxide cause dizziness, unconsciousness and even death. **Hydrocarbons (HC): Aut**omobiles plying on the road are the main source of hydrocarbon emissions in the atmosphere. Hydrocarbons with high concentrations of 500-1000 ppm (parts per million) are parti**cularly harmful to** the lungs, they irritate therespiratory tracts resulting in continuous coughing.

(iii) Sulphur Oxides (SO): Sulphuric Acid is the result of the reaction of sulphur dioxide with, and Hydrozone peroxide atmospheric water vapour) H_2SO_4 comes down the earth from acid rain.

(iv) Particulate Matter: Particulate matter or aerosols are air borne, small solid particles or liquid droplets combined. The size of particulate matter varies from the diameter of 2×10^{-8} cm to 5×10^{-2} cm. Particulate matter remains suspended in the air for a longer period. Particulate matter injected into the atmosphere by anthropogenic activities is absorbed by sulphur, hydrocarbon, and nitrogen andproduces smog. Particulate matter is organic (from the volcano, dust storms, forest and grassland fire, etc) and inorganic (metal oxide, Vehicular exhaust industry process and acid rain) are harmful particularly for human lungs. Penetration into the lungs may lead to severe respiratory diseases like black lungs, silicosis, etc.

Secondary Pollutants

Secondary pollutants are the result of the reaction of primary pollutants with normal atmospheric compounds for example ozone due to affects the respiratory and the nervous systemby photochemical reaction between primary pollutant and natural gas. Peroxy Acetyl Nitrate (PAN) a secondary pollutant is formed when hydrocarbon radicals (Primary Pollutants) react with nitrogen dioxide. It Causes Smog and also leads to irritation of the eyes, nose and throat.

SAQ I

a. What is atmospheric pollution?
b. Name the important sources of atmospheric pollution.
c. Write down primary air pollutants.

17.3 GLOBAL WARMING AND ITS IMPACTS

In the previous section, we discussed atmospheric pollution, types of pollution and the pollutants, and their impact. This section is exclusively dedicated to global warming and its impact. After studying the previous section and the present one you would be able to establish a relationship between atmospheric pollution and global warming. After this section, you would understand global warming is fallout of atmospheric pollution.

Global warming is a gradual increase in the earth's temperature which is mainly caused by the greenhouse effect. Carbon dioxide, Methane, and Nitrous oxide are important Greenhouse Gases. Increased concentration of GHGs has triggered temperature rise inthe lower atmosphere and the earth. GHGs particularly the CO_2 are transparent to incoming short waves of the solar radiation, and opaque to the outgoing longwave terrestrial radiation, thereby acting as a blanket. The concentration of GHGs has increased manifold since the year 1800, resulting in an almost 0.8℃ rise in the earth's average temperature. Efforts at the international level are on to restrict the emission of GHGs throughout the present century so much so that the average global temperature does not exceed the 1.5℃ upper limit, as agreed upon by the nations at Paris Convention in 2015. After the advent of the industrial revolution, the world has witnessed a sudden spurt in GHGs emissions by burning of fossil fuels, vehicular exhaustsand emissions from chimneys of the industries and thermal power plants have aggravated the situation.

Since the problem is global, a collective, combined, and concerted effort on behalf of the world community is the need of the hour.

17.3.1 Impacts of Global Warming

The earth's temperature had already warmed by 1°C compared to pre-industrial levels. This temperature rise may appear small, but the small temperature rise causes into big changes in the world's climate. This is because the amount of extra energy needed to increase the world's temperature, even by a little, is vast. This extra energy is like force-feeding the global climate system.

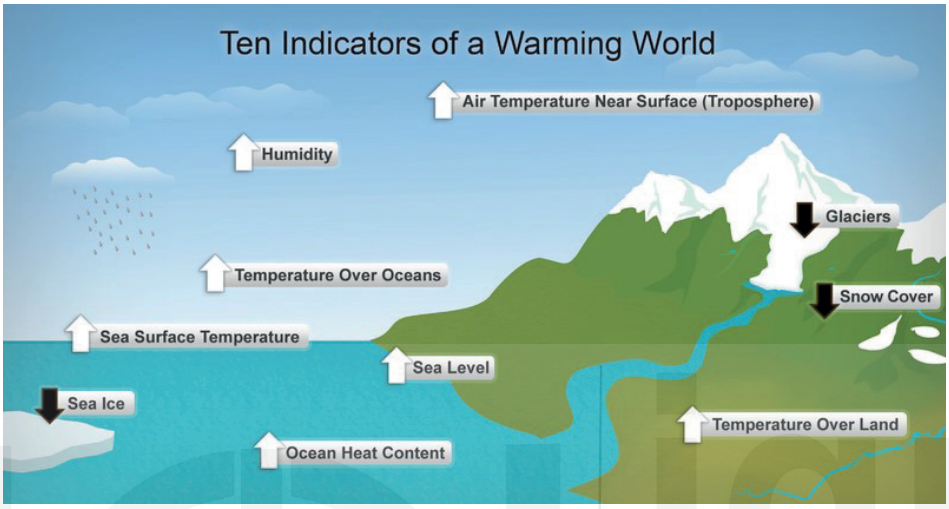

Fig. 17.1: Global Warming and its Impact.
(Source: https://no.m.wikipedia.org/wiki/Fil:Diagram_showing_ten_indicators_of_global_warming.png, CC: Public Domain)

Global warming stresses ecosystems through **temperature rises, water shortages, increased fire threats, drought, weed and pest invasions, increased cyclones, floods and droughts in frequency as well as intensity, intense storm damage, and salt water intrusion**, just to name a few.

Following are some perceptible impacts of Global Warming that you need to understand.

1. Hotter Temperature

Since the mid-1980s, surface temperature of Arctic have warmed at least twice as fast as the global average, while sea ice, the Greenland ice sheet, and glaciers have declined over the same period and permafrost temperatures have increased. The global surface temperature has increased faster since 1970 than in any other 50- year period over at least the last 2000 years. Melting of the ice in Polar Regions and recession of glaciers in the high altitudes are already a matter of grave concern.

2. More Severe Storms

More water vapour in the atmosphere due to increased temperature has exacerbated extreme rainfall and flooding in many parts of the world. Ocean warming has triggered some of the most powerful tropical cyclones over the last few decades. Frequently and intensity of cyclones has increased.

Fig. 17.2: Flood in the Urban Area.
(Source: https://www.pickpik.com/high-water-elbe-meissen-emergency-not-savior-75959#google_vignette)

3. Increased Drought

One of the ubiquitous impacts of the warming is recurrent agricultural and metrological droughts, particularly in the arid and semi-arid regions of the world. The spread of deserts in the form of moving sand dunes is also a common phenomenon in the different parts of the world. In India shifting of dunes in the Thar Desert in the north-western part of the country is an example of the spread of the desert.

Fig. 17.3: Dry and Cracked Farm Land.
(Source: https://pxhere.com/en/photo/562621, CC: Public domain)

4. Rise in the temperature of the Oceans

The oceans act as the Carbon sinks and also absorb upto 90 per cent of the heat from global warming. The rate of oceanic water temperature increase has been on the upswing in recent decades. The warming ocean expands as the volume of water increases. Coupled with the melting of the ice from the ice caps the rising ocean water presents a real threat to the islands and other low-lying areas. The

CO_2 absorption is making the oceans more acidic engendering a threat to marine living forms as well as coral reefs.

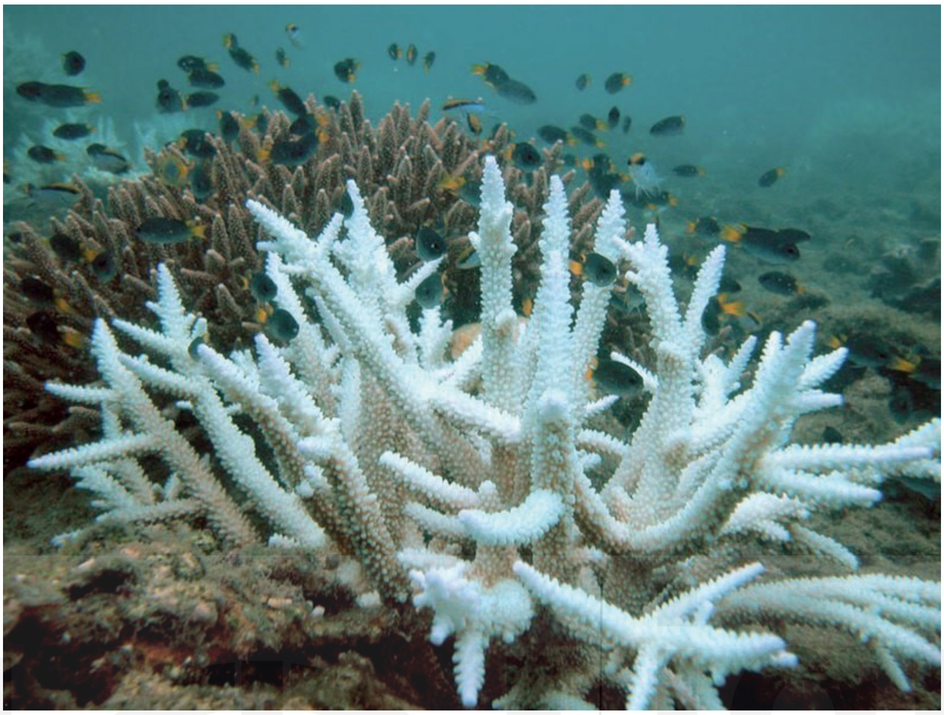

Fig. 17.4: Temperature Rise: Bleaching of Coral Reefs off Papua New Guinea.
(Source:https://en.m.wikipedia.org/wiki/File:Keppelbleaching.jpg, Creative Commons Attribution 3.0 Unported)

5. Loss in the Bio-diversity

Biodiversity is the Variety and Variability of life (including Plants, animals, and all living organisms) in a geographical area. The rising temperature has negatively affecting all forms of life on the planet, resultinga significant biodiversity loss. An estimate suggests that, the world is losing species at a rate of 1,000 times greater than at any other time in recorded human history. Almost ten Lakhs of the species are at risk of becoming extinct within the next few decades. Forest fires, extreme weather, and invasive pests and diseases are among some common causes of species loss.

6. Food Shortage

Extreme weather events owing to global warming are among the reasons behind a rise in hunger and poor nutrition, particularly in the tropical world. Fisheries, crops, and livestock may be destroyed or become less productive. Heat stress can diminish potable water, soil moisture, and grasslands for grazing. Up to 811 million people in the world faced hunger in 2020, as many as 161 million more in 2019. If the trend of GHGs emissions continues, the situation may further worsen.

7. Impact on Health

Both air and water-borne diseases are not only on the rise but are also spreading dueto the changing weather patternsin the world. Global warming is posing a serious threat to the health of humanity as hunger and malnutrition are on the rise in places where agricultural practices are vulnerable to drastic changes. The impacts are already harming health through air pollution, disease, extreme weather events, forced displacement, food insecurity and stresson mental health. Over 90 per cent of people breathe unhealthy levels of air pollution, largely resulting from burning fossil fuels every year.

8. Poverty and Displacement

Climate change is among the significant causes of poverty. Floods may sweep away urban slums, destroying homes and livelihoods. Weather-related disasters displace 2.3 crore people a year, leaving many vulnerable to poverty.

Weather-related crises have triggered more than twice as much displacement as conflict and violence in the last decade.

SAQ 2

a. What is global warming?
b. What are the main causes of global warming?
c. Enlist the impacts of global warming?

17.4 CLIMATE CHANGE: ADAPTATION AND MITIGATION MEASURES

The previous section gave you an idea of Global warming and a glimpse into the undesirable negative effects of global warming. The present section on Climate change takes the discussion further and here you will learn about climate change of which global warming is the greatest manifestation. This section will make you aware of the adaptation strategies and mitigation measures to climate change.

Mitigation in the climate change context means methods/measures to reduce climate change impacts or in other words to check the climate change itself. It involves reducing the release of heat-trapping greenhouse gases into the atmosphere, either by reducing sources of these gases or by enhancing the "sinks" that absorb these gases. The greenhouse gases include carbon dioxide, methane, carbon monoxide and the oxides of nitrate are the main culprits which trapsthe heat in the lower atmosphere. Sinks that trap and sequester the atmospheric CO_2 and other greenhouse gases are the forests, oceans, and the soils commonly known as the lungs of the earth.

The goal of mitigation is to avoid significant human interference with the climate system, and "stabilise even of greenhouse gases levels in a timeframe sufficient to allow ecosystems to adapt naturally to climate change, ensure that food production is not threatened and enable economic development to proceed sustainably. On the other hand, '**Adaptation**' simply suggests how to adapt to the condition of changing climate. It involves adjusting to the actual or expected future climate. The goal is to reduce our vulnerability to the harmful effects of climate change, sea-level rise, more intense extreme weather events or food insecurity.

Adaptation to climate change refers to the vast range of actions societies, can take to reduce the adverse impacts of global warming on the environment, society, public health, the economy and more. Climate adaptation includes measures such as developing and rolling out new varieties of drought-resistant crops, designing better flood-defence infrastructure to protect coastal cities, improving early warning systems for climate-induced disasters and restoring ecosystems that act as buffers extreme weather conditions.

Mitigation and adaptation are the two integral concepts associated with Climate change.

It would be noteworthy that the earth's climate has remained stable for more than 12000 years. However, it has undergone phenomenal changes not in congruence with the coping capacity of the earth, during a few decades.

Climate unlike general perception is dynamic and ever-changing. Shreds of evidence of climate change are littered all over the geological history of the earth. However, it is during the last few decades that climate change has acquired a significant, cardinal, and all-encompassing importance among the academician, politicians, and the general public alike. A surge in carbon dioxide emissions is more noticeable after the industrial revolution. The release of obnoxious gases into the atmosphere has set off an alarm, and rightly so. The anthropogenic interventions inform of tinkering with the delicate balance of nature have precipitated spiralling and cascading effects. The greenhouse gas effect is further aggravated by an increase in carbon emissions and other greenhouse gases. The average temperature of the earth is witnessing an upswing; an expected rise in temperature from 1.5^0 to 2^0C will be catastrophic. Extreme weather events such as hot and cold spells of temperature or wet or dry spells of rainfall, cyclones or floods etc. have become more erratic and yet frequent. In tropical regions, though the average annual rainfall more or less remains the same, the distribution is a big problem. Instead of being more equitable throughout the year, it is concentrated only in few months. Similarly, spatial distribution across the tropical and temperate world is highly skewed. The rapid climate change observed since the last century, experts believe, it is not cyclic and natural; the pattern observed lately does not fit into any available model of climate change except the unwanted anthropogenic intervention.

Adaptation and mitigation are two strategies which go hand in hand. Mitigation includes retrofitting buildings to make them more energy efficient; adopting renewable energy sources, designing more sustainable transport systems (such as electric vehicles, biofuels, etc.) and promoting more sustainable uses of land and forest. **Adaptation** on the other hand, is the resilience of the community. In other words, adaptation is to prepare for the adverse impact of climate change, such as rising sea levels, extreme temperatures, and other extreme and erratic events in the weather. Adaptation measures are to safeguard development gains and to address the needs of the communities/ countries exposed to climate change impacts.

To meet the global challenge of climate change adaptation and mitigating measures to climate change, a global collective response is the need of the hour. The Intergovernmental Panel on Climate Change (IPCC), the group of the world's leading climate change scientists along with the United Nations Framework Convention on Climate Change (UNFCCC) are working in tandem.

Besides the global efforts under the UNFCCC, there are some conventional and non-conventional measures of climate change mitigation mentioned below:

There are three main climate change mitigation approaches which are discussed here.

17.4.1 Climate Change Mitigation Approaches and Methods

First, conventional mitigation efforts employ decarbonisation technologies and techniques that reduce CO_2 emissions, such as **renewable energy**, **fuel switching, efficiency gains**, **nuclear power**, **and carbon capture storage and utilisation**. Most of these technologies are well established and carry an acceptable level of managed risk.

It constitutes a new set of technologies and methods that have been recently proposed. These techniques are potentially deployed to capture and sequester CO_2 from the atmosphere and are termed **negative emissions technologies,** also referred to as **carbon dioxide removal methods.** The main negative emissions techniques include bioenergy carbon capture and storage, biochar (black carbon produced from biomass sources), enhanced weathering, direct air carbon capture and storage, ocean fertilisation, ocean alkalinity enhancement, soil carbon sequestration, afforestation and reforestation, wetland construction and restoration, as well as the alternative negative emissions utilisation and storage methods such as **mineral carbonation and using biomass in construction**.

The third approach revolves around the principle of altering the earth's radiation balance through the management of solar and terrestrial radiation. The main objective of these **geoengineering techniques** is temperature stabilisation or reduction. Unlike negative emissions technologies, this can be achieved without altering greenhouse gas concentrations in the atmosphere. The main radiative forcing geoengineering techniques include **stratospheric aerosol injection**, **marine sky brightening**, **cirrus cloud thinning**, **space-based mirrors**, **surface-based brightening** etc.

According to a recent global status report on renewables, the share of renewable energy from the total final energy consumption globally, has been estimated at 18.1% in 2017. The important renewable energy sources are solar energy, wind, hydropower, marine power, geothermal, biomass and biofuels.

In terms of the power production renewable energy share has reached up to 26.2% of the total world's production. The share of the Hydropower at 15.8% is the largest followed by Wind power at 5.5%, Solar at 2.4%, Bio-power at 2.2% and Geothermal and marine collectively having 0.46% share of the global power production in 2018. China ranks first among the power-producing countries through renewable energy sources. Besides Power Production, renewable energy can be deployed within the industry, transportation and building sectors.

Solar energy and industrial end-use fuel switch to renewable fuels such assolid, liquid and gaseous biofuels for combined thermal and power production are examples of decarbonisation efforts through the renewables. Buildings can also benefit from solar as well as biomass-based technologies. In the transportation sector, an end-use fuel switch is an important approach to decarbonising. Some examples of bio-fuels are bio-diesel, bio-ethanol, bio-hydrogen, bio-methane and bio-dimethyl ether. An electric vehicle using renewable power is another example of decarbonisation through renewable energy deployment.

The use of nuclear power for non-military purposes particularly in power generation may reduce the release of GHGs in the atmosphere significantly. Along with power generation, nuclear energy has great potential in the fields of medicines. Nuclear technology has a seminal role to play in the decarbonisation of the global energy system.

Carbon Capture, Storage and Utilisation

It is an important technique and goes a long way in decarbonisation in the power and industrial sector. The technology consists of separating and capturing CO_2 gases from the processes that rely on fossil fuels suchas coal, oil or gas. The captured CO_2 is then transported and stored in geological reservoirs for very long periods. This technique focuses on the reduction of emissions even while continue using fossil fuels. Issue of safety becomes very important with regard to capture and storage of CO_2. The CO_2 is liquified and transported through the pipelines to be stored in the depleted oil and gasfields, coal beds and underground saline aquifers not used forpotable water.

Fuel Switch and Efficiency Gains

These two are important steps to mitigate carbon emissions in the atmosphere. The emphasis is over switching to Compressed Natural Gas (CNG) from the conventional use of coal, petroleum, and other fossil fuels. 'Efficiency gains' is primarily related to improving the efficiency of fuel combustion in thermal power plants to reduce carbon as well as particulate matter injection in the lower atmosphere. This technique is also used in iron and steel, cement and other industries where the heat can be recovered or utilised for on-site heating and cooling processes.

Negative Emission Technologies

This technology along with decarbonisation is used effectively to check carbon emissions. Carbon removal technology is still in its infancy. IPCC namely (Intergovernmental Panel on Climate Change) have recognised only two methods: the use of bioenergy and afforestation or reforestation under carbon removal technology.

Negative Emissiontechnologies include a plethora of techniques. Some of them are mentioned below:

- Bioenergy carbon capture and storage
- Afforestation and Reforestation
- Soil Carbon Sequestration
- Direct air carbon capture and storage

- Ocean fertilisation
- Enhanced terrestrial weathering
- Ocean alkalinity enhancement
- Wetland restoration and construction

Bioenergy and afforestation and reforestation are considered important methods to remove CO_2. Bioenergy is the use of biomass as fuel. Biomass traps and stores atmospheric CO_2 and acts as a global sink. The release of CO_2 after the use of different bio-energies is captured and stored using decarbonisation technology. Similarly, the process of afforestation (planting saplings of trees on vacant land to increase forest cover) and reforestation (planting tree saplings to replenish the existing forests) provide optimum results in close association with decarbonisation methods. Forests are the lungs of the earth that absorb atmospheric carbon dioxide and store it as biomass. Carbon can be stored in the forests for a very long period. However, it is vulnerable to human and natural interventions in the form of deforestation and natural hazards like forest fires. The capacity to store CO_2 also varies according to the species and age of the trees. Usually, the capacity gradually increases with age and reaches saturation level at a certain point of age. In other words, not every stretch of forest and every tree has the same absorption capacity of carbon dioxide.

The geo-engineering techniques focus on altering and deflecting the incoming shortwave solar as well as the outgoing longwave terrestrial radiation of the earth. All these techniques are at a nascent stage and are full of uncertainty and risk in terms of large scale deployment. You must, however, know about these techniques. The most important methods include:

- Stratospheric aerosol injection
- Marine sky brightening
- Space-based mirrors
- Surface-based brightening
- Cirrus cloud thinning

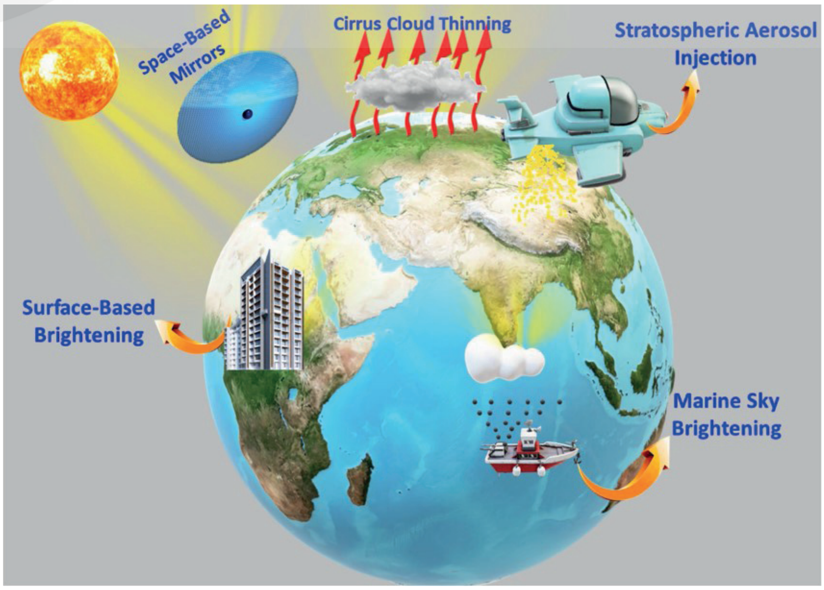

Fig. 17.5: Major Radiative Forcing Geoengineering Techniques.
(Source: Taken from Strategies of Mitigation of Climate Change; a Review Published in Queen's University, Belfast- Research Portal, 2020.)

All these methods are intended to deflect the radiation to reduce the atmospheric temperature. The stratospheric aerosol injection is inspired by the incidents of volcanic eruptions which injected the volcanic ashes and other soot up into the atmosphere causing a deflection of incoming solar radiation causing a temperature drop of 0.4℃ - 0.6℃. Marine sky brightening involves cloud seeding with seawater and chemicals to enhance cloud reflectivity.

Space-based mirrors and surface brightening are solar radiationmanagement techniques that aimto reflect part of the incoming solar radiation to reduce global temperatures. Surface brightening considerably enhances the earth's albedo hence may reduce the temperature of the atmosphere. Cirrus cloud thinning is another radiation management technique. Thinning of cirrus clouds will through, injection of aerosols, help to escape longwave terrestrial earth's radiation to the outer spacethus having a cooling effect as the heat is not trapped in the lower atmosphere. The opacity of the cirrus clouds absorbs parts of the incoming solar radiation and is partially transparent to the outgoing longwave radiation. The cirrus clouds normally have a warming effect, as it absorbs more incoming radiation and let go of less longwave radiation. Thinning will allow more radiation in the form of heat to escape the lower atmosphere.

SAQ 3

a. What is an adaptation to climate change?

b. What are the geoengineering techniques for climate change mitigation?

c. What do you understand by Negative Emission Technology?

17.5 SUMMARY

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

About pollution, global warming and climate change. You are now in a position to explain atmospheric pollution its sources and causes. In this unit, global warming and its negative impact have also been explained. The mitigation measures and adaptation strategies to address the impacts of climate change have also been presented to you for your awareness and understanding. The unit elaborates on atmospheric pollution; global warming and climate change to help you to develop a comprehensive, systematic, and logical comprehension of the three contemporary and interrelated concepts. Adaptation and mitigation measures to address the challenges of recent climate change and future prospective impacts have also been handled for your benefit in the unit.

17.6 TERMINAL QUESTIONS

1. Explain the impact of global warming on food availability and biodiversity?

2. What do you understand about the process of decarbonisation? How it Works?

3. Why the geoengineering techniques of carbon removal have still not been widely accepted?

17.7 ANSWERS

Self-Assessment Questions (SAQ)

1. a) Atmospheric pollution is defined as limited to the situation in which the outdoor ambient atmosphere contains materials in concentrations, which are harmful to humans and their surrounding environment.

   b) Volcanic Eruptions, extraterrestrial dust particles(Natural Source),Burning of the Fossil Fuels and Fires, Vehicular Discharges, Industrialisation and Agricultural Activities (Anthropogenic Sources) are important sources of atmospheric pollution.

   c) Primary air pollutants are as follows:

   - Oxides of Carbon
   - Nitrogen Oxides (NO)
   - Hydrocarbons (HC)
   - Sulphur Oxides (SO)
   - Particulate Matter

2. a) Global warming is the gradual increase in the earth's temperature. It is mainly caused by the greenhouse effect.

   b) The main causes of global warming are emissions of greenhouse gases, viz, CO_2, CO, CH_4, oxides of nitrogen and oxides of sulphur.

   c) Hotter temperatures, more severe storms, increased drought, rise in the temperature of the oceans, loss in the bio-diversity, food shortage, aadverse impact on health, poverty and displacement are some of the impacts of global warming.

3. a) Adaptation is the way of adjustment to changing climates. It is the resilience and adaptability measures taken by the world community to address climate change.

   b) Geoengineering techniques are the techniques of altering the earth's radiation balance through the management of solar and terrestrial radiation.

   c) The negative emission techniques are designed to capture and sequester CO_2 from the atmosphere and are also referred to as carbon dioxide removal methods.

Terminal Questions

1. Refer to section 17.3.1.
2. Refer to section 17.4.1.
3. Start your answer by mentioning what are the Geoengineering Techniques.
   - Explain how it works.
   - Highlight the economic and technical viability of these techniques.
   - Highlight the enormity and scale of implementations.

- Widespread scientific research in this field is still lacking.

17.8 REFERENCES AND FURTHER READINGS

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8. www.carbonfootprints.com

UNIT 18

WEATHER FORECASTING

Structure

18.1 INTRODUCTION

In this course, so far, you have studied about the fundamentals of climatology like elements and controls of weather and climate, origin and evolution of atmosphere and its composition and vertical structure. You are also aware of the atmospheric processes of insolation, heat balance and pressure systems. You know about atmospheric disturbances in the form of fronts, cyclones and difference in air masses. You have studied in detail about climatic classification of both Koppen and Thornthwaite. Under contemporary issues, you have been acquainted with climate change theories and issues like global warming.

In this unit, you will study about weather forecasting. Sec. 18.2 will give you a brief introduction to weather forecasting and its types. In Sec. 18.3, you will get acquainted with procedures or steps required in weather forecasting. You will learn about different tools required for weather forecasting in Sec. 18.4. Sec. 18.5, will brief you about different methods of weather forecasting. Lastly you will have a brief tour about the weather forecasting India in Sec. 18.6.

In the next unit, you will study about Applied Climatology which would be the last unit of this course.

Expected Learning Outcomes

After studying this unit, you should be able to:

- define weather forecasting and discuss the different types of weather forecasting;

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- explain the procedure of weather forecasting;
- describe the tools used for weather forecasting;
- differentiate between different methods of weather forecasting; and
- discuss histogenesis of weather forecasting and its development in India.

18.2 DEFINITION AND SIGNIFICANCE OF WEATHER FORECASTING

Weather forecasting involves predicting atmospheric conditions such as air temperature, humidity, sky conditions, air pressure, and the overall atmospheric circulation in a specific location or region. This prediction utilises scientific tools and technological knowledge, serving as a means to predict the atmospheric conditions before they occur. The process is supported by various statistical and empirical techniques, and forecasts can be made at different temporal levels, such as daily, weekly, or monthly, depending on the available information sources. Conducting weather prediction requires extensive research in atmospheric sciences.

In contemporary times, there is a growing demand for weather forecast data across various segments of society. For instance, tourists planning a week-long trip need a comprehensive weather forecast to make proper plans and take necessary precautions. Similarly, fishermen require forecasts regarding different time frames, ranging from a few hours to several days, depending on the duration of their fishing trips. Sports events are also significantly influenced by weather conditions, with the success of outdoor games or tournaments relying on favorable weather and accurate forecasts.

Weather forecasting plays a crucial role in agricultural activities, spanning from the initial stages of sowing to the application of fertilisers, the need for irrigation, and the eventual harvesting of crops. It also aids in the storage and transportation of crops. In essence, weather forecasting is a scientific product that impacts various aspects of our daily lives.

Now, let us familiarise ourselves with various types of weather forecasting based on different time scales.

18.2.1 Types of Weather Forecasting

Weather forecasting is categorised into four types based on different time scales, each serving distinct purposes with varying accuracy parameters. Let us explore them briefly:

Long Range Weather Forecast

- Extends over periods like a fortnight, month, season, or even a year.
- Presented as statements or estimates due to lower accuracy compared to shorter duration forecasts.
- Considers departures from normal atmospheric conditions based on past observations.
- Important for predictions like monsoon success or failure.

Medium Range Weather Forecast

- Provided for 3 days to 3 weeks, offering greater accuracy than long-range forecasts.
- Crucial for weather-sensitive activities such as farming, flood forecasting, and transportation.
- Made possible by global forecasting models developed at various meteorological centers.

Short Range Weather Forecast

- Encompasses a few hours to a day or 72 hours, with high accuracy, especially for the first 12 hours.
- Applicable for day-to-day activities like aviation, transport, tourism, and disaster management.
- Relies on maps, weather charts, satellite imagery, or changes in atmospheric conditions.

Nowcast

- A brief forecast for a few hours, focusing on the current weather details and extrapolated forecasts.
- Enables detailed predictions of individual storms for small areas using radar, satellite images, and observational data.
- Offers pre-warnings for extreme weather events like cyclones, thunderstorms, and tornados.
- Essential for disaster management, aviation, marine safety, and various industries.

Nowcasting proves valuable in preventing casualties, minimising property loss, and safeguarding the economy. Its applications extend to aviation, marine safety, water and power management, offshore oil drilling, construction, and leisure industries.

SAQ I

a) What is meant by weather forecasting and what is its significance in our daily lives?

b) List out the different types of weather forecasting based on time scales?

18.3 PROCEDURES OF WEATHER FORECASTING

Today, the field of weather forecasting has evolved into a highly scientific endeavor, encompassing a series of well-defined steps. These include the meticulous recording, collecting, transmitting, compiling, plotting, analysing, and ultimately forecasting of weather-related information. Let us briefly acquaint ourselves with each of these steps.

The ***recording*** of weather data, such as temperature, pressure, wind speed, direction, and precipitation, is carried out using an array of instruments and tools at weather and meteorological stations worldwide. These stations, situated on land and water surfaces, conduct recordings at various times throughout the day, specifically at 6 a.m., 6 p.m., 12 a.m., and 12 p.m. Additionally, satellite imagery is employed to capture and document weather-related information.

The ***collection*** of weather-related information is facilitated by numerous weather recording centers and stations strategically positioned across different global locations, including mountains, plains, plateaus, oceans, and seas. These centers gather meteorological, climatological, hydrological, and oceanographic data from a vast network of satellites, moored buoys, drifting buoys, aircraft, ships, and land-based observation stations, etc. constituting the World Meteorological Organisation (WMO).

Following the recording and collection processes, the ***transmission*** of weather-related data takes place. The World Meteorological Organisation, a scientific body under the United Nations founded in 1950, today includes 193 member countries and a substantial network of observatories and stations. The WMO collaborates with the National Meteorological and Hydrological Services of its member countries, sharing weather-related data internationally through the World Weather Watch. Three primary collection centers, situated in Washington D.C. (USA), Melbourne (Australia), and Moscow (Russia), facilitate the transmission of information from local and regional centers. This system ensures the dissemination of daily weather forecasts and timely warnings for significant weather and climate events.

Following the recording, collection, and transmission processes, climatological experts take on the tasks of compiling and ***analysing*** the data. Computers play a crucial role in this final analysis, with experts utilising various models, which will be explored in subsequent sub-sections. Finally, after the analysis, the data is interpreted in the form of a weather forecast.

18.4 TOOLS IN WEATHER FORECASTING

You are already acquainted with various instruments utilised for collecting weather-related data, such as thermometers, barometers, hygrometers, and rain gauges, which provide localised measurements of weather variables. The advent of satellite climatology has extended the capability to obtain weather-related information over larger areas and measure upper air weather conditions. Instruments like radiosondes, satellites, and radars play crucial roles in gathering upper atmospheric data. Let us study briefly the details of these instruments.

Radiosondes, illustrated in Fig. 18.1, are instruments lifted by balloons equipped with radio transmitters. The term "radiosonde" combines "radio" for the onboard transmitter and "sonde," an old English term meaning messenger. These instruments contain sensors capable of directly measuring pressure, temperature, and wet bulb temperature up to an altitude of approximately 30 km. The collected data is promptly transmitted to ground stations via the onboard radio transmitter, with ground-based antennas tracking the motion of the radiosonde for measurement purposes.

Fig: 18.1: Radiosonde.
(Source: https://en.m.wikipedia.org/wiki/File:Radiosonde-wx-balloon.jpg, cc: Public Domain)

Rawinsondes, akin to radiosondes, offer wind speed and direction at various altitudes through radar tracking. These balloons filled with hydrogen and featuring a metal target, reflect radar signals, allowing horizontal drift measurements in addition to ascent.

Both ***airplanes*** and ***satellites*** contribute to capturing images of earth's atmosphere at different levels. Airplanes provide aerial photos of cloud covers, particularly at lower altitudes, while satellites, categorised as geostationary and polar orbital satellites, play a crucial role in capturing images and recording atmospheric data. Geosynchronous satellites, positioned at extremely high altitudes (about 36,000 km), cover larger areas, while polar satellites, due to their lower altitudes (about 800 km), capture detailed information on smaller areas like cloud cover and water vapour.

Satellites are equipped with two types of sensors: sounding sensors, exemplified by AVHRR (Advanced Very High Resolution Radiometer), which provide information on thermal conditions, cloud cover, and water vapour and are attached to polar satellites; and imaging sensors, attached to high-altitude geosynchronous or geostationary satellites, offering insights into thermal and humidity conditions, as well as capturing images of the physical and cultural landscape.

Radars, operating on microwave wavelengths, are active remote sensing systems. Unlike passive systems, radars can capture images during day or night, and in various weather conditions, including clouds and precipitation. The fundamental principle involves transmitting a microwave signal toward a target object, detecting the backscattered radiation, and measuring the strength of the signal to discern different targets. The time delay between transmitted and reflected signals determines the distance or range of the target object from the radar. Refer to Fig. 18.2 to understand better.

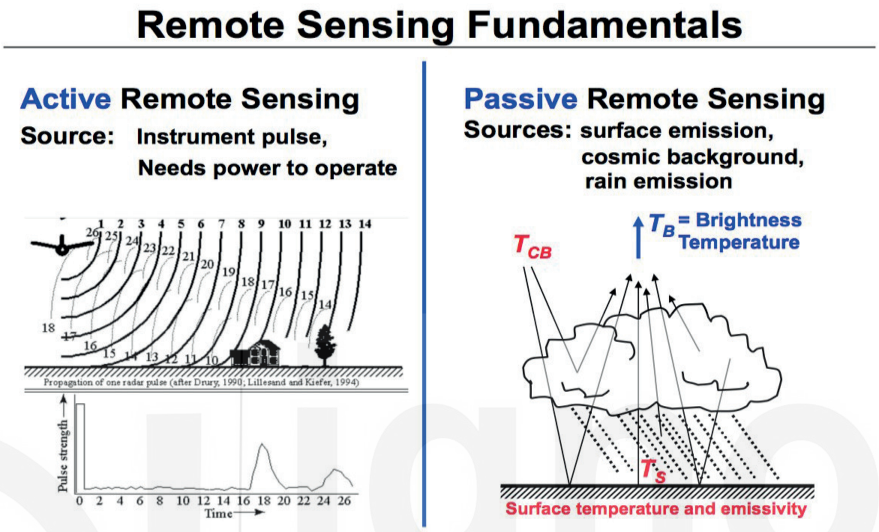

Fig. 18.2: Active and Passive Remote Sensing.
(Source: http://pmm.nasa.gov/image-gallery/active-and-passive-remote-sensing-diagram, Credit: NASA)

Before we proceed to the next section, let us answer some short answer type questions.

SAQ 2

a) What are some of the instruments used for collecting weather-related data on a localised level?

b) How is weather-related data transmitted internationally?

Let us now delve into different methods of weather forecasting.

18.5 METHODS OF WEATHER FORECASTING

Various methods are employed for weather forecasting and they are chosen based on forecaster experience, available information, and forecast complexity. Weather forecasting involves extensive atmospheric research, incorporating mathematical and statistical techniques. Professional weather scientists and forecasters employ these methods. Let us explore some well-defined forecasting methods.

Persistence Method

As its name implies, this method is the most straightforward and is based on the idea that "today equals tomorrow." This approach makes the assumption that the current atmospheric conditions will continue to exist tomorrow. For instance, if this form of prediction is used and it is sunny today with a temperature of 36°C, then tomorrow will likewise be the same. This approach functions well in locations where seasonal or temporal variations in the weather are minimal. For instance, predictions during the summer months in Mumbai can be produced using the persistence approach because the daily weather conditions there do not vary much at that time of year. Although this strategy seems to be more appropriate for short-range weather forecasts, but it is also suitable for long-range weather forecasts such as monthly or seasonal forecasts. In that case, a cold and dry month may be followed by another cold and dry month.

Trends Method

This method, as its name implies is based on predictions on specific *trends* that are seen. These trends could be similar to wind direction and speed during a cyclonic event, which could help forecast the weather conditions with precision as to when the cyclone would make landfall at a certain location. For instance, a cyclone that is moving West at a speed of 300 km/day and is 1500 km East of a region, it will reach that particular region in five days. If the forecast is prepared for a few hours, the trends method can also be used for nowcasts. Take for example, a cyclone is located about 100 km south-west of a place and is moving in north-easterly direction at a speed of 50 km/hr. It will take only two hours to reach the place. However one thing has to be kept in mind that this method applies only when there is some sort of consistency in the elements of weather in a particular system.

Climatology Method

Just as climate of a place is determined by average weather conditions over a long period of time, so this method involves the predictions of weather conditions of particular place and time by finding out the average weather conditions of that particular place and time that has accumulated over a long period of time. For example if one has to make predictions of weather conditions of Chennai for 10^{th} of December, then all weather data recorded in over the years for Chennai city for December 10, would be accounted for. As this method also relies of previous weather trends of a particle day or month, and that too for a long period of time, it works well if the weather conditions are more or less similar for that particular place for that particular time. If the weather condition at that period of time for that particular place is not uniform then the results will not be so appropriate and this method will not be suitable.

Analog Method

This method is based on regularity or periodicity of weather conditions in the past and belief of recurrence or repetition of similar weather events in future. Analog method thus finds an analogy of a particular day's forecast scenario with a day in the past when the weather scenario looked similar. Take for example; if a cyclone had developed in an area after a warm afternoon, then if similar temperature conditions persist in the afternoon, one can predict the arrival of a cyclone. It is however true that this method is complicated as there is impossibility to find a perfect analog. Even small differences can lead to faulty results and inaccurate predictions.

Numerical Weather Prediction (NWP) Method

The numerical weather prediction method uses computers and sophisticated computer programmes and equations related to atmospheric variables such as temperature, pressure and humidity. These equations are then used by model-running on supercomputers to predict weather predictions. The equations used in numerical weather prediction method must always be very precise so as to give accurate results. Otherwise, when the models are used, errors multiply and give wrong results. Errors are also caused by certain gaps in the prior data that forms the basis of the equations and are used in a model. Despite these flaws, numerical weather prediction method is considered to be the best of the above methods and provides accurate daily weather forecast. However, it also requires immense expertise and only skilled forecasters use the model to provide accurate weather information.

These methods cater to different forecasting needs and challenges. Numerical Weather Prediction, although complex, stands out for its precision. Learners are encouraged to explore additional resources for a deeper understanding of weather forecasting types and methods.

Learners can watch the following videos related to weather forecasting from the following YouTube links:

1) Observing Weather:

https://www.youtube.com/watch?v=Y6p5fGCJbtI&list=PLDCsGRRaAZqf0UAvuVbte3ZssrUXVHBcb&index=4&t=8s

2) Predicting Weather:

https://www.youtube.com/watch?v=4Nq-LGsm8_U&list=PLDCsGRRaAZqf0UAvuVbte3ZssrUXVHBcb&index=3&t=90s

SAQ 3

a) What is the Persistence Method in weather forecasting?

b) What are the challenges and advantages of the numerical weather prediction method?

18.6 WEATHER FORECASTING IN INDIA

Established in 1875, the India Meteorological Department (IMD) serves as the country's National Meteorological Service, consolidating all meteorological activities under a single authority. Its primary goals include conducting meteorological observations, acting as a governmental agency for forecast-related activities in sectors like agriculture, water resource management, industries, oil exploration, shipping, and aviation. Additionally, IMD plays a crucial role in providing pre-warnings for extreme weather events such as cyclones, floods, thunderstorms, heat waves, and cold waves. This information is disseminated to disaster management agencies and the public to prevent potential loss of life and property.

IMD's objectives also extend to fostering high-end research in meteorology and related fields. The department actively detects and locates earthquakes in different parts of the country, aiding in vulnerability assessments for development projects.

Over the past 140 years, IMD has evolved from the telegraph age to the computer age and, currently, the satellite era. India proudly operates its own geostationary satellites for continuous atmospheric monitoring and precise weather predictions. The INSAT series, equipped with the Very High Resolution Radiometer (VHRR), contributes essential data for cloud motion vectors, cloud top temperature, water vapour content, rainfall estimation, weather forecasting, and cyclone genesis and track prediction. The Oceansat-2 satellite, launched in 2009, carries instruments like the Ocean Color Monitor (OCM), Ku-band Scatterometer, and Radio Occultation Sounder for Atmospheric studies (ROSA).

In addition to space-based systems, the Indian Space Research Organisation (ISRO) has developed ground-based observation systems such as the Automatic Weather Station (AWS), Agro-meteorological (AGROMET) Tower, Doppler Weather Radar (DWR), GPS Sonde, and Boundary Layer LIDAR (Light Detection and Ranging), abbreviated as BLL. These ground-based systems complement space-based observations and validate outcomes related to various earth system processes.

Fig. 18.3 illustrates the forecast accuracy of IMD during Cyclone Hudhud in 2014, with the red line representing the forecasted track and the black line indicating the actual observed track. The minimal difference underscores the high level of accuracy achieved by IMD in contemporary forecasts, with expectations of even greater precision in the future.

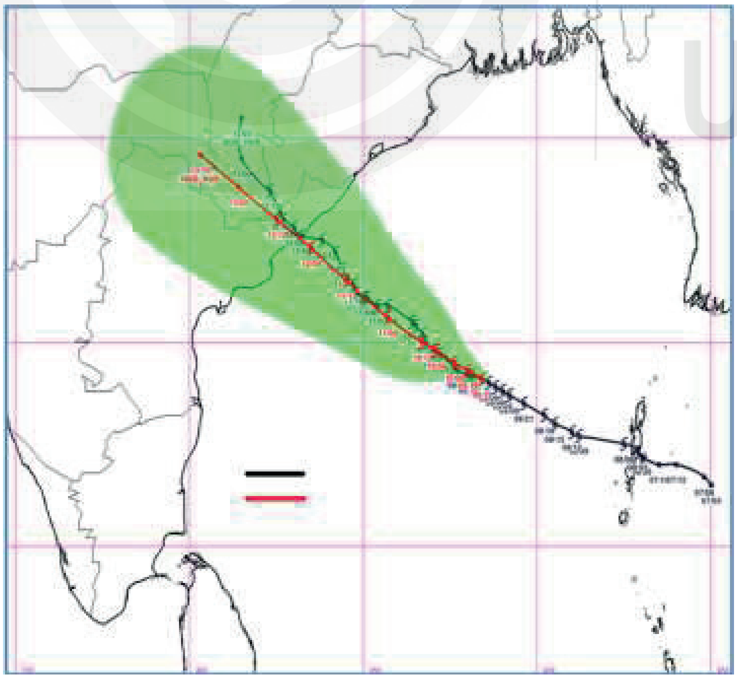

Fig: 18.3: Forecast Performance of IMD Regarding Cyclone Hudhud 2014.
(Source: IMD)

18.7 SUMMARY

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

- Weather forecasting is defined as prediction of atmospheric conditions like air temperature, humidity, sky conditions, air pressure and general circulation of the atmosphere of a particular place or a region using scientific tools and technological knowledge. During ancient times, much of the forecasting was done in a crude manner like sky colour, wind direction, cloud colour and its cover, lightening, thunder, behaviour of some animals and birds, certain folklores etc. Systematic weather data recording started with the advent of instruments like thermometer, barometer, telegraph, radiotelegraphy, radar technology and finally satellites namely sun synchronous and geosynchronous satellites.
- Weather forecasting involves some well-defined steps like recording, collecting, transmitting, compilation, plotting, analysing and then the final forecasting of the weather related information. The tools used in weather forecasting are thermometers, barometers, hygrometers, rain gauge, radiosondes, rawinsondes, aeroplanes, satellites and radars etc.
- Weather forecasting is done for different temporal scales which have different uses and have different parameters for accuracy like long range weather forecast, medium range weather forecast, short range weather forecast and nowcast.
- There are several different methods used for weather forecasting. Some of the well-defined forecasting methods used by climatologists are persistence method, trends method, climatology method, analog method, numerical weather prediction method.

18.8 TERMINAL QUESTIONS

1. Define weather forecasting? What are the different types of weather forecasting based on different time scales?
2. Describe briefly different methods of weather forecasting.
3. What procedures are followed in forecasting of weather?
4. Which organisation or department provides meteorological services in India? Explain briefly how weather prediction is done in India.

18.9 ANSWERS

Self-Assessment Questions (SAQ)

1. a) Weather forecasting involves predicting atmospheric conditions such as air temperature, humidity, sky conditions, air pressure, and overall atmospheric circulation in a specific location or region. It utilises scientific tools and technological knowledge to anticipate atmospheric conditions before they occur. This is important as it allows individuals and various

sectors of society to make informed plans, take necessary precautions, and optimise their activities based on weather conditions.

b) Weather forecasting is categorised into four types based on different time scales. These include:

- Long Range Weather Forecast
- Medium Range Weather Forecast
- Short Range Weather Forecast
- Nowcast

2 a) Thermometers, barometers, hygrometers, and rain gauges are commonly used instruments for collecting weather-related data on a localised level.

b) Weather-related data is transmitted internationally through the World Weather Watch, which is facilitated by the World Meteorological Organisation (WMO). The WMO collaborates with the National Meteorological and Hydrological Services of its member countries and operates three primary collection centers in Washington D.C., Melbourne, and Moscow. These centers receive data from local and regional centers and ensure the dissemination of daily weather forecasts and timely warnings for significant weather and climate events.

3. a) The Persistence Method is a straightforward approach that assumes the current weather conditions will continue to exist in the future. It works well in locations with minimal seasonal or temporal variations in weather, such as predicting daily weather in Mumbai during the summer months.

b) The numerical weather prediction method requires precise equations to ensure accurate results. In this method errors can multiply and lead to incorrect predictions. Additionally, gaps in prior data used in the equations can also introduce errors. However, despite these flaws, the method is considered the best and provides accurate daily weather forecasts when used by skilled forecasters.

Terminal Questions

1. Your answer should contain definition of weather forecasting and a little bit of explanation. Then discuss all the types of weather forecasting as in Sec. 18.2
2. You can start with a paragraph briefing the meaning of weather forecasting and its types. Then you can elaborate on different methods of weather forecasting as given on sec. 18.5.
3. Refer to Sec. 18.3 and answer.
4. Refer to Sec. 18.6 and answer.

18.10 REFERENCES AND FURTHER READINGS

1. Lal, D. S. (2013). Climatology, Sharda Pustak Bhawan, Allahabad.
2. Singh, S. (2005). Climatology, Prayag Pustak Bhawan, Allahabad.

Web Links

- Weather Data Recording and Weather Forecasting

  https://www.youtube.com/watch?v=x0Z88o_EKHo, published on Nov 30, 2017 (UGC ePGPathshala)

- Observing Weather: https://www.youtube.com/watch?v=EKWrrkI1xrY

  (IGNOU SOS YouTubevideo)

- Predicting weather: https://www.youtube.com/watch?v=ZJE2VrdFxDg

  (IGNOU SOS YouTubevideo)

- https://en.m.wikipedia.org/wiki/File:Radiosonde-wx-balloon.jpg

- http://pmm.nasa.gov/image-gallery/active-and-passive-remote-sensing-diagram

UNIT 19

APPLIED CLIMATOLOGY

Structure

19.1 INTRODUCTION

In this course, so far you have learnt about fundamentals of climatology, atmospheric processes, atmospheric disturbances, climatic classification etc. In Block 5, you are studying about contemporary issues like climate change especially human induced climate change, weather forecasting etc. In this unit, you will study about Applied Climatology

Every field of study should incorporate practical applications to contribute to the society, rather than remaining solely theoretical. Given that, the weather and climate of a region significantly influence our daily activities and lifestyles, climatology holds substantial practical value. Therefore, it is imperative to explore the practical applications of climatology alongside its academic aspects. Sec. 19.2 will give you a brief introduction to the applied aspects of climatology. Subsequent sections 19.3 and 19.4 will acquaint you with the applied aspects of climatology in different natural and societal systems.

Expected Learning Outcomes

After studying this unit, you should be able to:

- define applied climatology and elucidate its significance in understanding the earth's climate systems;
- identify different sources of climatological data;
- analyse the intricate relationship between climate and natural systems, particularly in terms of water distribution and biodiversity dynamics; and
- evaluate the intersection of climate with societal systems, such as agriculture, tourism, and public health.

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19.2 DEFINITION AND SIGNIFICANCE

Applied climatology is a branch of study that researches into the practical implications of climate on both natural and societal systems. In simpler terms, it investigates how climate influences various aspects of our environment and human activities. This field has garnered significant attention in recent years, as researchers and practitioners recognise the importance of understanding and utilising climatic information to address social, economic, and environmental challenges.

To better understand the concept of applied climatology, let us explore several definitions provided by prominent scholars in the field. H. Landsberg and W.C. Jacobs (1951) described applied climatology as the scientific analysis of climatic data with a focus on its practical applications for operational purposes. According to K. Smith (1987), applied climatology involves utilising both historical and real-time climatic data to solve a diverse array of problems in agriculture, industry, energy, and other sectors. G.A. Marotz (1989) defines applied climatology as the scientific utilisation of climatic data and theoretical frameworks to address specific challenges.

The emergence of applied climatology as a distinct field can be traced back to the mid-20th century, particularly during the 1940s and 1950s. During this period, there was a growing recognition of the profound impact of climate on human activities and the environment. Researchers began to explore how climate influences various aspects of life, ranging from agriculture to urban planning.

Indeed, climate plays a crucial role in shaping our lifestyles and daily routines. In desert climates, such as those found in parts of the Middle East or North Africa, housing structures are adapted to cope with extreme heat during the day and cold temperatures at night. One notable example is the construction of traditional adobe houses. Adobe, a building material made from sun-dried mud bricks, provides excellent thermal insulation, helping to keep interiors cool during the scorching daytime temperatures and warm during chilly nights. Additionally, architectural features such as thick walls, small windows, and flat roofs are common in desert dwellings. Thick walls provide further insulation, while small windows minimise heat gain from direct sunlight. Flat roofs are often used to collect rainwater during rare precipitation events, contributing to sustainable water management in arid regions. Furthermore, courtyard designs are prevalent in desert architecture, providing shaded outdoor spaces that promote airflow and ventilation. Courtyards also serve as social hubs for families, allowing for communal gatherings while remaining sheltered from the harsh desert sun. Overall, the design of housing in desert climates reflects a deep understanding of local environmental conditions, demonstrating how architecture can adapt to and harmonise with the natural world.

Moreover, vegetation serves as a reliable indicator of climate, influencing the types of crops that can be grown in a particular region. In regions with temperate climates, farmers often follow seasonal patterns for planting and harvesting crops, taking advantage of optimal temperature and precipitation conditions. For instance, in areas where winters are cold and summers are warm, crops like wheat, corn, and barley are planted in the spring and harvested in the fall. Conversely, in tropical climates with consistent temperatures and abundant rainfall, agricultural practices may differ. Farmers in these regions might practice year-round cultivation of crops such as rice, bananas, and sugarcane. They may also employ techniques like terracing or irrigation to manage water resources effectively in areas prone to heavy rainfall or drought.

The impact of climate extends beyond housing and agriculture to our choice of clothing. In warmer regions, lightweight and breathable fabrics like cotton are preferred to stay cool and comfortable, while in colder climates, insulated garments are necessary to retain body heat and protect against the cold.

Despite advancements in technology, which have enabled us to mitigate the effects of extreme temperatures through devices like air conditioners and heaters, the influence of climate remains profound. Therefore, it is essential to consider weather and climatic factors when formulating economic and social policies to ensure their effectiveness and sustainability.

In the subsequent sections of this module, we will delve deeper into the applied aspects of climatology. Specifically, we will explore different sources of climatic data and their relevance in understanding and addressing real-world challenges.

19.2.1 Climatological Data Sources

Recently, there has been an increase in the accessibility of climatological data, facilitated by the services provided by numerous weather agencies and meteorological departments. This enhanced accessibility has empowered climatologists with the ability to acquire vital climatic data for their research endeavors. Additionally, relevant climatic data can be found on the internet, either freely accessible or at a nominal cost.

In terms of sources for collecting climatic data, they can be broadly categorised into two types:

A) Primary Sources: Primary sources include the data collected through direct involvement of the investigator who ventures into the field to gather climatic data utilising various instruments such as thermometers, radiometers, hygrometers and moisture sensors.

B) Secondary Sources: Secondary sources encompass data that is collected elsewhere and subsequently compiled and rigorously quality-checked before being made available to climatologists and researchers. In this scenario, climatologists do not directly gather the data themselves but instead rely on external sources, agencies, or meteorological departments worldwide, including organisations such as the World Meteorological Organisation (WMO), the National Center for Atmospheric Research, the National Oceanic and Atmospheric Administration (NOAA), and the India Meteorological Department (IMD). Nowadays, meteorological data is also accessible on the internet. Subsequently, climatologists reanalyse this data, segregating various atmospheric variables for utilisation in research or other climate-related studies.

Now, let us turn our focus to the direct and indirect impacts of weather and climate elements on human beings and their activities, beginning with the discussion on the impact of climate on natural systems.

19.3 CLIMATE AND NATURAL SYSTEMS

The earth's natural system is a complex web of interconnected spheres, each playing a crucial role in shaping the planet's environment and supporting life. These spheres include the lithosphere, atmosphere, hydrosphere, biosphere, and cryosphere. Climate, defined as the long-term pattern of weather in a particular region, serves as a fundamental driver influencing various processes within these spheres. Understanding the impact of climate on each sphere is essential for comprehending the complex dynamics of the earth's natural systems.

The lithosphere, the solid outer layer of the earth, encompasses the planet's landmasses, mountains, and geological formations. Climate exerts a significant influence on the lithosphere through processes such as weathering, erosion, and landform development. Temperature and precipitation patterns dictated by climate determine the rate and intensity of these geological processes. Various climatic elements, including temperature, humidity, and wind, affect erosional processes such as fluvial, aeolian, and glacial erosion. Spatial variations in climatic parameters lead to diverse landforms; for instance, regions with high temperatures and humidity foster dense vegetation, reducing erosion. Conversely, deforested areas experience increased erosion, while humidity contributes to landslides and soil creep. Glaciers and wind also shape landforms, representing key areas of research in climatic geomorphology.

The atmosphere is a gaseous envelope surrounding the earth and contains gases and aerosols vital for supporting life. Nitrogen and oxygen constitute the majority of the atmosphere, with trace gases including greenhouse gases like carbon dioxide and methane. Human activities, notably burning fossil fuels, have increased greenhouse gas concentrations, causing atmospheric warming by trapping outgoing radiation. Temperature changes affect other climatic elements, impacting landscapes, water bodies, ice sheets, and biogeochemical cycles.

The cryosphere constitutes the frozen components of the earth's system, encompassing both ice and snow on land and frozen portions of water bodies. Land-based snow cover includes vast continental ice sheets such as those found in Greenland and Antarctica, along with snow and permafrost in various regions. The aquatic part of the cryosphere comprises frozen areas of polar oceans, frozen rivers, and lakes. Climate exerts significant influence on the cryosphere. High albedo (reflectivity of solar radiation) of snow, play a crucial role. It reflects approximately 90% of incoming light, maintaining cooler temperatures. However, even slight temperature increases lead to snowmelt, reducing albedo and accelerating further melting. Conversely, colder temperatures reverse this process.

In summary, the interplay between climate and the earth's spheres is evident in the lithosphere's response to climatic processes, the atmosphere's role in regulating climate dynamics and the cryosphere's sensitivity to temperature changes. Understanding these interactions is crucial for addressing environmental challenges like climate change and preserving biodiversity.

19.3.1 Climate and Water

Climate and water are intricately linked, with climate patterns profoundly influencing the distribution, availability, and quality of water resources across the globe. Water is essential for life and integral to countless natural processes. It is highly sensitive to changes in climate, making the relationship between climate and water a critical aspect of understanding and managing earth's hydrological systems.

Climate influences water availability through various processes such as precipitation, evaporation, and runoff. Precipitation, including rain, snow, sleet, and hail, is a direct result of atmospheric conditions driven by climate factors such as temperature, humidity, and air pressure. Changes in climate patterns, such as alterations in temperature and precipitation regimes, can significantly impact precipitation patterns, leading to shifts in the timing, intensity, and distribution of rainfall and snowfall events.

For instance, global warming is altering precipitation patterns, causing changes in the frequency and intensity of extreme weather events such as hurricanes, droughts, and heavy rainfall. These changes can have far-reaching consequences for water availability, leading to water scarcity in some regions and increased flood risk in others.

Evaporation, the process by which water transitions from liquid to vapor and returns to the atmosphere, is also influenced by climate factors such as temperature, humidity, wind speed, and solar radiation. Warmer temperatures generally lead to increased evaporation rates, while humidity levels and wind speed can affect the rate at which water evaporates from surfaces such as oceans, lakes, rivers, and soil.

Changes in climate can disrupt the balance between precipitation and evaporation, leading to shifts in water availability and impacting ecosystems, agriculture, and human populations. In regions experiencing increased temperatures and decreased rainfall, evaporation rates may exceed precipitation rates, leading to reduced water availability and drought conditions. Conversely, in regions experiencing increased precipitation or melting snow and ice, runoff rates may increase, leading to flooding and water quality issues.

Climate also plays a crucial role in shaping the earth's water cycle, the continuous movement of water between the atmosphere, land, and oceans. The water cycle is driven by solar energy, which heats the earth's surface, causing water to evaporate and rise into the atmosphere. As water vapour cools and condenses, it forms clouds and eventually falls back to the earth's surface as precipitation, completing the cycle.

Changes in climate can disrupt the water cycle, altering the timing and magnitude of precipitation events, increasing the frequency and intensity of extreme weather events, and impacting water storage, distribution, and availability. These changes can have significant implications for water resources management, ecosystem health, and human well-being.

Moreover, climate change is affecting the earth's cryosphere. As temperatures rise, glaciers and ice caps are melting at an accelerated rate, contributing to sea-level rise and altering freshwater availability in glacier-fed rivers and lakes. Permafrost, frozen ground found in polar and high-latitude regions, is also thawing, releasing stored carbon and methane gases into the atmosphere and impacting ecosystems and infrastructure.

In addition to affecting water quantity, climate change is also impacting water quality. Changes in temperature, precipitation patterns, and runoff can influence the transport and distribution of pollutants, nutrients, and sediments in water bodies, affecting water quality and ecosystem health. For example, increased runoff from urban areas and agricultural fields can carry pollutants such as fertilizers, pesticides, and heavy metals into rivers, lakes, and coastal waters, leading to eutrophication, algal blooms, and contamination of drinking water sources.

Addressing the complex challenges posed by climate change and water requires integrated and adaptive water resources management strategies that consider the interactions between climate, water, and ecosystems. These strategies may include implementing water conservation measures, improving water infrastructure, enhancing water-use efficiency, restoring degraded ecosystems, and promoting sustainable land and water management practices.

In conclusion, the relationship between climate and water is multifaceted and dynamic, with climate patterns exerting significant influence on water availability, quality, and distribution. Climate change is exacerbating water-related challenges, including water scarcity, flooding, and pollution, and posing significant risks to ecosystems, agriculture, and human well-being. Effective management of water resources in the face of climate change requires holistic approaches that consider the interconnected nature of climate, water, and ecosystems and prioritise sustainability, resilience, and adaptation.

19.3.2 Climate and Biodiversity

Climate and biodiversity are intricately linked, forming the foundation of the earth's natural systems and supporting the abundance of life on our planet. Biodiversity is defined as the variety of life forms existing in a particular habitat or ecosystem. It encompasses a wide range of organisms, from microscopic bacteria to towering trees and majestic mammals. Climate, on the other hand, refers to the long-term patterns of temperature, precipitation, wind, and other atmospheric conditions in a given region.

The relationship between climate and biodiversity is complex and multifaceted, with climate playing a fundamental role in shaping the distribution, abundance, and diversity of species across the globe. Understanding this relationship is essential for addressing pressing environmental challenges such as habitat loss, species extinction, and climate change.

Climate serves as a primary driver of biodiversity patterns by influencing the physical environment and ecological processes that govern the distribution and evolution of species. Temperature and precipitation regimes, for example, determine the types of habitats and ecosystems that can exist in a particular region. Tropical rainforests, characterised by high temperatures and abundant rainfall, support some of the most diverse ecosystems on earth, housing an astonishing array of plant and animal species. In contrast, arid deserts, with their extreme heat and limited water availability, harbor fewer species but are uniquely adapted to survive in harsh, arid conditions.

Moreover, climate variability and change can directly impact the survival and reproduction of species, leading to shifts in population dynamics, species distributions, and community interactions. For instance, changes in temperature and precipitation patterns can alter the timing of seasonal events such as flowering, migration, and hibernation, disrupting the delicate balance of ecosystems and threatening the survival of species dependent on specific environmental cues.

Climate also plays a crucial role in shaping the evolution and adaptation of species over time. Through a process known as natural selection, organisms that are better suited to their environment are more likely to survive and reproduce, passing on their advantageous traits to future generations. As climate conditions change, species may undergo adaptations or evolve new characteristics to cope with shifting environmental conditions. For example, polar bears have evolved specialised adaptations such as thick fur and layers of fat to survive in their icy Arctic habitat, while cacti in desert regions have developed water-storing tissues and spines to thrive in arid conditions.

In addition to influencing individual species, climate also affects the structure and function of entire ecosystems, driving important ecological processes such as nutrient cycling, primary productivity, and energy flow. Changes in climate can disrupt these processes, leading to cascading effects throughout the food web and altering the dynamics of entire ecosystems. For instance, warming temperatures in the Arctic are causing permafrost to thaw, releasing stored carbon and methane gases into the atmosphere, which in turn contributes to further climate change.

Furthermore, climate interacts synergistically with other drivers of biodiversity loss, such as habitat destruction, pollution, overexploitation, and invasive species, exacerbating the negative impacts on ecosystems and species. For example, deforestation in tropical regions not only reduces habitat availability for countless species but also disrupts local climate patterns, leading to changes in temperature, precipitation, and humidity that can further stress ecosystems and increase the risk of species extinction.

Addressing the interconnected challenges of climate change and biodiversity loss requires coordinated efforts at local, national, and global scales. Conservation strategies aimed at protecting and restoring natural habitats, implementing sustainable land management practices, reducing greenhouse gas emissions, and promoting biodiversity-friendly policies can help mitigate the impacts of climate change on biodiversity and enhance the resilience of ecosystems and species to future environmental changes.

Thus the relationship between climate and biodiversity is fundamental to the functioning of earth's natural systems and the survival of life on our planet. Climate influences the distribution, abundance, and diversity of species, shapes ecosystem dynamics and processes, and drives evolutionary adaptations over time. As we confront the challenges of climate change and biodiversity loss, it is essential to recognise and address the complex interactions between these two critical components of our planet's biosphere. Only through concerted action and collective stewardship can we safeguard the rich tapestry of life that sustains us all.

Refer to Figure 19.1 to get a clear picture of the effect of climate on different natural and societal systems.

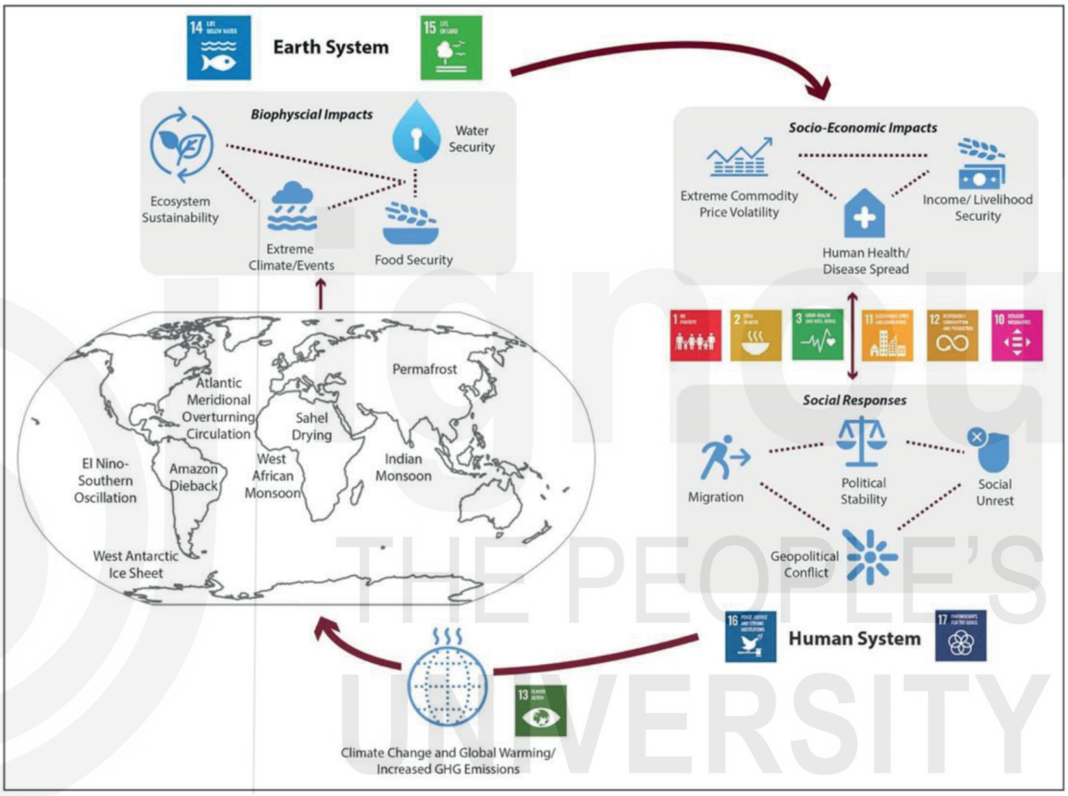

Fig. 19.1: Climate and Natural and Societal Systems.

(Source: https://en.wikipedia.org/wiki/File:Franzke_2022_Environ_Res_Lett_Fig2_-_Schematic_of_some_possible_interactions_and_cascading_effects_between_the_Earth_system_and_the_Human_system.jpg, Creative Commons Attribution 4.0 International)

SAQ I

Explain how climate variability can directly impact biodiversity patterns and species interactions, providing examples to support your explanation.

Let us now study about the impact of climate on societal systems.

19.4 CLIMATE AND SOCIETAL SYSTEMS

Climate exerts significant influence on various societal systems, both directly and indirectly. Direct impacts are evident in sectors such as agriculture, where temperature and precipitation patterns directly affect crop yields and agricultural productivity. Similarly, the transport sector is directly impacted by extreme weather events such as storms, floods, and heavy snowfall, leading to disruptions in transportation networks and infrastructure. Additionally, climate influences recreational activities, as outdoor pursuits like skiing, hiking, and beach tourism are highly dependent on weather conditions. Energy and power requirements are also directly influenced by climate, with changes in temperature affecting heating and cooling demands, and fluctuations in wind and sunlight influencing renewable energy generation.

Indirect impacts of climate on societal systems are equally significant. For instance, changes in climate can lead to shifts in disease patterns, affecting public health systems and healthcare infrastructure. Furthermore, extreme weather events can impact insurance sectors, leading to increased claims and financial losses. Overall, understanding the multifaceted impacts of climate on societal systems is essential for effective adaptation and mitigation strategies to address the challenges posed by climate change.

19.4.1 Climate and Agriculture

Agriculture, the cornerstone of human civilisation, has evolved from the nomadic lifestyle of hunting and gathering to a sedentary existence focused on cultivating crops for sustenance and commerce. Climate, comprising elements like temperature, humidity, and precipitation, plays a pivotal role in shaping agricultural practices and determining crop distribution and productivity.

In the contemporary technological era, agricultural advancements have enabled cultivation in diverse and adverse conditions, yet the influence of climate remains profound. Temperature, a primary climatic parameter, exerts significant effects on crops throughout their developmental stages, from sowing to maturity. Optimal temperature ranges are crucial for various physiological processes in plants, and deviations can impact crop quality and yield. For instance, in regions like India, sudden temperature spikes in early spring accelerate wheat ripening, diminishing yield potential.

Frost and hailstorms pose substantial threats to crops, causing damage to a wide range of produce including potatoes, tomatoes, and oilseeds. Fruit orchards in mountain valleys are particularly vulnerable to frost damage due to temperature inversions. Hailstorms associated with weather disturbances pose additional risks to standing crops of wheat, vegetables, and oilseeds, particularly during the winter cropping season (rabi).

Moisture is another critical climatic factor that profoundly influences crop cultivation. Soil moisture levels, ranging from saturation to wilting point, dictate plant growth and development. Crops like paddy and sugarcane thrive in saturated soil conditions, while millets, maize, and wheat prefer soil at field capacity. Field capacity is the water remaining in a soil after it has been thoroughly saturated and allowed to drain freely, usually for one to two days. Conversely, prolonged moisture deficits lead to wilting and crop failure.

Atmospheric moisture and precipitation patterns significantly impact agricultural productivity, with drought being a major concern. Permanent drought characterises arid regions, while seasonal droughts occur in areas with distinct wet and dry seasons. Occasional droughts result from rainfall variability, exacerbating water stress and compromising crop yields.

Incoming solar radiation is a fundamental determinant of crop productivity, influencing photosynthesis and plant growth. Solar energy availability varies with latitude, affecting temperature regimes and determining suitable crop types for specific regions. The efficiency of solar energy conversion into chemical energy by plants fundamentally shapes agricultural productivity and crop choices.

Moreover, climate variability and change pose unprecedented challenges to agriculture. Erratic weather patterns, extreme events, and shifting climatic zones disrupt traditional cropping calendars, exacerbating risks for farmers and threatening food security. Rising temperatures, altered precipitation patterns, and increased frequency of extreme events intensify water stress, pest and disease pressures, and soil degradation, further jeopardising agricultural sustainability.

Addressing the complex interplay between climate and agriculture requires holistic approaches integrating climate-smart practices, resilient crop varieties, and adaptive water management strategies. Investments in research and innovation, extension services, and climate-resilient infrastructure are essential to enhance agricultural resilience and mitigate climate-related risks.

Furthermore, promoting sustainable agricultural practices, conserving natural resources, and enhancing agro-ecosystem resilience are critical for ensuring food security and livelihood sustainability amidst a changing climate. Collaborative efforts among policymakers, researchers, farmers, and stakeholders are imperative to foster climate-resilient agriculture and safeguard global food systems for future generations.

19.4.2 Climate and Tourism

The impact of climate on recreation and tourism is multifaceted, shaping various outdoor activities and travel experiences worldwide. From skiing in sub-freezing temperatures to exploring scenic hill stations during the summer months, climate influences the attractiveness and feasibility of recreational pursuits and tourism destinations.

Recreational activities such as skiing, hill trekking, gliding, and surfing are directly dependent on specific weather conditions, particularly sub-freezing temperatures and snowfall. These activities thrive in regions where climatic conditions support winter sports and outdoor adventures. Ski resorts, for example, rely on consistent snowfall and cold temperatures to attract visitors seeking exhilarating downhill runs and pristine powder slopes.

Conversely, outdoor sports events like football, cricket, rugby, and volleyball are subject to weather interference, with rainfall, thunderstorms, dust storms, fog, and other meteorological phenomena disrupting gameplay. Inclement weather conditions can lead to match cancellations, delays, or alterations, affecting both players and spectators alike.

Climatic factors such as air temperature, sunshine duration, humidity levels, cloud cover, and wind speed significantly influence tourism experiences and destination choices. Based on these factors, tourism activities can be categorised into two main groups: climate-dependent tourism and attractiveness-dependent tourism.

Climate-dependent tourism revolves around destinations where visitors seek specific climatic conditions for recreational purposes. For instance, visits to hill stations during the summer months offer relief from sweltering heat in lower-altitude regions, attracting tourists seeking cooler temperatures and scenic landscapes. These destinations rely on favorable climate conditions to attract visitors and sustain local economies.

Attractiveness-dependent tourism, on the other hand, focuses on destinations prized for their natural beauty, cultural heritage, or unique attractions rather than specific climatic conditions. For example, visits to Sahastra Dhara falls in Dehradun exemplify attractiveness-dependent tourism, where travelers are drawn to the picturesque waterfalls and surrounding landscapes irrespective of weather conditions.

Religious tourism also bears the influence of weather and climatic conditions, particularly in regions where religious sites are situated in high-altitude areas prone to landslides and extreme temperatures. The path leading to Vaishno Devi shrine is susceptible to landslides during the rainy season, prompting tourists to avoid visiting during periods of heightened landslide risk. Additionally, religious sites situated at high elevations may have limited accessibility during extreme weather conditions, with some locations only open to visitors during certain seasons to mitigate risks associated with freezing temperatures or adverse weather conditions.

For instance, pilgrimage sites like the "Char Dham" circuit (comprising Kedarnath, Badrinath, Yamunotri, and Gangotri) and Kailash Mansarovar are accessible only during specific months to avoid extreme weather conditions prevalent at high elevations. These sites experience a surge in religious tourism during favorable weather conditions, with pilgrims embarking on spiritual journeys to seek blessings and fulfillment of religious obligations.

Understanding the interplay between climate and tourism is crucial for destination management, sustainable development, and risk mitigation. Tourism stakeholders must adapt to changing climate patterns, implement resilience measures, and diversify offerings to ensure visitor satisfaction and destination competitiveness amidst evolving climatic conditions. Collaborative efforts between governments, tourism industry stakeholders, and local communities are essential to foster climate-resilient tourism practices and safeguard tourism-dependent economies for future generations.

Fig. 19.2: Climate Dependent Tourism (A View Munnar Hills Station Kerala).

(Source: https://en.m.wikipedia.org/wiki/File:Munnar_hillstation_kerala.jpg,Creative Commons Attribution 2.0 Generic)

19.4.3 Climate and Health

The human body's ability to thrive is intricately linked to specific climatic conditions, encompassing factors such as light, temperature, humidity, precipitation, and oxygen levels. When these parameters deviate from optimal levels, adverse effects on human health ensue. Understanding the impact of climate on human physiology is crucial for mitigating health risks and ensuring well-being in diverse environmental contexts.

One notable example of climate-induced health challenges occurs at high altitudes, such as in mountainous regions, where low air pressure leads to decreased oxygen availability. This phenomenon is known as mountain sickness and manifests in symptoms like nausea and nosebleeds as the body struggles to adapt to the reduced atmospheric pressure. At extreme altitudes, breathing may become nearly impossible without supplemental oxygen, necessitating the use of oxygen cylinders by mountaineers embarking on high-altitude expeditions like those to Mount Everest. Figure 19.3 depicts mountaineers equipped with oxygen cylinders and insulated clothing to withstand the harsh conditions encountered at high elevations.

Temperature extremes also pose significant health risks. The human body's normal temperature of 98.6°F (37°C) is maintained through metabolic processes and heat exchange with the surrounding environment. In extremely cold conditions, hypothermia can occur as the body loses heat faster than it can generate, leading to frostbite and, in severe cases, tissue damage and death. Conversely, hyperthermia occurs in excessively hot environments, causing the body's temperature to rise and potentially resulting in heat-related illnesses such as heat exhaustion and heatstroke. Maintaining a comfortable temperature within the body's normal range is essential for overall well-being, highlighting the importance of physio-climatic indices like the heat index stress, standard effective temperature, and apparent temperature in assessing human comfort and health risks.

Medical climatology, an emerging field within climatology, focuses on studying the effects of weather and climate on human health. Climate influences the prevalence and distribution of certain diseases, with global warming and increased humidity contributing to the expansion of vector-borne diseases like malaria and dengue fever beyond their traditional geographic ranges. Understanding these relationships between climate and health is essential for developing effective strategies to mitigate disease transmission and protect human populations from emerging health threats associated with climate change.

The interplay between climate and human health underscores the need for proactive measures to address climate-related health risks and promote resilience in vulnerable communities. Public health interventions, such as disease surveillance and vector control programs, can help mitigate the spread of climate-sensitive diseases. Additionally, enhancing healthcare infrastructure and capacity-building efforts can improve communities' ability to respond to climate-related health emergencies effectively.

Education and awareness campaigns play a crucial role in empowering individuals and communities to adopt adaptive measures and minimise health risks associated with climate variability and change. Strategies such as heat wave preparedness plans, air quality alerts, and hydration campaigns can help reduce the burden of climate-related health impacts and enhance community resilience.

Furthermore, interdisciplinary collaboration among climatologists, public health professionals, policymakers, and community stakeholders is essential for addressing complex climate-health challenges. By integrating climate data, health surveillance systems, and community engagement strategies, stakeholders can develop targeted interventions that promote both environmental sustainability and human well-being.

In conclusion, the relationship between climate and human health is multifaceted, encompassing physiological responses to temperature extremes, altitude-related challenges, and disease transmission dynamics. Medical climatology offers valuable insights into understanding these interactions and guiding effective public health interventions. By adopting a proactive and collaborative approach, societies can mitigate climate-related health risks and build resilient communities capable of adapting to the challenges of a changing climate.

SAQ 2

How does temperature variability affect human health? What is the potential health risk associated with extreme temperatures? Provide examples to illustrate your answer.

Fig. 19.3: Mountaineers Climbing to Kalindi mountains of Himalayas, Uttarkashi, Uttarakhand, India.

(Source: https://commons.wikimedia.org/wiki/File:Climbing_to_Kalindi_mountains_of_Himalayas,_Uttarkashi,_Uttarakhand,_India.jpg, Creative Commons Attribution 2.0 Generic)

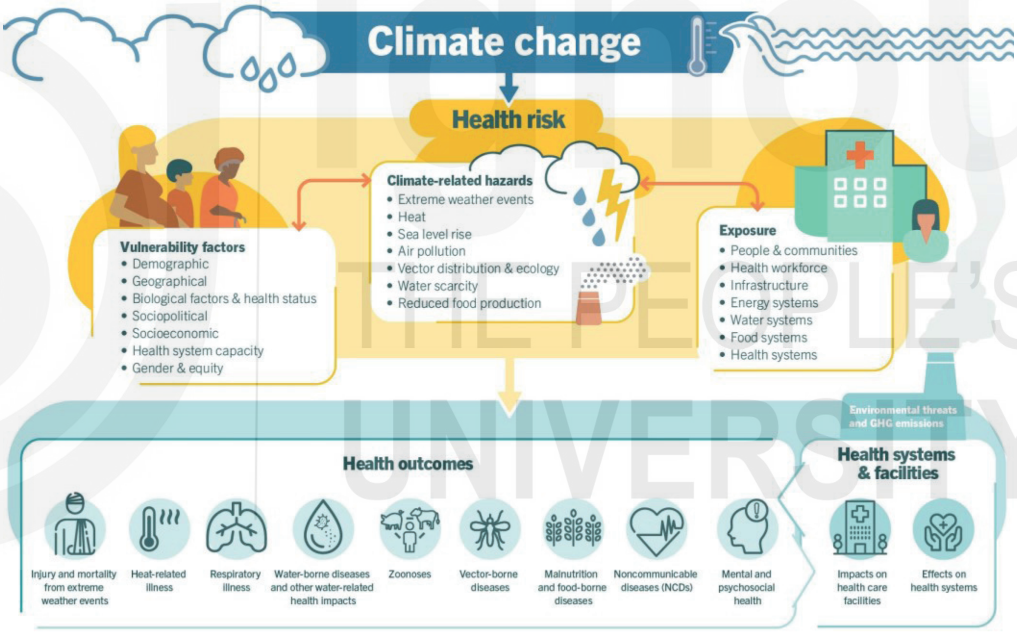

Fig. 19.4: Climate and Health.

(Source: https://www.who.int/news-room/fact-sheets/detail/climate-change-and-health)

Now let us sum up what we have learnt so far.

19.5 SUMMARY

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

- Climate is the long-term pattern of weather conditions in a particular region, including temperature, precipitation, humidity, wind patterns, and other atmospheric variables. Understanding climate is crucial as it directly influences natural systems, societal activities, and human well-being.
- Climatological data sources provide valuable information for studying climate patterns. These sources include weather stations, satellites, ocean

buoys, and climate models. They collect data on temperature, precipitation, atmospheric pressure, and other relevant variables, enabling scientists to analyse climate trends and make predictions about future changes.

- Climate has a profound impact on natural systems. Changes in climate can alter ecosystems, affecting biodiversity, habitats, and species distribution. For example, shifts in temperature and precipitation patterns can disrupt the life cycles of plants and animals, leading to declines in populations and changes in species composition.
- Water resources are highly influenced by climate. Variations in temperature and precipitation can affect the availability of water for drinking, agriculture, industry, and ecosystems. Changes in climate can lead to more frequent droughts or floods, impacting water availability and quality, as well as ecosystems dependent on aquatic habitats.
- Similarly, climate significantly influences agricultural practices and productivity. Changes in temperature and precipitation patterns can affect crop yields, pest and disease prevalence, and the suitability of land for farming. Farmers must adapt their practices to cope with these changes, utilizing techniques such as crop diversification and water management strategies.
- Tourism is also influenced by climate. Climate conditions can affect travel patterns, destination choices, and the timing of tourist seasons. Extreme weather events and natural disasters can disrupt tourism activities and infrastructure, impacting local economies and livelihoods.
- Moreover, climate has a direct impact on human health. Extreme heat waves, storms, and changing disease patterns can pose risks to human well-being. Vulnerable populations, such as the elderly and those with pre-existing health conditions, are particularly at risk from climate-related health impacts.

19.6 TERMINAL QUESTIONS

1. How does climate influence recreational activities and tourism experiences globally?
2. What is Applied Climatology? What are the data sources used in Climatology?
3. Explain the impact of climate on Water.

19.7 ANSWERS

Self-Assessment Questions (SAQs)

1. Climate variability directly affects biodiversity patterns and species interactions by disrupting ecological processes. For instance, changes in temperature and precipitation alter the timing of key events like flowering or migration, upsetting ecosystems' delicate balance. For example, warmer temperatures can lead to earlier flowering times, causing mismatches with pollinators' emergence, impacting both plants and pollinators. Additionally,

altered climate conditions may force species to shift their ranges, leading to new interactions with other species, potentially resulting in competition or predation dynamics. Thus, climate variability can significantly influence biodiversity distribution and species interactions, affecting ecosystem stability and resilience.

2. Temperature variability significantly impacts human health, with extremes posing notable risks. In cold conditions, hypothermia may occur as the body loses heat faster than it generates, leading to frost bite and tissue damage. Conversely, hyperthermia in hot environments can cause heat-related illnesses like heat exhaustion and heatstroke. So, extreme cold can result in hypothermia, while extreme heat can lead to heatstroke. It is crucial to maintain a comfortable temperature range within the body's normal limits to ensure well-being, emphasising the importance of assessing human comfort and health risks using physio-climatic indices like heat stress and apparent temperature.

Terminal Questions

1. Refer to Sec. 19.4.2 and answer.
2. Start your answer with the definition of Applied Climatology and explain its significance. Then explain different data sources as mentioned in Sec. 19.2.1.
3. Refer to Sec. 19.3.1 and answer.

19.8 REFERENCES AND FURTHER READINGS

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Web Link

- Applied Climatology, https://www.youtube.com/watch?v=CXsX0oqEed0

GLOSSARY

Acid Rain : The chemical reaction between Sulphur dioxide and Nitrogen Oxide results in acid rain.

Adaptation : It simply suggests how to adapt or adjust to the condition of changing climate.

Applied Climatology : It is a branch of study that researches into the practical implications of climate on both natural and societal systems.

Environmental Degradation : It is the lowering of environmental quality at local, regional, and at global level by both natural processes and human activities.

Global Warming : Global warming is a gradual increase in the earth's temperature which is mainly caused by the greenhouse effect.

Mitigation : It means methods/measures to reduce climate change impacts

Nowcast : A brief forecast for a few hours, focusing on current weather details and extrapolated forecasts.

Numerical Weather Prediction Method : It uses computers and sophisticated computer programmes and equations related to atmospheric variables such as temperature, pressure and humidity.

Persistence Method : It is a straightforward approach that assumes the current weather conditions will continue to exist in the future.

Phytoplanktons : These are microscopic marine algae.

Pollution : Pollution means lowering of environmental/ atmospheric (as the case may be since atmosphere and environment are not the same) quality at the local scale/ level caused exclusively by human activities.

Primary Sources : It includes the data collected through direct involvement of the investigator who ventures into the field to gather climatic data.

Secondary Sources : Secondary sources encompass data that is collected elsewhere and subsequently compiled and rigorously quality-checked before being made available to climatologists and researchers.

Smog : It is the combination of smoke and fog that generally occur over the cities and industrial regions.

Sunspots : Sunspots are storms on the sun's surface that are marked by intense magnetic activity and play host to solar flares and hot gassy ejections from the sun's corona.

Weather Forecasting : It is predicting atmospheric conditions such as air temperature, humidity, sky conditions, air pressure, and the overall atmospheric circulation in a specific location or region through various statistical and empirical techniques at different temporal levels, such as daily, weekly, or monthly, depending on available information sources.