UNIT 2 SOLAR RADIATION AND GLOBAL ENERGY BUDGET

Structure

2.1 INTRODUCTION

The Earth has a blanket of atmospheric gases around it. Most of these gases, such as carbon dioxide, are formed naturally but are now also being produced by activities such as the burning of fossil fuels. Many gases such as CFCs are produced exclusively due to human activities. Some of these gases have the capacity to absorb infrared radiation that is reflected from the earth's surface so that it is not lost to space but retained within the atmosphere. As the concentration of these gases has increased, a greenhouse effect has resulted in a slow but steady warming of the earth, leading to changes in climate worldwide. In the unit 1, we have discussed about the differences between weather and climate; gaseous composition of the atmosphere; and vertical structure of the atmosphere. In this unit, we endeavour to discuss the importance of solar radiation, and the concept of greenhouse effect, which has made our planet liveable. Further, we will discuss about the major greenhouse gases and their atmospheric concentration.

2.2 OBJECTIVES

After studying this unit, you should be able to:

- explain the importance of solar radiation;
- explain the concept of greenhouse effect; and
- discuss the role played by different GHGs in accelerating global warming.

2.3 SOLAR RADIATION

The ultimate source of energy that drives the climate system is radiation from the Sun. The sun is constantly radiating electromagnetic waves and high energy particles. The main source of energy available to the earth is sun's energy. Perhaps, a small amount of energy also emanates from the radioactive materials present in the earth's crust. The amount of the solar energy reaching the top of the atmosphere is primarily influenced by the factors such as solar output; the distance between the sun and the earth; the altitude of the sun; and length of the day. As regards the wavelength range of the solar radiation, "about 7 per cent is ultraviolet (0.2-0.4 μm), 41 per cent visible light (0.4–0.7 μm) and 52 per cent near-infra-red (>0.7 μm)". It is pertinent here to introduce the Wien's displacement law. The Wien's law states that the wavelength of maximum emission (ëmax) varies inversely with the absolute temperature of the radiating body. The mean temperature of the earth's surface is about 288 K (15°C), and the terrestrial radiation emitted from the earth's surface has a peak intensity at about 10 μm and a range from about 4 to 100 μm. With regards to the solar radiation, they are indeed intense, and shortwave radiation with a peak intensity of 0.5 μm. Further, the "energy received at the top of the atmosphere on a surface perpendicular to the solar beam for mean solar distance is termed the solar constant". The solar constant exhibits small periodic variations of about 1 Wm^{-2} due to the sunspot activity. In other words, the solar output vary with respect to the number of sunspots. It is reported that the "sunspot cycles have wavelengths averaging 11 years (the Schwabe cycle, varying between 8 and 13 years), the 22-year (Hale) magnetic cycle, much less importantly 37.2 years (18.6 years – the luni–solar oscillation), and 88 years (Gleissberg)". It is also reported that the "a persistent anomaly of 1 per cent in the solar constant could change the effective mean temperature of the earth's surface by as much as 0.6°C, provided earth behaves as a black body".

Further, the varying distance of the earth from the sun causes variations in solar energy received by the earth. Due to the eccentricity of the earth's orbit around the sun, the solar energy received on the earth surface varies between perihelion and aphelion. Nevertheless, this differential receipt of solar energy is masked by the atmospheric circulation and also due to the continentality. Further, about 11,000 years ago, the aphelion occurred in the northern hemisphere winter. Presently, the aphelion occurs in the northern hemisphere summer.

The amount of solar radiation received at the surface of the earth are also influenced by the altitude of the sun. The factors that influence altitude of the sun are "the latitude of the site", "the time of day" and "the season". When the sun's altitude is higher, the radiation intensity per unit area at the earth's surface is more and also the path to be followed by the solar radiation to reach the earth surface is shorter. As regards the relation between the length of the day and solar radiation reaching on the earth surface, it is quite evident that at the equator, the length of the day is close to 12 hours and eventually more solar radiation reaches the earth surface at this region. In effect, the factors such as solar output; the distance between the sun and the earth; the altitude of the sun; and length of the day, in unison influence the amount of solar radiation reaching the earth surface.

Solar radiation is indeed in the short-wavelength range i.e. less than 4 μm. It is reported that "about 18 per cent of the insolation is absorbed directly by ozone and water vapour". In effect, ozonosphere is responsible for absorbing the harmful ultra-violet radiation, as the ozone absorption is concentrated in spectral bands such as 0.20–0.31 μm, 0.31–0.35 μm and 0.45–0.85 μm. About 30 per cent of insolation is reûected back into space from the atmosphere, clouds and the earth's surface, leaving only 70 per cent of insolation to heat the earth and its atmosphere. The "proportion of incident radiation that is reûected" is termed the albedo. The albedo is also called as reûection coefûcient. The cloud type also affects the albedo. For instance, it is reported that for cumulonimbus, the albedo is 90 per cent; the albedo values for cirrostratus varies between 44 to 50 per cent. It is reported that the earth surface absorbs almost half of the incoming energy available at the top of the atmosphere and re-radiates it as terrestrial long wave infra-red radiation of greater than 3 µm. Further, much of the terrestrial radiation is absorbed by the gases present in the atmosphere such as water vapour, carbon dioxide, ozone, etc. This absorption of the terrestrial radiation by the atmospheric gases are important for the existence of life on the earth. Nevertheless, different parts of the earth's surface receive varied amounts of solar radiation. The factors responsible for this differential receipt of solar radiation are season, day length, altitude, continentality. Latitude determines the day length, and the distance travelled by the sun's radiation through the atmosphere. Further, the elevation of the land and its aspect also influence the amount of solar radiation received. It is evident that high elevations receive more solar radiation than the places near mean sea-level or lower elevations under clear skies.

Each square meter of the Earth's spherical surface outside the atmosphere receives an average (throughout the year) of 342 Watts per square meter (Wm^{-2}) of solar radiation. 31% of this is immediately reflected back into space by clouds, by the atmosphere, and by the earth's surface. The remaining 235 Wm^{-2} is partly absorbed by the atmosphere but most (168 Wm^{-2}) warms the Earth's surface (the land and the ocean).

The earth's surface returns that heat to the atmosphere, partly as infrared radiation, partly as sensible heat and as water vapour which releases its heat when it condenses higher up in the atmosphere as clouds. This exchange of energy between surface and atmosphere maintains (under present conditions) a global mean temperature near the earth's surface, of 15°C. It decreases rapidly with height reaching a mean temperature of –58°C at the top of the troposphere. For a stable climate, a balance is required between incoming solar radiation and the outgoing radiation emitted by the climate system. Therefore the climate system itself must radiate on average 235 Wm^{-2} back into space.

Details of this energy balance can be seen in Figure 2.1, which shows on the left hand side what happens with the incoming solar radiation, and on the right hand side how the atmosphere emits the outgoing infrared radiation.

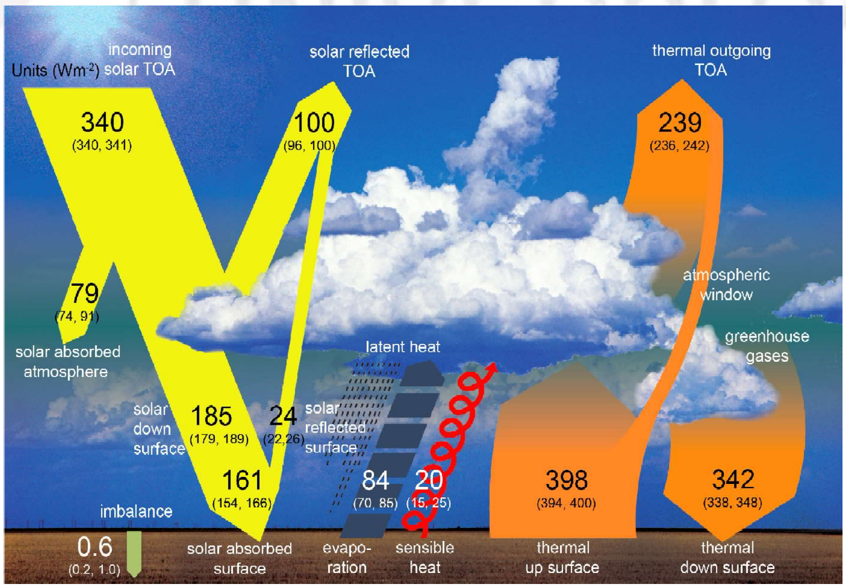

Fig. 2.1: Global Heat Budget (Source: IPCC, 2013)

Any physical object radiates energy of an amount and at wavelengths typical for the temperature of the object. At higher temperatures more energy is radiated at shorter wavelengths. For the Earth to radiate 235 Wm^{-2}, it should radiate at an effective emission temperature of - 19°C with typical wavelengths in the infrared part of the spectrum. This is 34°C lower than the average temperature of 15°C at the Earth's surface.

2.4 THE GREENHOUSE EFFECT

While the solar radiation is predominantly short-wave, the terrestrial radiation from the earth surface is long-wave, or infra-red, radiation. Due to the presence of gases such as water vapour, carbon dioxide and other trace gases, the atmosphere is absorbent to infra-red and long-wave radiation, except between about 8.5 and 13.0 µm – the 'atmospheric window'. "The opaqueness of the atmosphere to infra-red radiation, relative to its transparency to short-wave radiation, is commonly termed as the greenhouse effect". In other words, greenhouse effect relate to "the infrared radiative effect of all infrared-absorbing constituents in the atmosphere. Greenhouse gases, clouds, and (to a small extent) aerosols absorb terrestrial radiation emitted by the Earth's surface and elsewhere in the atmosphere. An increase in the concentration of greenhouse gases increases the magnitude of this effect". Greenhouse gases are "those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere". Further, human-made greenhouse gases such as the halocarbons and other chlorine- and bromine containing substances, sulphur hexafluoride (SF6) are important radiatively active gases to reckon with. Human caused greenhouse gases emissions cause instantaneous radiative forcing. "Surface temperature and troposphere warm in response to this forcing, gradually restoring the radiative balance at the top of the atmosphere".

In effect, the "total greenhouse effect" emanates from the "net infra-red absorption capacity of water vapour, carbon dioxide and other trace gases – methane (CH_4), nitrous oxide (N_2O) and tropospheric ozone (O_3). Nevertheless, the "contribution of the natural greenhouse gases to the mean 'effective' planetary temperature of 255 K is approximately 33 K. Water vapour accounts for 21 K of this amount, carbon dioxide 7 K, ozone 2 K, and other trace gases (nitrous oxide, methane) about 3 K". Water vapour is found to strongly absorb the infra-red radiation around the spectral bands 2.4–3.1 µm, 4.5–6.5 µm and above 16 µm. As regards the thermal role played by ozone, it is very complex, as it absorbs both incoming harmful ultraviolet radiation, and outgoing terrestrial long-wave infra-red radiation. So the increase in ozone concentration in the stratosphere i.e. above 30 km, would have positive effect, as it absorbs the short wave radiation. On the other hand, increase in ozone concentration in the lower altitude or less than 25 km, would absorb more of terrestrial radiation causing increase in surface air temperature.

It is pertinent to note here that the natural greenhouse effect is a product of the infra-red radiation absorbing properties of the natural atmospheric gas constituents such as water vapour, carbon dioxide, and methane. The natural greenhouse gases are indeed responsible for making the Earth a livable planet, as the global surface air temperature is 15 °C. In other words, in absence of these gases earth's average temperature would be approximately 34 °C colder than today and indeed the earth would have been a frozen and uninhabitable planet.

Nevertheless, the enhanced greenhouse effect is due to the increased greenhouse gases emissions caused by human activity.

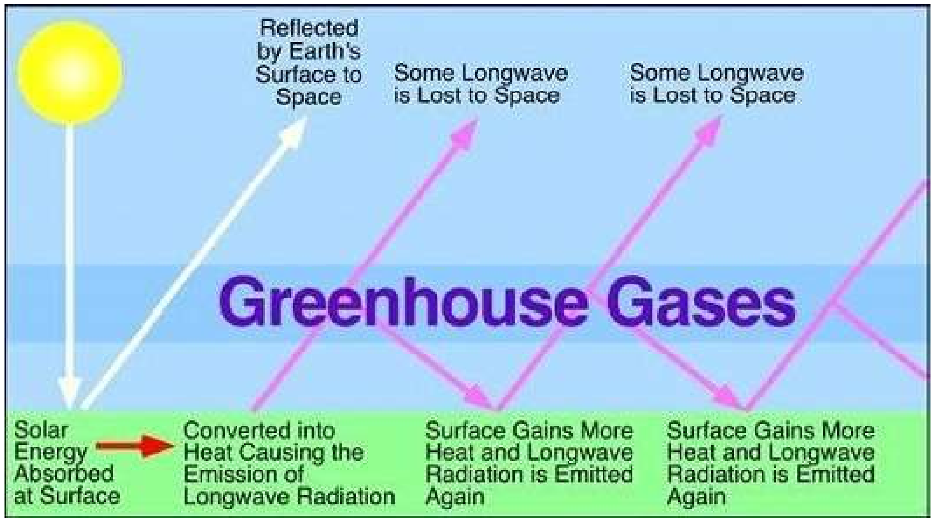

Fig. 2.2: Greenhouse effect

(Source: https://yluglobalwamring.wordpress.com/the-global-warming/)

Check Your Progress 1

Note: 1) Use the space given below for your answers.

2) Check your answers with those given at the end of this unit.

1. What is solar constant? What are the factors that influence the amount of solar radiation reaching the earth surface?

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2. What are the infra-red absorption bands of water vapour?

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2.5 GREENHOUSE GASES

Gases that trap heat in the atmosphere are often called greenhouse gases. The primary greenhouse gases in the Earth's atmosphere are water vapour, carbon dioxide, methane, nitrous oxide and ozone. The contribution of a gas to the greenhouse effect depends upon both the characteristics of the gas and its abundance. When these gases are ranked by their contribution to the greenhouse effect, the most important are water vapour followed by carbon dioxide, methane and ozone.

Important Greenhouse Gases

1. **Water Vapour**

   Water vapour contributes to more than 50% of the greenhouse effect. It is produced naturally by continuous evaporation from water bodies. However, as temperatures rise, more evaporation occurs and the amount of water vapour in the atmosphere rises further. It is removed by condensation and precipitation.

2. **Carbon dioxide**

   It is a "naturally occurring gas, also a by-product of burning fossil fuels from fossil carbon deposits, such as oil, gas and coal, of burning biomass, of land use changes and of industrial processes (e.g., cement production). It is the principal anthropogenic greenhouse gas that affects the Earth's radiative balance". It is needed by plants for the process of photosynthesis. Carbon dioxide is emitted into the atmosphere by plants and animals through natural processes like respiration. The largest source of CO_2 emissions globally is the combustion of fossil fuels such as coal, oil and gas in power plants, automobiles, industrial facilities and other sources. It is the reference gas against which other greenhouse gases are measured and therefore it has a Global Warming Potential of 1.

3. **Methane**

   Methane is formed naturally in wetland regions during the decay of organic material and by termites. Additionally, there are many man-made sources of CH_4that have contributed to an increase in the global average atmospheric concentration, including rice cultivation, biomass burning, fossil fuel combustion and disposal of domestic refuse in landfill sites. Methane is "one of the six greenhouse gases to be mitigated under the Kyoto Protocol and is the major component of natural gas and associated with all hydrocarbon fuels, animal husbandry and agriculture".

4. **Nitrous Oxide (N_2O)**

   "Nitrous oxide is one of the six greenhouse gases to be mitigated under the Kyoto Protocol. The main anthropogenic source of nitrous oxide is agriculture (soil and animal manure management), but important contributions also come from sewage treatment, combustion of fossil fuel, and chemical industrial processes. Nitrous oxide is also produced naturally from a wide variety of biological sources in soil and water, particularly microbial action in wet tropical forests".

5. **Chlorofluorocarbons**

   Chlorofluorocarbons (CFCs) are a group of man-made compounds containing chlorine, fluorine and carbon. The production of CFCs began in the 1930s for the purpose of refrigeration. Since then they have been extensively utilised as propellants in aerosols, as blowing agents in foam manufacture, in air conditioning units and in various other applications. There are no sinks for CFCs in the lower atmosphere. As a result, they are transported to the stratosphere (10 to 50km altitude) where they are broken down by UV radiation, releasing free chlorine atoms which cause significant ozone depletion. The concentration of CFCs in the atmosphere will remain significant into the next century because of the relatively long lifetimes associated with these compounds.

5. **Ozone**

Ozone is a form of oxygen. It consists of three atoms of oxygen bound together (O_3). Most of the atmosphere's ozone occurs in the stratosphere at altitudes between 19 and 30 km above the earth's surface, where it is produced naturally. This band of ozone-rich air is known as the "ozone layer". Stratospheric ozone blocks harmful solar radiation. Ground-level ozone, in contrast, is simply a pollutant which absorbs incoming solar radiation. It is produced through a reaction between sunlight and volatile organic compounds (VOCs) and nitrogen oxides (NOx), some of which are produced by human activities such as automobiles. Ground-level ozone is a component of urban smog and can be harmful to human health.

6. **Fluorinated Gases**

Hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride are synthetic, powerful greenhouse gases that are emitted from a variety of industrial processes. Fluorinated gases are sometimes used as substitutes for ozone-depleting substances (i.e., CFCs, HCFCs, and halons). These gases are typically emitted in smaller quantities, but they are potent greenhouse gases (https://www.epa.gov/ghgemissions/overview-greenhouse-gases).

2.6 GLOBAL WARMING POTENTIAL

Global Warming Potential (GWP) is an estimate of how much a given mass of any greenhouse gas will contribute to the hazards of global warming. It is considered relative to the same mass of carbon dioxide. It depends on the infrared absorption capacity of the molecule and its lifetime in the atmosphere. In effect, Global Warming Potential (GWP) is "*an index, based on radiative properties of greenhouse gases, measuring the radiative forcing following a pulse emission of a unit mass of a given greenhouse gas in the present day atmosphere integrated over a chosen time horizon, relative to that of carbon dioxide. The GWP represents the combined effect of the differing times these gases remain in the atmosphere and their relative effectiveness in causing radiative forcing*". The GWP is influenced by factors such as "*the radiative forcing associated with the addition of a unit mass of each GHG into the atmosphere; rate at which the unit mass of injected GHG decays over time; and cumulative radiative forcing that the unit addition of GHG will have over some period of time into the future*".

Table 2.1: Global Warming Potential of GHGs relative to carbon dioxide.

Chemical Species	Lifetime (Years)	GWP 20-years	GWP 100-years
Carbon dioxide	50-200	1	1
Methane	12	84	28
Nitrous oxide	114	264	265
CFC-11	45	6900	4660

CFC-12	100	10800	10200
CFC-113	85	6490	5820
CFC-115	1700	5860	7670
HCFC-22	12	5280	1760
HFC-23	270	10800	12400
Sulphur hexafluoride	3200	17500	23500
Carbon tetrachloride	35	3480	1730
Methyl bromide	1	9	2
Halon-1301	65	7800	6290

Source: IPCC (2013)

2.7 TRENDS IN GREENHOUSE GASES EMISSIONS

Since the beginning of the industrial revolution, concentrations of most of the greenhouse gases have increased. Recent data shows that the concentration is increasing at a higher rate. The obvious reason for this increase is human activities related to the use of fossil fuels (e.g. for electric power generation), agricultural activities and land-use change (mainly deforestation) (Table 2.2). Agriculture and allied sectors are also responsible for the emission of greenhouse gases (Box 2.1). Global greenhouse gas (GHG) emissions have grown since pre-industrial times, with an increase of 70% between 1970 and 2004. Human activity increases the greenhouse effect primarily through release of carbon dioxide. But human influences on other greenhouse gases emissions are equally important. The important variable greenhouse gases, whose atmospheric concentrations can be influenced by anthropogenic activities are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and chlorofluorocarbons (CFCs) and troposphere ozone (O_3).

Table 2.2: The pre- and post-industrial concentrations of GHGs

Greenhouse	Concentration 1755	Concentration 2011	Natural and Anthropogenic Sources
Carbon Dioxide	276.7 ppm	390.5 ppm	Organic decay; Forest fires; Volcanoes; Fossil fuels burning; Deforestation; Land-use change.
Methane	723 ppb	1803 ppb	Wetlands; Organic decay; Termites; Natural gas & oil extraction; Biomass burning; Rice cultivation; Cattle; Refuse landfills
Nitrous Oxide	272.8 ppb	324 ppb	Forests; Grasslands; Oceans; Soils; Fertilizers; Biomass burning; Burning of fossil fuels.

Sulphur hexafluoride	0	7.3 ppt	Used as electrical insulators.
HFC-23	0	24 ppt	Refrigerators; Aerosol spray propellants; Cleaning solvents
HFC-32	0	4.9 ppt	
HFC-125	0	9.6 ppt	
HFC-134a	0	63 ppt	
HFC-143a	0	12 ppt	
CFC-11	0	238 ppt	
CFC-12	0	528 ppt	
CFC-113	0	74 ppt	
CFC-114	0	15.8 ppt	
CCl_4	0	86 ppt	
Ozone	Unknown	Varies with latitude and altitude in the atmosphere	Ozone is formed by photochemical reactions involving short-lived precursor gases like NO_X, VOC, CO.

Source: IPCC (2013)

"Total annual anthropogenic GHG emissions have increased by about 10 $GtCO_2$-eq between 2000 and 2010. This increase directly came from the energy (47%), industry (30%), transport (11%) and building (3%) sectors". Further, "in 2010, 35% of GHG emissions were released by the energy sector, 24% (net emissions) from AFOLU, 21% by industry, 14% by transport and 6.4% by the building sector". It is beyond doubt that the population growth along with economic development lead to increase in atmospheric GHG emissions, as the economic growth is driven by the intensive use of energy resources.

Box 2.1: Greenhouse gas emissions from agriculture

"The total GHG emissions due to anthropogenic action is about 49 gigatonne of CO_2-equivalent per year ($GtCO_2$-eq/yr) (IPCC 2014a). The agriculture, forestry and other land use (AFOLU) sector contributes about 10–12 gigatonne of CO_2-equivalent per year. GHGs from agriculture are mainly due to land use and land use changes and forestry related activities, enteric fermentation in ruminants, biomass and biofuel burning, lowland paddy cultivation, and use of synthetic nitrogen fertilizers (Lipper et al. 2014; Smith et al. 2014). On account of land use and land use changes like deforestation and degradation, CO_2 is emitted into the atmosphere and the atmospheric CO_2 is sequestered by land use activities such as afforestation, and reforestation. Global net CO_2 emissions due to land use change from 2000-2009 is estimated at 1.1 + 0.8 Pg C yr^{-1} (Ciais et al. 2013). Increase in atmospheric methane is mainly due to anthropogenic emissions. Anthropogenic biogenic emissions of methane is important as it is increasing due to the human activities like low land paddy cultivation,

rearing of ruminants, man-made lakes and waste management including the emissions from landfills. Ruminants like cattle, sheep, goats, etc. produce CH_4 due to food fermentation occurring in their anoxic rumen environment. Increase in atmospheric concentration of N_2O after 1950's is mainly due to agricultural intensification which involves extensive use of synthetic N fertilizers and manure application (Matson et al.1997). Soil microbial processes like nitrification and denitrification are squarely responsible for increased atmospheric N_2O concentration. N_2O emissions from soil processes may increase on account of growing food demand and dependency of modern agriculture on external inputs like nitrogenous chemical fertilizers (IPCC 2014a, b, c)".

Source: Venkatramanan et al. 2019

In effect, three greenhouse gases (GHGs) viz. carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) have increased markedly in the atmosphere since the pre-industrial period. Indeed, the increasing concentration of the GHGs are the principal driving cause of climate change. Further, it is reported that these three greenhouse gases in total account for 80% of the total radiative forcing from well-mixed greenhouse gases. The concentration of these three GHGs increase due to the fossil fuel burning, land use changes and also agricultural practices.

As regards the carbon dioxide concentration during the "past 800,000 years prior to 1750, atmospheric carbon dioxide concentration varied from 180 ppm during glacial (cold) up to 300 ppm during interglacial (warm) periods". Further, during the last 7000 years prior to 1750, atmospheric carbon dioxide concentration varied from 260 ppm to 280 ppm. Nevertheless, since pre-industrial times, "CO_2 concentration has increased by 40% from 278 ppm to 390.5 ppm between 1750 and 2011. While the CH_4 concentration has increased by 150% from 722 ppb to 1803 ppb, N_2O increased by 20% from 271 ppb to 324.2 ppb in 2011". Anthropogenic carbon dioxide emissions are primarily due to fossil fuel combustion; cement production; and land use changes. During the last decade, the carbon dioxide concentration in the atmosphere increased at a rate of 2.0 ± 0.1 ppm per annum. With respect to atmospheric methane, it is reported that the methane emissions are likely to increase in the future due to intensive agricultural practices. The principal sources for methane emissions are rice cultivation, domestic grazing animals, termites, landfills, coal mining, and oil and gas extraction. Human caused emissions account for 50 to 65% of total methane emissions. IPCC (2013) reports that "*the methane budget for the decade of 2000– 2009 (bottom-up estimates) is 177 to 284 Tg(CH_4)/year for natural wetlands emissions, 187 to 224 Tg(CH_4)/ year for agriculture and waste (rice, animals and waste), 85 to 105 Tg(CH_4)/year for fossil fuel related emissions, 61 to 200 Tg(CH_4)/year for other natural emissions including, among other fluxes, geological, termites and fresh water emissions, and 32 to 39 Tg(CH_4)/year for biomass and biofuel burning*".

Further, to meet the growing food demand, the intensive agricultural practices may rely on the synthetic nitrogenous fertilizers, use of which lead to increased N_2O emissions from soils. In fact, over the last three decades, concentration of nitrous oxide in the atmosphere increased at a rate of 0.73 ± 0.03 ppb/year. The nitrous oxide emissions into the atmosphere are due to the by "nitrification" and "denitrification" process. Also the nitrous oxide emissions were observed from the "fossil fuel use and industrial processes", and "biomass burning".

As regards ozone, it is not a "well-mixed" greenhouse gas. Its concentration vary with place and time across the globe. Nevertheless, it is very important GHG, when it is present in the troposphere region. The ozone in the troposphere is formed by the photochemical reactions involving short-lived precursor gases such as NO_x, CO, Volatile Organic Compounds (VOC). Further, tropospheric ozone concentration is higher in the northern hemisphere as compared to the southern hemisphere. The concentration of the tropospheric ozone is reported to be more during the summer.

Check Your Progress 2

Note: 1) Use the space given below for your answers.

2) Check your answers with those given at the end of this unit.

1. What is the status of water vapour as a greenhouse gas?

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2. What are the important greenhouse gases?

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2.8 LET US SUM UP

The ultimate source of energy that drives the climate system is radiation from the Sun. The main source of energy available to the earth is sun's energy. The amount of the solar energy reaching the top of the atmosphere is primarily influenced by the factors such as solar output; the distance between the sun and the earth; the altitude of the sun; and length of the day. Solar radiation is indeed in the short-wavelength range i.e. less than 4 µm. The earth surface absorbs almost half of the incoming energy available at the top of the atmosphere and re-radiates it as terrestrial long wave infra-red radiation of greater than 3 µm. The mean temperature of the earth's surface is about 288 K (15°C), and the terrestrial radiation emitted from the earth's surface has a peak intensity at about 10 µm and a range from about 4 to 100 µm. Much of the terrestrial radiation is absorbed by the gases present in the atmosphere such as water vapour, carbon dioxide, ozone, etc. "The opaqueness of the atmosphere to infra-red radiation, relative to its transparency to short-wave radiation, is commonly termed as the greenhouse effect". The concentrations of most of the greenhouse gases have increased since the industrial revolution. In effect, human activities related to the use of fossil fuels (e.g. for electric power generation), agricultural activities and land-use change (mainly deforestation) are considered as the main driving force for increase in GHGs. In fact, three greenhouse gases (GHGs) viz. carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) have increased markedly in the atmosphere since the pre-industrial period. In this unit, we have discussed the importance of solar radiation, and the concept of greenhouse effect, due to which, the global average air temperature is 15°C. We have also discussed about the major greenhouse gases and their atmospheric concentration.

2.9 KEYWORDS

Insolation : The amount of solar radiation reaching the Earth by latitude and by season measured in Wm^{-2}. Usually, insolation refers to the radiation arriving at the top of the atmosphere.

Albedo : The fraction of solar radiation reflected by a surface or object, often expressed as a percentage. Snow-covered surfaces have a high albedo, the albedo of soils ranges from high to low, and vegetation-covered surfaces and oceans have a low albedo.

Greenhouse Effect : The infrared radiative effect of all infrared-absorbing constituents in the atmosphere. Greenhouse gases, clouds, and (to a small extent) aerosols absorb terrestrial radiation emitted by the earth's surface and elsewhere in the atmosphere.

Greenhouse Gases : Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of terrestrial radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. This property causes the greenhouse effect. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary greenhouse gases in the Earth's atmosphere. Moreover, there are a number of entirely human-made greenhouse gases in the atmosphere, such as the halocarbons and other chlorine- and bromine containing substances.

Global Warming Potential (GWP) : An index, based on radiative properties of greenhouse gases, measuring the radiative forcing following a pulse emission of a unit mass of a given greenhouse gas in the present day atmosphere integrated over a chosen time horizon, relative to that of carbon dioxide.

Halocarbons : A collective term for the group of partially halogenated organic species, which includes the chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), hydrofluorocarbons (HFCs), halons, methyl chloride and methyl bromide. Many of the halocarbons have large Global Warming Potentials. The chlorine and bromine-containing halocarbons are also involved in the depletion of the ozone layer.

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http://www.ipcc.ch/report/ar5/wg3/

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

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

2.11 ANSWERS TO CHECK YOUR PROGRESS

Check Your Progress 1

1. The “energy received at the top of the atmosphere on a surface perpendicular to the solar beam for mean solar distance is termed the solar constant”. Each square meter of the Earth’s spherical surface outside the atmosphere receives an average (throughout the year) of 342 Watts per square meter (Wm^{-2}) of solar radiation. The factors that influence the amount of solar radiation reaching the earth surface are solar output; the distance between the sun and the earth; the altitude of the sun; and length of the day.

2. Water vapour is found to strongly absorb the infra-red radiation around the spectral bands 2.4–3.1 µm, 4.5–6.5 µm and above 16 µm.

Check Your Progress 2

1. Water vapour is the most important greenhouse gas. It is produced continually by evaporation from water bodies and constitutes more than 50% of the GHGs. Its abundance is not a problem because it is short lived and can diminish rapidly by condensation or rain. Its importance lies in the fact that it amplifies temperature rise by creating a positive feedback loop in the atmosphere. As temperature rises, more water evaporates and more water vapour raises the temperature further. A feedback loop also increases the heating effect of other gases.

2. The important greenhouse gases are water vapour, carbon dioxide, methane, nitrous oxide, CFCs and ozone.