Change is the law of nature. Everything in the world changes and so does climate. The earth's atmosphere is dynamic and has been changing ever since it came into being after the birth of the earth. Accordingly global climatic changes have occurred both in geological and historical times. Climatic fluctuations have taken place varying from a few years to a few million years. Over a long period of time, climatic fluctuations may be such that a shift of climate prevailing over a given area takes place. This change in climate is known as **climate change.**

There are several evidences which show the climatic changes have taken place. Geological records have indicated that there had been alteration of glacial and inter-glacial periods. The geomorphological features in cold areas exhibit traces of advances and retreats of glaciers. The sediments deposits in glacial lakes also reveal the occurrence of warm and cold periods. The rings in the trees provide clues about wet and dry periods. Historical records describe the vagaries in climate.

In India, Rajasthan was wet and cool around 8000 B.C. The area experienced higher rainfall from 3000 B.C. to 1700 B.C. and was the centre of the Harappan civilisation from 2000 to 1700 B.C. It became a dry land after that period.

In the geological past, the earth was warm some 500-300 million years ago, through the Cambrian, Ordovician and Silurian periods. During the Pleistocene epoch, glacial and inter-glacial periods occurred, the last major peak glacial period was about 18,000 years ago. The period from 18,000 to 5,500 years ago corresponds to the deglaciation of the earth. By 12,000 years ago, only scattered areas of ice sheets remained in western North America, with the main ice sheet confined to eastern Canada.

A very strange event occurred about 10,200 years ago which had a great influence on Scandinavia and particularly on Scotland. The margins of the remaining ice sheet expanded and some small ice sheets reappeared. This period is known as the *Younger Dryas* (named

after a small flower found in cold climates). However, this period did not last long and shortly after, climatic conditions in the northern hemisphere resembled those of the present day conditions. Figure 32.1 shows the pattern of temperature change over the past 18,000 years.

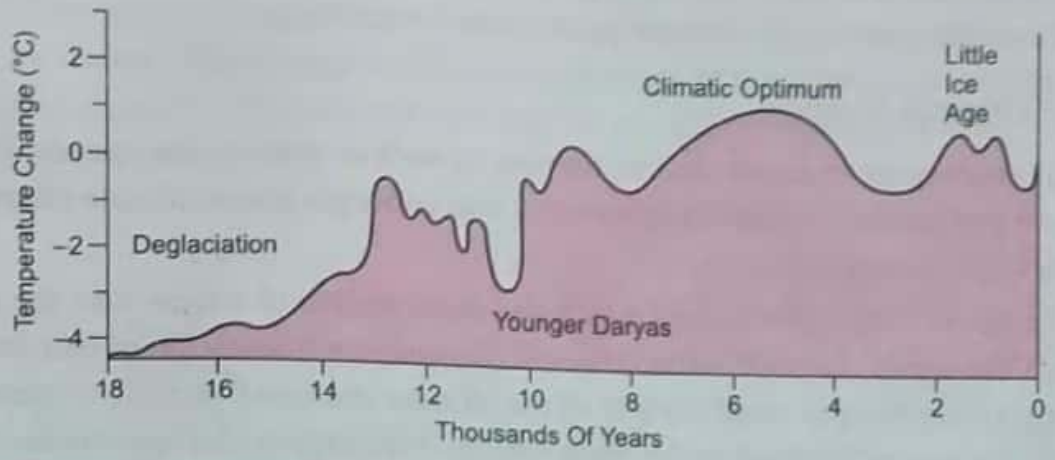

FIG. 32.1. Patterns of surface temperatures of the last 18,000 years. Vertical axis provides temperature change from the current global temperature.

The global climate experienced warming effect after the cooling spell associated with the Younger Dryas. By 7,000 years ago only the remnants of ice remaned. The warm period peaked about 5,500 yeas ago, and most ice disappeared leaving only the Greenland Ice sheet and the Arctic Ice that we have today. At this time the mean atmosphere temperature of the mid-latitudes was about 2.5°C above that of the present. This is called ***climatic Optimum***—a term originally applied to Scandinavia when temperatures were warm enough to favour more varied flora and fauna.

The Last 1,000 years. The time extending from about 950 to 1250 A.D. is called the ***Little Climate Optimum*** when Greenland was settled by Vikings due to better living conditions caused by rise in temperature (Fig. 32.2). Between 1250 and 1450 A.D., climate deteriorated

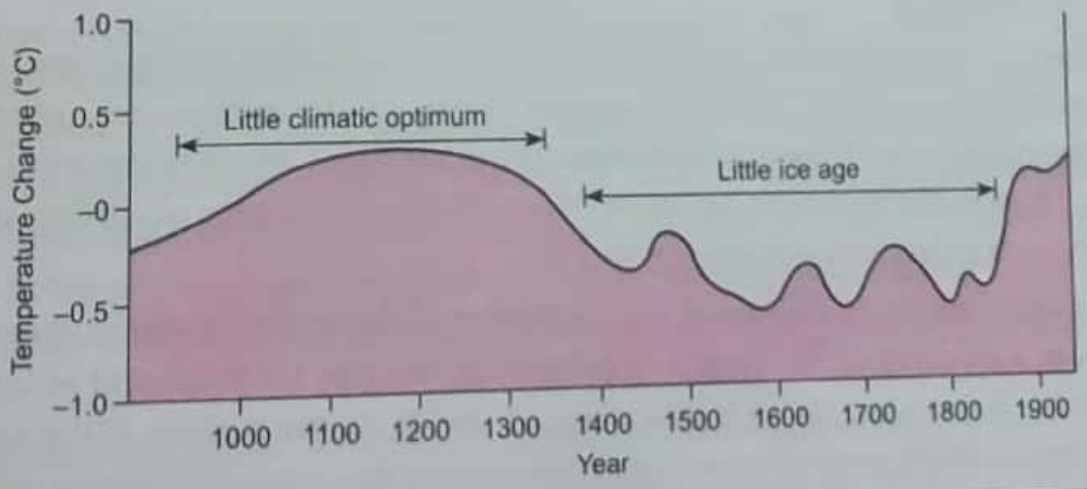

FIG. 32.2. Variations from current average surface temperature over the last 1000 years. Note that Little Climatic Optimum was followed by deterioration to little ice age.

over vast areas and Iceland's population declined. Conditions continued to worsen and the duration of time from 1450 to 1880 A.D. is known as ***Little Ice Age.*** During this period, Alpine graciers enlarged and rivers and lakes were frozen. North America also experienced similar conditions and the year 1816 is described as **"the year without a summer"**. But by the end of the 19th century, the climate again started improving.

Causes of Climate Change

Climate undergoes changes due to natural as well as man made causes. Experts of climate have put forward a number of theories and concepts about climate change. Some of them are briefly described as under :

1. **Variation in Solar Irradiation.** Sun is the main source of energy and the output of energy from the sun is assumed to be constant. However, a fluctuation of less than 10 per cent in output from the sun could explain all the climate changes that have occurred on the earth. The solar energy received at the earth's surface undergoes changes because amount of energy given off by the sun changes with the transparency of the atmosphere, or changes in distance between the earth and the sun. The average temperature at the surface of the sun is about 6000°C. However, it varies slightly and hence the energy output varies. The actual variation in solar irradiation is small and difficult to measure. But measurements made since the beginning of January, 1977 show that the temperature of the sun's surface fell 11°C in a single year. This measurement was made by Kitt Peak National Observatory near Tuscon, Arizon in the U.S.A.

According to measurements made by satellites outside the earth's atmosphere, the irradiance of the sun declined by 0.07 per cent from 1981 to 1984. A small change of 0.1 per cent for a decade or more might change the earth's climate in a measurable fashion. Computer models show that a 1 to 2 per cent drop in solar radiation would bring about conditions similar to those of *Little Ice Age.* A decline of 2 per cent for 50 years would be enough to cause renewed glaciation. A drop of 5 per cent should be adequate to bring about glaciation on the earth.

2. **Sunspots.** Scientists believe that sunspots are responsible for changes in weather patterns and climatic cycles. Detailed studies of sun's outer surface, *i.e., photospheres,* show dark circular areas known as ***sunspots.*** These are areas where temperature is about 1400°C lower than the surrounding areas. The number of sunspots occurring at any one time varies from as few as 5 or 6 as many as 100.

Sunspots follow an 11 year cycle and multiples of that cycle appear at intervals of 22 and 33 years. Still other cycles appear at periods as short as 5.5 years and as long as 90.4 years. The key to sunspot cycles is that magnetic fields on the surface of the sun reverse their magnetic polarity every 22 years—an interval twice the apparent sunspot cycle.

3. **Earth-Sun Relations.** Earth sun relations are not constant and keep on changing, some of them rather periodically. Some of the important variations in the earth-sun relations are briefly discussed as under :

(*i*) ***The obliquity of the Ecliptic.*** The obliquity of the ecliptic refers to the angle of the axis in relation to the plane in which the earth revolves around the sun. At present, the earth's axis is inclined at an angle of 23.5° on the plane of its orbit round the sun. This angle is not constant. It varies from 22° to 25° during the cycle of 41,000 years (Fig. 32.3(*a*)]. In Figure 32.3(*b*), three cases are shown where the present angle of inclination, *i.e.*, 23.5°, 0° and 54° are shown. This change brings about changes in the position of equator. Tropic of Cancer and Tropic of Capricorn and will result in climate change appreciably.

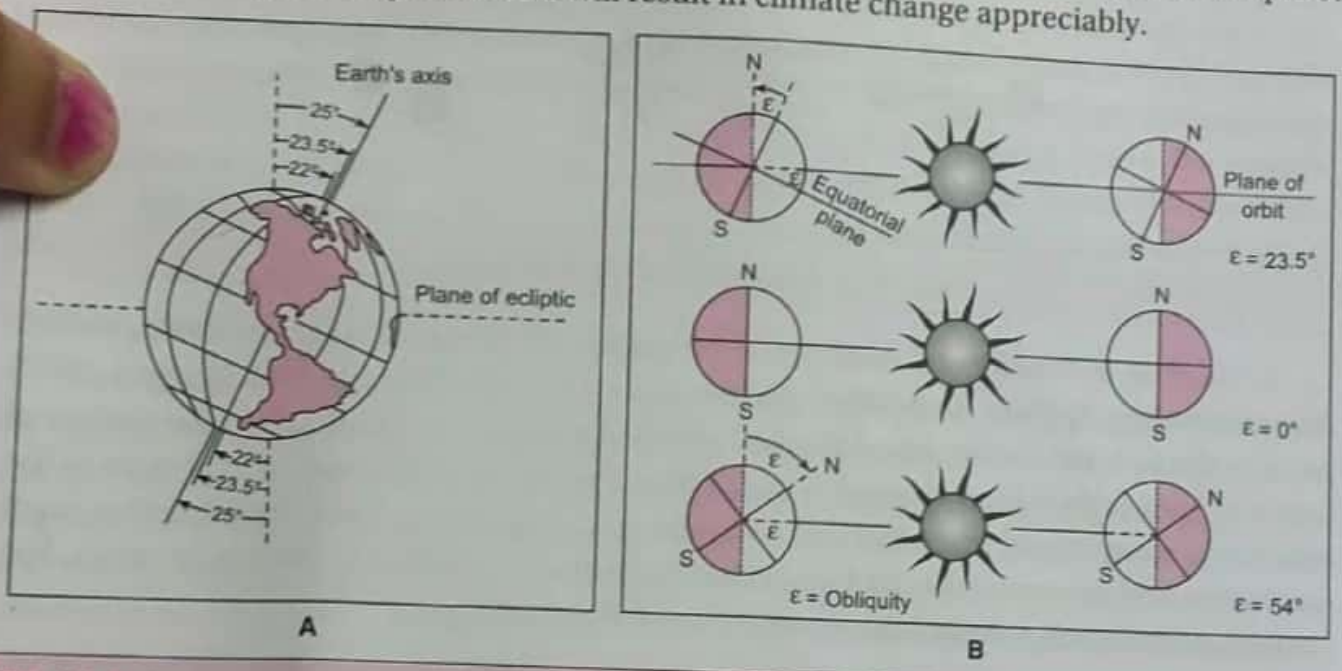

FIG. 32.3. Obliquity of the ecliptic. **(A)** The amount of tilt of the earth's axis changes between 22° and 25° over a 41,000-year period. The present value is 23.5° (from *Weatherwise*, 35(3), 1982, a publication of the Helen Dwight Reid Educational Foundation); **(B)** In the three cases shown (present angle, 0°, and 54°), the earth's climate would change appreciably.

The top diagram shows the present position and the middle and lower diagrams represent hypothetical cases. An obliquity of 0° would result in equal duration of day and night all over the globe and there would be no seasonal changes. However, climatic zones will be well defined. The lower diagram shows an extreme obliquity of 54° which will lead to great extremes in the lengths of summer and winter days and nights. For example, in December solitic position shown in the figure, much of the northern hemisphere would have 24 hours of darkness. Extreme summer and winter temperature differences would be noticed. Although, the actual changes in the angle of obliquity are not likely to be as large as cited in these examples, they are sufficient enough to cause large scale changes in earth's climates.

(*ii*) ***Earth's Orbital Eccentricity.*** The earth moves around the sun in an elliptical orbit, the eccentricity of which is derived by comparing it with a circular path. This eccentricity changes with time. The earth's orbit undergoes a change of shape during a cycle of 90,000 to 1,00,000 years. Sometimes the orbit forms a longer ellipse and then it returns to more or less a circular shape. At the time of greater eccentricity of the earth's orbit, the amount of

heat received at the earth's surface at peribelion (position of minimum distance between the earth and the sun) may be 20 to 30 per cent greater than that of aphelion (position of maximum distance between the earth and the sun). This change in the amount of solar radiation would result in change in solar constant, thereby affecting temperature and climate of the earth.

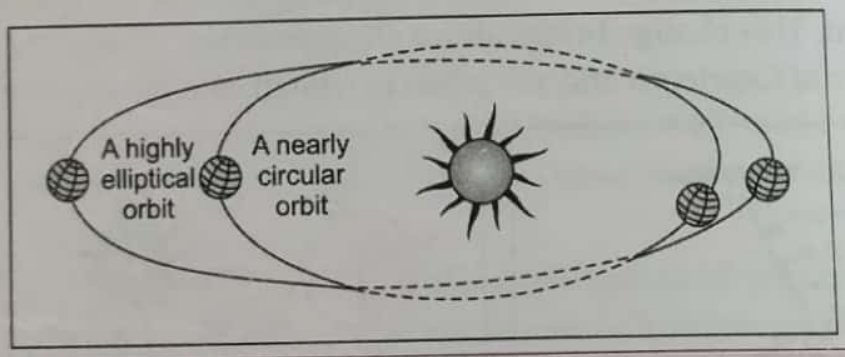

FIG. 32.4. Eccentricity of the earth's orbit

4. Theories of Continental Drift. The continental drift theory of Weganer (1912), the Sea Floor Spreading by Hary Hess (1961) and the Plate Tactonic theory by W.J. Morgan (1967) point to the fact that continents of the world formed a single vast landmass in the geological past and later drifted apart to assume their present position. This resulted in change in the position of equator and poles and led to significant change in the horizontal distribution of continents and oceans. Table 32.1 describes the drift of north pole in geological times. The position of the south pole and the equator changed accordingly.

TABLE 32.1

Drift of poles in geological times

Time (Million Years)	Geological Period	Position of North Pole	
600	Pre-cambrian	3° N	107° W
350	Silurian	14° N	124° W
285	Carboniferous	16° N	147° W
.70	Tertiary	51° N	.53° W

Large scale concentration of coal deposits in the temperate lands of the northern hemisphere indicates that these areas must be experiencing tropical climate in the carboniferous period when coal was formed. Similarly evidences of ice-sheets of carboniferous period in South America, Africa, Peninsular India and Australia is a clear indication that these areas were very cold at that time but are quite hot now.

5. Theories about the changes in the Atmospheric Composition. The contents of carbon dioxide, nitrous oxide, methane, water vapour dust particles, etc. in the atmosphere are not constant but keep on changing with time. The proportion of carbon dioxide changed in the past due to volcanic eruptions. The carbon dioxide theory about the climatic change was propounded by T.C. Chamberlin. The theory claims that variations in

the carbon dioxide in the atmosphere play a significant role in covering climatic change at the global level. This gas is transparent to the incoming short wave solar radiation but absorbs outgoing long wave terrestrial radiation. Thus any change in carbon content in the atmosphere results in changes in the temperature of the atmosphere. However, high concentration of carbon dioxide has been caused by human activities in the recent past which will be discussed later on this chapter.

6. The Volcanic Dust Theory. A lot of dust and other materials are thrown out at the time of volcanic eruption. Volcanic dust deflects light of short wavelengths coming from the sun. On the contrary, long have terrestrial radiation can easily pass through volcanic dust without any loss. In this way, the presence of volcanic dust brings down the earth's temperature to a certain extent. The volcanic dust is considered to be responsible for '*Little Ice Age*'. Frequent volcanic eruptions had initiated the process of Ice Age in the geological past.

GREENHOUSE EFFECT

Literally speaking greenhouse is the name given to a glass house which is used for protecting delicate and rare plants that require warmth. The glass panels of the greenhouse allow short wave heat radiations from the sun to pass through them into the greenhouse but obstruct the long wave terrestrial radiations reflected from the earth's surface. This process makes the house warmer and protects the plants from cold conditions. This phenomenon which helps tropical plants to grow even in cold conditions is known as greenhouse effect.

The earth's atmosphere behaves the same way as the glass panels of greenhouse. It behaves differently with the different wavelengths of radiations. While the atmosphere absorbs only about 20 per cent of the incoming short wave radiations, certain gases, particularly carbon and water vapour, absorb more than 90 per cent of the outgoing long wave terrestrial radiation. Thus the terrestrial radiation is the most important source of heating the earth's atmosphere. In this respect the atmosphere acts somewhat like the glass in a greenhouse or automobile, letting through much of the incoming solar radiation but absorbing most of the outgoing long-wave radiation. This is called *greenhouse effect.*

If you park your car in the sun with the windows of the car closed, you will find that after sometime, say after about two hours, the temperature inside the car is much higher

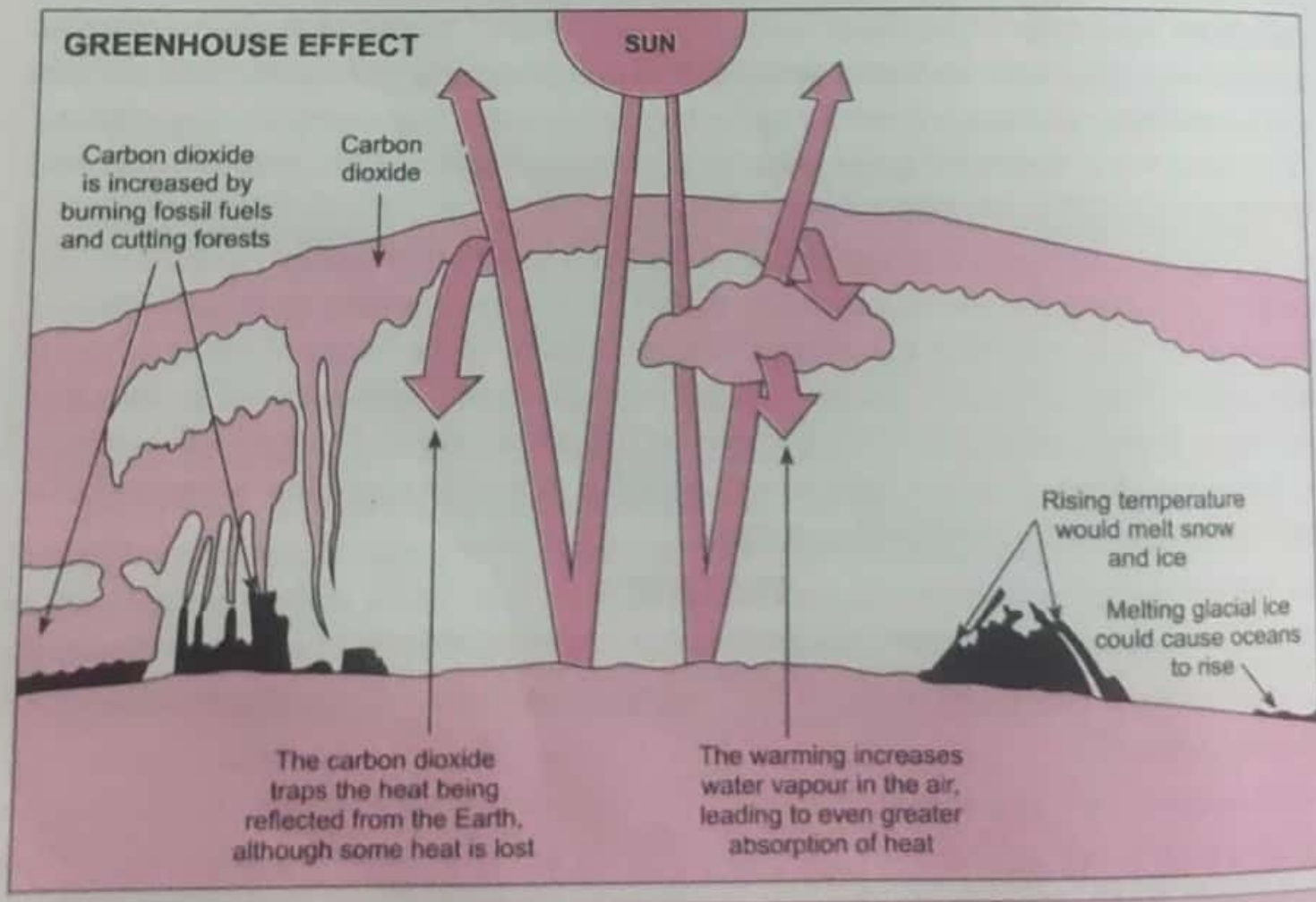

FIG. 32.5. Greenhouse effect

than that prevailing outside. Greenhouse effect can be used to grow summer vegetables in winter. This effect has been gainfully used to grow vegetables in cold region at high altitude in Ladakh where normal atmospheric temperatures are exceptionally low.

The effect of greenhouse is that more heat enters the atmosphere than the amount of heat which leaves it. Without natural "greenhouse effect" the earth would be as cold as the moon and no life could be possible on the earth. The greenhouse gases present in the atmosphere act as blanket and if these gases are taken out of the atmosphere, the earth's climate would have been 33°C cooler than what it is today.

GLOBAL WARMING

Global warming is the slow increase in world temperature caused by the greenhouse effect. Global warming is taking place due to the presence of Greenhouse gases (GHGs) in the atmosphere. The main greenhouse gases that cause global warming are carbon dioxide (CO_2), chlorofluorocarbons (CFCs), methane (CH_4), nitrous oxide (N_2O) and ozone (O_3). Some other gases such as nitric oxide (NO) and carbon monoxide (CO) easily react with GHGs and affect their concentration in the atmosphere.

Figure 32.6 shows that among all the greenhouse gases, carbon dioxide is the most important and causes more than half the greenhouse effect. About 35 to 40 per cent greenhouse effect is caused by methane and CFCs.

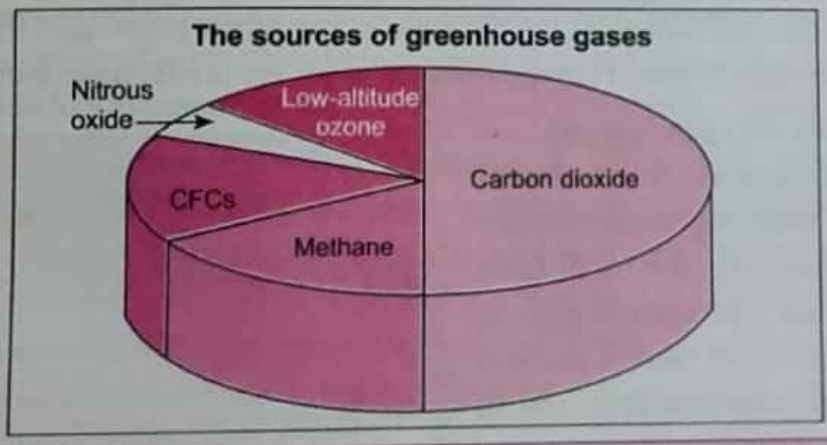

FIG. 32.6. Greenhouse Gases

Who is responsible for greenhouse effect and global warming ?

Although greenhouse effect and global warming are world-wide problems, yet advanced countries are more responsible for such sad state of affairs as compared to developing and underdeveloped countries.

In Asia, most of the countries are at the developing stage and contribute only small per cent of the total carbon dioxide emissions of the world. Industrial growth is at its initial stage in most countries of Africa and South America and these countries are least responsible for the present problem. Australia is an exception. Although this is an advanced

country, yet it is responsible for only 1.1 per cent of the total carbon dioxide emission of the world.

Table 32.3 shows that China has overtaken the U.S.A. with respect to carbon emission. However, the U.S.A. is still the top emitter when per capita carbon emission is taken into consideration.

TABLE 32.3

Word's top carbon emitted in 2018

Country	Total emission ((billion tons of CO_2)	Per capita emission (tons CO_2 per person per year)
1. China	9.8	7
2. U.S.A.	5.3	16.2
3. European Union (28 countries)	3.5	7
4. India	1.8	1.7
5. Russia	1.7	11.8
6. Japan	1.2	9.5
Global Total	37.1	4.8

Source : Global Carbon Project.

The effectiveness of any given greenhouse gas molecule depends on the magnitude of the increase in its concentration, its life time in the atmosphere and the wavelength of radiation that it absorbs. Some of the greenhouse gases are briefly described as under :

Carbon dioxide. Of all the greenhouse gases, the largest concentration is that of carbon dioxide. With rapid industrialization and urbanization, the fossil fuels like coal, petroleum and natural gas are used at an accelerated rate. This has resulted in unprecedented increase in carbon dioxide in the atmosphere. Under the pre-industrial conditions of recent centuries, *i.e.* before 1780, the atmosphere content of carbon dioxide was maintained at a reasonably low level. In 1880-1890 the carbon dioxide content was about 290 parts per million (ppm). It rose to about 315 ppm in 1980, 340 ppm in 1990 400 ppm in 2000 and 418 in 2018. This means that proportion of carbon dioxide had increased by 9 per cent by 1950 and

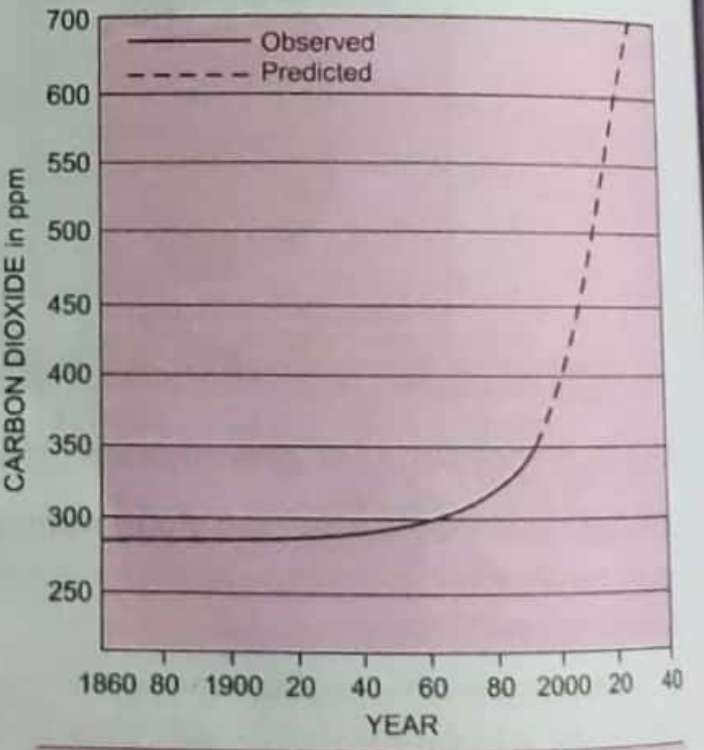

FIG. 32.7. Observed and Predicted Atmospheric Carbon Dioxide

nearly 17 per cent by 1990. The rate of increase has become still greater during last one decade.

Assuming that the annual rate of increase of fossil fuels is about 4 per cent, the level of carbon dioxide will be doubled by the year 2030. However, doubling time can be delayed until about 2050 with fuel combustion rate reduced to half of the present value.

The above mentioned facts about increase in carbon dioxide content in its atmosphere are only rough estimates and different agencies have made different estimates. The figures given by World Resource Report are reproduced in table 32.3.

TABLE 32.4

Lower Atmospheric Concentration of CO_2

Years	CO_2 Concentration	PPM
1825	0.021	210
1885	0.028	280
1985	0.035	350
2000	0.036	360
2018	0.0418	418
2050 (Projected)	0.045	450

There has been a considerable increase in *methane concentration* also. During past 100 years the concentration of methane has more than doubled (from 7.0×10^{-7} to 15.5×10^{-7}) and carbon dioxide has increased by 20 per cent (from 2.90×10^{-4} to 3.49×10^{-4}).

Global warming and environment pollution takes place in several other ways. According to some estimates, rice cultivation in the world is responsible for 20 per cent methane being added to atmosphere, and the coal mining accounts for 6 per cent of methane. The deforestation is responsible for 20 per cent of the carbon dioxide gas being added to the atmosphere. Similarly, industrialization is adding 25 per cent of chlorofluorocarbon to the aerosol of the atmosphere. Consequently, global temperature increase is by about 1.5°C.

Chlorofluorocarbons (CFCs) are products of human activity. Ozone occurs in the stratosphere where ultra-violet rays convert oxygen into ozone. Thus, ultra-violet rays do not reach the earth's surface. The CFCs which drift into the stratosphere destroy the ozone. Large depletion of ozone occurs over Antarctica. The depletion of ozone concentration in the stratosphere is called the ***ozone hole.*** This allows the ultra-violet rays to pass through the troposphere.

Increase in atmospheric carbon dioxide and other greenhouse gases increases the capacity of the atmosphere to absorb the outgoing terrestrial long-wave radiation which results in the rise of atmospheric temperature. The overall rise in the atmospheric temperature is called ***global warming.*** In 1979 a group of scientists convened by the National Academy of Sciences came to the conclusion that a doubling of atmospheric

carbon dioxide will cause an average global warming of about 3°C by the middle of 21st century.

An increasing trend in temperature was discernible in the 20th century. The greatest warming of the 20th century was during the two periods, 1901-44 and 1977-99. Over each of these two periods, global temperatures rose by about 0.4°C. In between, there was a slight cooling, which was more marked in the Northern Hemisphere.

The globally averaged annual mean temperature at the end of the 20th century was about 0.60°C above that recorded at the end of the 19th century. The seven warmest years during the 1856-2000 were recorded in the 1990s. The year 1998 was the warmest year, probably not only for the 20th century but also for the whole millennium.

during the 1990-2000 were recorded in the 1990s. The year 2005 was the warmest year, probably not only for the 20th century but also for the whole millennium.

GLOBAL TEMPERATURE DATA

- 1998 was the warmest year of record
- 2006 was the warmest year of U.K.
- Seven of the 10 warmest years of record occurred since 1990
- The 1990s were the warmest decade on record
- The 1980s were the second warmest decade on record
- The 10 warmest years of record occurred since 1983
- The mean temperature of Earth increased about 1°F (0.4°C) in the 20th century
- The 20th century was the warmest century of the millennium

Fig. 32.8 shows that the atmospheric temperature has risen considerably. If the rising trend in the increase of temperature continues, it will have far reaching effects on the global environment. Several glaciers will melt and the rivers will be flooded. The water of the snow melt will reach the sea and there will be rise in sea level upto 15-20 metres. Most of the low lying coastal areas will be drowned and almost all the major ports of the world would perish. Besides it will change the rainfall patterns, create new plant diseases and pose problems and enlarge ozone hole.

Efforts at international level are being initiated to control emission of greenhouse gases and to arrest the trend towards global warming. The most important one is the Kyoto protocol proclaimed in 1997. This protocol went into effect in 2005, ratified by 141 nations. Kyoto protocol bounds the 35 industrialised countries to reduce their emissions by the year 2012 to 5 per cent less than the levels prevalent in the year 1990.

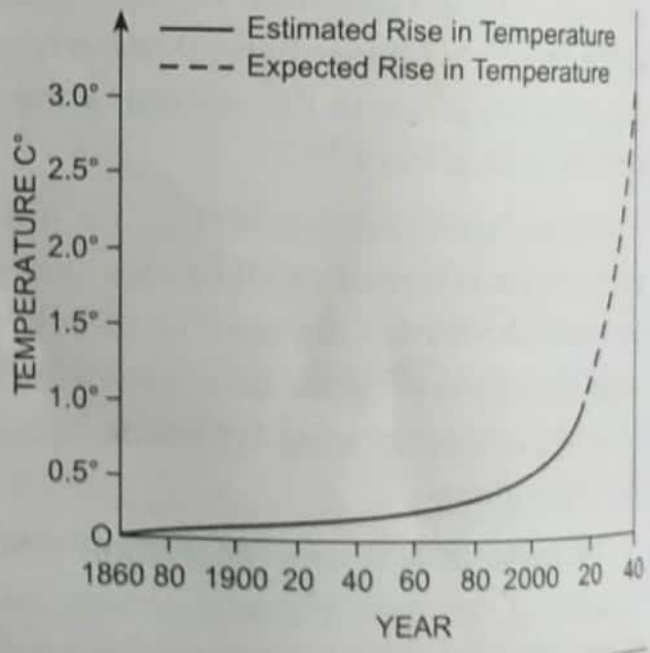

FIG. 32.8. Estimated and expected rise in global temperature

Evidence for Climate Change

Following evidences are enough to prove that climate changed over the years.

- Temperature is rising
- Mountain glaciers are melting
- Antarctica's ice sheets are breaking
- Sea level is rising
- Temperature of the ocean water is rising (whales & sharks are dying bcoz it is difficult for them to survive in warm water)
- Snow lines in the tropical and sub-tropical mountains are shifting upwards
- Thawing of permafrost in the northern hemisphere
- Arctic pack ice is thinning and retreating.
- Tree line in mountain ranges is moving upward
- Limit of arable land in Eurasia and North America is shifting northward.
- Many tropical disease are spreading toward the poles and to higher elevations in the tropics.
- There is shifting in seasonal weather phenomena and change in precipitation patterns.
- Grass has appeared on some slopes of Antarctica.

Consequences of Climate Change

Although it is difficult to exactly assess the consequences of climate change, experts feel that climate change can have far reaching consequences. Following consequences are worth mentioning.

- Melting of Earth's Ice and shrinking of ice sheets
- Floods and Draughts
- Sea level change
- Changes in atmospheric circulation and ocean currents
- Spread of tropical diseases
- Changes in animal life
- Northward movement of Inter-Tropical Convergence Zone (ITCZ)
- Increase in tropical cyclones, cloud cover and storms
- Northern Hemisphere Melting of Permafrost
- Change in patterns of precipitation
- Change in natural vegetation and soil belts
- Change in cropping patterns and crop yields
- Reduction in soil moisture
- Expansion of deserts and more desertification

- Effect on food supply
- Effect on tourism
- Effect on national parks and natural reserves
- Impact on international trade
- Climate change and geopolitics
- Ozone depletion.

EXERCISES

I. VERY SHORT-ANSWER TYPE QUESTIONS

1. What are sunspots ?
2. Which gas is mainly responsible for greenhouse effect ?

3. Why concentration of carbon dioxide in the atmosphere is increasing rapidly ?
4. Which was the warmest year of the world in the recorded has history of climatology ?
5. In which part of Antarctica, ice is melting very fast ?
6. What was the position of sea level about 18 thousand years before present ?
7. What is Inter-Tropical Convergence Zone (ITCZ) ?
8. How many Bangladeshis are expected to migrate to India due to rise in sea level ?
9. Which ocean current transports a lot of heat towards North-west European coast ?
10. Name any two diseases which can spread to more areas as a result of global warming.

Answers

1. Sunspots are dark circular areas on the sun's surface.
2. Carbon Dioxide.
3. Due to large scale burning of fossil fuels like coal and petroleum.
4. 1998.
5. Ross Ice Shelf and Antarctic Peninsula.
6. 82 metres below the present level.
7. It is low pressure belt on the equator caused by convection currents.
8. 75 million.
9. Gulf Stream.
10. Malaria and Cholera.

II. SHORT-ANSWER TYPE QUESTIONS

1. Write short notes on the following :
   (*i*) Younger Dryas
   (*ii*) Climatic Optimum
   (*iii*) Little Ice Age
   (*iv*) Sunspots
2. Explain how continental drift is associated with climate change.
3. How does volcanic dust cause cooling on the earth's surface ?
4. Give major evidences for climate change.
5. Establish the relationship between global warming and spread of deserts.
6. What is impact of global warming on tourism ?

III. LONG-ANSWER TYPE QUESTIONS

1. Explain how obliquity of the Ecliptic and earth's Orbital Eccentricity affect climate on the earth.
2. What is meant by Greenhouse Effect ? Mention the Greenhouse gases and explain how it causes Global warming.
3. Explain the effect of Global Warming on the ice cover and sea level on the earth.
4. How global warming is responsible for spreading tropical diseases ? Give examples.
5. Climate change can have serious consequences with respect to agricultural production and food supply." Illustrate the statement with examples.