Lecture 8 Global warming and climate change : GHG emission, GH effect, impact on environment and agriculture – mitigation strategies, Ozone depletion and Acid Deposition

Air pollution problems are not necessarily confined to a local or regional scale. Atmospheric circulation can transport certain pollutants far away from their point of origin, expanding air pollution to continental or global scales; it can truly be said that air quality problems know no international boundaries. Some air pollutants are known to be associated with changes in Earth's climate, requiring consideration of governmental actions to limit their impacts. Two important air pollution problems that are generally considered worldwide in scope are **global warming** and **depletion of stratospheric ozone.**

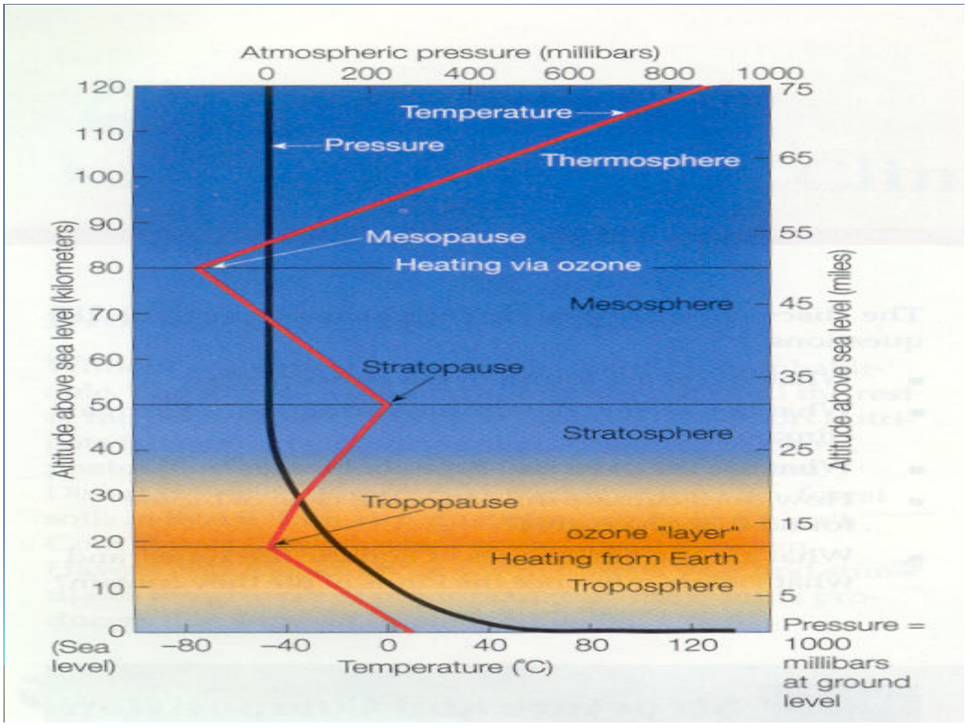
Greenhouse Gases

Since CO_2 is confined exclusively to the troposphere, its higher concentration may act a serious pollutant. Under normal conditions (with normal CO_2 Concentration) the temperature at the surface of the earth is maintained by the energy balance of the sun rays that strike the planet the planet and heat that is radiated back into space. However, when there is an increase in CO_2 concentration, the thick layer of this gas prevents the heat from being re-radiated out. This thick CO_2 layer thus functions like the glass panels of a greenhouse (or the glass windows of a motor car), allowing the sunlight to filter through but preventing the heat from being re-radiated in outer space. This is the so-called greenhouse effect. Nitrogen and oxygen, the main constituents of the atmosphere, play no part in the green house effect. But there are approximately 35 trace gases that scientists believe contribute to global warming. **Carbon dioxide (CO_2)** is considered to be one of the most important of these greenhouse gases, absorbing most of the heat trapped by the atmosphere.

Other gases of special importance in global warming are **chlorofluorocarbons** (CFCs), **methane, nitrous oxide** and **ozone.** Although the average concentrations of these gases are much lower than that of carbon dioxide, they are much more efficient than carbon di oxide at soaking up long – wave radiation. Overall, carbon dioxide is estimated to cause almost 60 per cent of the warming effect and CFCs about 25 per cent, and the remainder is caused by methane, nitrous oxide, ozone, and other trace gases.

More than 80% of the mass of the atmosphere and virtually all of water vapour, clouds and precipitation occur in the troposphere. Earth's surface, it consists of *troposphere, stratosphere, mesosphere* and the *thermosphere.* Troposphere extends upto 10-12 km at mid latitudes (at equator – 18 km, at poles 5-6 km). In troposphere, temperatures typically decrease at 5-7°C per km (wet adiabatic lapse rate).

Above the troposphere is a stable layer of very dry air called stratosphere. Pollutants that find their way into the stratosphere may remain there for many years, before they eventually drift back into the troposphere → removed by rainfall or settling. In the stratosphere, short wavelength UV energy is absorbed by ozone, causing the air to be heated. The resulting temperature inversion is what causes the stratosphere to be so stable. The troposphere and stratosphere combined account for 99.9% of the mass of the atmosphere. Together they extend to only about 50 km above the surface of the earth.



CARBON DIOXIDE

CO_2 has been recognized for its importance as a greenhouse gas for almost a century. Arrhenius (1896) is usually credited with the first calculations on global temperature as a function of atmospheric CO_2 content.

The carbon cycle

Carbon moves continually from the atmosphere into the food chain during photosynthesis and returns to the atmospheric during respiration.

- From the atmosphere it can be assimilated by plants on the land or in the oceans, or it can dissolve into the sea water.
- Respiration by living things, including decomposers that are feeding on dead organic matter, return CO_2 either to the oceans or to the atmosphere.
- A very small portion of the dead organic matter each year ends up being buried in sediments. The slow, historical accumulation of buried organic matter is the source of our fossil fuels – oil, gas and coal.
- When these are burned, C in the form of CO_2 is returned to the atmosphere. The rapid accumulation of CO_2 in the atmosphere is attributed mainly to fossil fuel burning and deforestation.

Historical emissions of CO_2

- The concentration of CO_2 in the atmosphere at the beginning of the 19^{th} century was around 280 ppm. By 1990 it was 355 ppm and was climbing at about 1.5 ppm per year

- CO_2 concentrations in 1990 were more than 25 per cent higher than those just before the industrial revolution.
- 1 ppm rise in CO_2 rise would add 2.12 Gt C into the atmosphere.
- However, some carbon added to the atmosphere will be absorbed by the oceans or taken up by the plants during photosynthesis, thus, not all emissions will result in increased CO_2 concentrations.
- It is convenient to represent the fraction of emissions that remain in the atmosphere with a quantity called the *airborne fraction*.

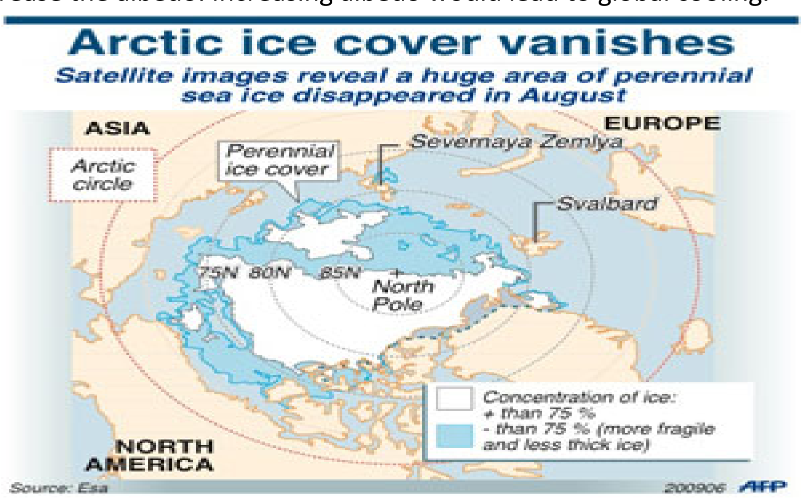
$$\text{Airborne fraction} = \frac{\Delta\, C\ \text{atmosphere}}{\Delta\, C\ \text{emissions}}$$

where (Δ c atmosphere) is the change in carbon content of the atmosphere and (Δ c emissions) is the total amount of carbon added to the atmosphere.

- Values of airborne fraction has been estimated at anywhere from 0.4 to 0.7, with 0.5 being a commonly used ratio.

Equilibrium temperature increase caused by CO_2

- Considerable effort has gone into attempting to quantify the relationship between expected global temperature change and CO_2 concentration.
- Typical of current understanding is that a doubling of CO_2 will likely result in an eventual global warming of approximately 1.5 –4.5°C.
- An increase of only 1.5°C over the pre industrial temperature would make the earth warmer than it has been in the last 10,000 years.
- In the past 100 years or so, an increase of 0.5°C has actually occurred in the global average surface temperature.
- Elevated temperatures increase evaporation, increasing the amount of water vapour in the air. Since water vapour is a green house gas, it might cause even more warming. On the other hand, increased cloudiness may increase the albedo. Increasing albedo would lead to global cooling.



CHLOROFLUOROCARBONS

- CFCs are mainly used as refrigerants, solvents, foaming agents in the production of rigid and flexible foams and as aerosol propellants for such products as deodorants, hairspray and spray paint.
- Chloroflurocarbons (CFCs) are molecules that contain chlorine, fluorine and carbon.
- As opposed to other greenhouse gases, CFCs do not occur naturally and their presence in the atmosphere is due entirely to human activities.
- CFCs absorb strongly in the atmospheric window (7-12 µm) and tend to have long atmospheric residence times. Hence they are potent greenhouse gases.
- The two CFCs that have received the most attention, in both ozone and climate change contexts are trichlorofluoromethane, $CFCl_3$ (CFC-11), and dichlorofluoromethane, CF_2Cl_2 (CFC-12).
- CFC molecules are inert and non–water soluble, so they are not destroyed through chemical reactions or removed with precipitation.
- The only known removal mechanism is photolysis by short wavelength solar radiation, which occurs after the molecules drift into the stratosphere. The chlorine freed during this process can go on to destroy stratospheric ozone.
- CFCs are mainly used as refrigerants, solvents, foaming agents in the production of rigid and flexible foams and as aerosol propellants for such products as deodorants, hairspray and spray paint.
- Some of the CFCs are based on a one-carbon methane structure, such as trichlorofluromethane ($CFCl_3$) and dichlorofluromethane (CF_2Cl_2), they were often referred as *chlorofluromethanes or CFMs*. The Duiont trade name freon has also been used.
- When molecules contain only fluorine, chlorine and carbon, they care called *fully halogenated CFCs*.
- Some CFCs contain hydrogen as well as chlorine, fluorine and carbon and they are called *hydrochlorofulorocarbons or HCFCs*.
- HCFCs have the environmental advantage that, due to the hydrogen bond, they are less stable in the atmosphere and hence, are less likely to reach the stratosphere to affect the ozone layer. The ozone depleting potential of HCFCs is only 2-5% compared most commonly used CFCs. The most widely used CFCs are CFC –11, CFC –12 and CFC –113.
- When no chlorine is present in the molecule, they are called *hydroflurocarbons or HFCs*. HFCs are important replacements for CFCs, since their lack of chlorine means they do not threaten the ozone layer.

OTHER GREENHOUSE GASES

- ***Methane*** is a naturally occurring gas that is increasing in concentration, as a result of human activities.
- It is produced by bacterial fermentation under anaerobic conditions, such as in swamps, marshes, rice paddies, as well as in the digestive systems of ruminants and termites.
- It is also released during the production, transportation and consumption of fossil fuels, as well as when biomass fuels are burned.
- After its release, methane is thought to have an atmospheric residence time of around 8-11 years. It is eventually removed through oxidation with various OH radicals.
- Methane concentrations have increased rapidly in the past 20 years and correlate quite well with human population size.

- ***Nitrous oxide*** is another naturally occurring greenhouse gas that has been increasing in concentration due to human activities.
- It is released into the atmosphere mostly during the nitrification portion of the nitrogen cycle

$$NH_4^+ \rightarrow N_2 \rightarrow N_2O \rightarrow NO_2^- \rightarrow NO_3^-$$

- Combustion of fossil fuels and nitrogen fertilizer consumption are thought to be the two most important human activities leading to increases in nitrous oxide levels.
- It apparently has no significant tropospheric sinks and is only slowly degraded in the stratosphere by photolysis.
- The destruction process in the stratosphere involves a reaction with atomic oxygen leading to formation of nitric oxide, which in turn reacts catalytically with ozone.
- The desired removal of nitrous oxide, then, has the undesired effect of reducing stratospheric ozone.
- Nitrous oxide has an extremely long residence time of 150 years in the atmosphere. It has strong absorption bands at 4.5, 7.8 and 17 µm and it is thought to be about 230 times as potent as CO_2 in causing global warming.
- ***Ozone*** plays an important role in both troposphere and stratosphere.
- About 90% of atmospheric ozone resides in the stratosphere and it protects life by absorbing short-wavelength ultraviolet radiation.
- Stratospheric ozone also affects climate, but in a very complex way. Incoming solar energy is absorbed, which heats the stratosphere. This, however, reduces the radiation arriving at the earth's surface, thereby cooling the surface.
- On the other hand, the warmed stratosphere radiates energy back to the earth's surface, thereby heating it. The net effect is uncertain.
- In the troposphere, ozone is a component of photochemical smog and it poses a serious health problem.
- Tropospheric ozone absorbs strongly at around 9.6 µm, right in the middle of the atmospheric window. Increasing concentrations could contribute to raising global temperatures.
- Ozone, however, has a rather short residence time in the troposphere, measured in days. It is irregularly distributed by time of day, geographic location, and altitude. So it has been difficult to assess its overall change with time, leaving us uncertain as to its impact on climate.

The Greenhouse effect

- Nearly all the incoming solar energy arrives extra terrestrially, with wavelength less than 4 µm (short wavelength radiation), while the outgoing energy radiated by the earth has essentially all of its energy in wavelength greater than 4 µm (long wavelength or thermal radiation)
- Essentially all the incoming solar radiation with wavelengths less than 0.3 µm (ultraviolet) is absorbed by oxygen and ozone in the stratosphere.
- Most of the long wave-length energy radiated by the earth is affected by a combination of radiatively active gases, most importantly water vapour (H_2O), CO_2, N_2O and CH_4.
- Radiatively active gases that absorb wavelengths longer than 4 µm are called *greenhouse gases*.

- These gases trap most of the outgoing thermal radiation attempting to leave the earth's surface. This absorption heats the atmosphere, which, in turn, radiates energy back to the earth as well as out to space.
- The greenhouse effect adds 33°C of warming to the surface of the earth, i.e., if there was no greenhouse effect, the earth would have an average temperature of –18°C or about 0°C.
- Distributed over the entire surface of the earth, the incoming solar radiation is equal to 343 W/m^2.
- Since the albedo is 30% (103 W/m^2), the amount of incoming radiation absorbed by the atmosphere and earth is 240 W/m^2.
- Of that 240 W/m^2, 86 W/m^2 are absorbed by the atmosphere and the remaining 154 W/m^2 are absorbed by the surface of the earth.

Global Warming and Climate Change

Carbon dioxide is a green house gas that is confined to the troposphere and its higher concentration may act as a serious pollutant. Under normal conditions the temperature at the surface of the earth is maintained by energy balance of the sun rays that strike the planet and heat that is reradiated back into space. However when there is an increase in CO_2 concentration, the thick layer of the gas prevents the heat from being reradiated out. This thick CO_2 layer functions like the glass panel of a green house, allowing the sun light to filter through but preventing the heat from being reradiated into outer space. Therefore, it is warmer inside the green house than outside. Similar condition is resulted in the troposphere of the earth and termed as **'Green house effect'**.

Carbon dioxide concentration of the troposphere has been increasing steadily due to industrial growth. Nearly hundred years ago the CO_2 concentration was 275 ppm, today it is 350 ppm and by the year 2040 it is expected to reach 450 ppm. Certain gases in the atmosphere, known as 'green house' gases like CO, CO_2, CH_4 are able to absorb and emit heat. When sunlight strikes the earth's surface it warms up, emits heat, which radiates upwards into space. This heat warms up the green house gases so that they also emit heat, some into space and some back down to earth, which results in heating up of the earth atmosphere, also known as **Global warming.**

Average land surface temperatures are increasing worldwide. In fact, the decade of the 1990s was the warmest ever recorded, and the trend of gradually rising average temperatures seems to be continuing. By some estimates, global mean temperature has risen roughly 0.5^{o}C (1°F) since the end of the 19th century. This may seem to be an insignificant rise, given the wide variation in temperatures that occur on a daily and annual basis at any given location, as well as the obvious difficulty in measuring, collecting, and interpreting world wide temperature records dating as far back as a century or more ago. But most atmospheric scientists think that even a small increase in average global temperature can have a noticeable impact on Earth's climate.

Potential impacts of global warming on Environment, Agriculture and Human Health

One of the methods that scientists used to estimate the impacts of global warming involves computer analysis of mathematical equations that model Earth's atmosphere. Typically, these sophisticated computer programs are called General Circulation Models (GCMs). As a basis for predicting future global impacts, most models assume that the concentration of greenhouse gases will effectively double. On this basis, the GCMs generally predict an average global warming of up to 42^{o}C (7.5^{o}F) and an overall increase in precipitation of about 10 per cent by the year 2050. It is also expected that global warming will create a more active hydrologic cycle, increasing cloudiness as well as precipitation.

Recent estimates suggest that global sea level has risen by about 0.15 m during the 20th century, with most of the rise occurring since 1930. Some scientists believe that, because of global warming, average sea levels may raise by at least 0.3 m and as much as 1.4 m by the year 2030. This is likely to cause extensive economic and social hardship in coastal areas all over the world. Temperature would increase by 1.5 to 4.5°C . The polar icecaps would melt. A rise of five degrees would raise the sea level by five meters within a few decades increase the evaporation of water, thus reducing grain yield.

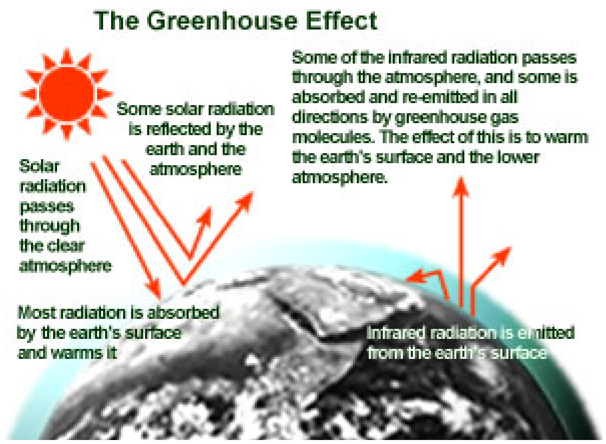
Potential impacts of global warming on ecosystems mainly include the effects on agriculture and forest growth. Plant growth and development will be influenced by an increase in carbon di oxide levels, which stimulates photosynthesis and decreases water losses from transpiration. In addition to affecting agriculture and forests, global warming is expected to have other impacts. For example, higher temperatures and humidity may increase the chances of disease in humans and animals in some parts of the world.

Ozone and Photochemical smog

Ozone (O_3), a secondary air pollutant in the troposphere, is formed by a set of exceedingly complex chemical reactions between nitrogen dioxide (NO_2) and volatile organic compounds (VOCs). VOCs are hydrocarbons that quickly evaporate under normal atmospheric conditions. The reactions are initiated by the ultraviolet energy in sunlight. Actually, a number of secondary pollutants (collectively termed photochemical oxidants) are formed in the reactions. Ozone, the most abundant of the oxidants, is the key component of photochemical smog. It is universally accepted that the ozone layer in the stratosphere protects us from the harmful UV radiations from sun. The depletion of this O3 layer by human activities may have serious implications and this has become a subject of much concern over the last few years. The ozone near the earth's surface in troposphere creates pollution problems. Ozone and other oxidants such as hydrogen peroxide are formed by light dependent reactions between NO_2 and hydrocarbons. Ozone may also be formed by NO_2 under UV-radiations effect. These pollutants cause photochemical smog.

A series of harmful effects are caused by an increase in UV radiation. Cancer is the best established threat to man. When the O_3 layer becomes thinner or has holes, it causes cancers, especially relating to skin like melanoma. A 10% decrease in stratospheric ozone appears likely to lead a 20-30% increase in skin cancer. The other disorders are cataracts, destruction of aquatic life and vegetation and loss of immunity. Photochemical smog is highly oxidizing polluted atmosphere comprising largely of O_3, NO_x, H_2O_2, organic peroxides, PAN, and PB_z N. This is produced as a result of photochemical reaction among NO_z hydrocarbons and oxygen.

The word **smog** is coined by combining smoke and fog which characterized air pollution episode in London, Glasgow, Manchester and other cities of U.K. where sulphur-rich coal was used. The term smog is said to have been coined in 1905 by H.A. Des Voeux. The U.K. smog was a mixture of reducing pollutants and has been called reducing smog, whereas Los angels smog, a mixture of oxidizing pollutants is called oxidizing smog or photochemical smog.



Greenhouse gas inventory estimation – Indian Scenario

Estimations of anthropogenic GHG emission inventories in India, began in a limited scale in 1991, which were enlarged and revised and the first definitive report for the base year 1990 was published4 in 1992. Since then, several papers and reports have been published which have upgraded the methodologies for estimation, included country-specific emission factors and activity data, accounted for new sources of emissions and new gases or pollutants. A comprehensive inventory of the Indian emissions from all energy, industrial processes, agriculture activities, land use, land use change and forestry and waste management practices has recently been reported in India's Initial National Communication to the UNFCCC for the base year 1994.

In 1994, 1228 million tonnes of CO_2 equivalent emissions took place from all anthropogenic activities in India, accounting for 3 per cent of the total global emissions. About 794 million tonnes, i.e. about 63 per cent of the total CO_2 equivalent emissions was emitted as CO_2, while 33 per cent of the total emissions (18 million tonnes) was CH_4, and the rest 4 per cent (178 thousand tonnes) was N_2O. The CO_2 emissions were dominated by emissions due to fuel combustion in the energy and transformation activities, road transport, cement and steel production. The CH_4 emissions were dominated by emissions from enteric fermentation in ruminant livestock and rice cultivation. The major contribution to the total N_2O emissions came from the agricultural soils due to fertilizer applications. At a sectoral level, the energy sector contributed 61 percent of the total CO_2 equivalent emissions, with agriculture contributing about 28 per cent, the rest of the emissions were distributed amongst industrial processes, waste generation, and land use, land use change and forestry.

Comparative national emission trends

The compounded annual growth rate of CO_2 equivalent emissions from India is between 1990 and 2000 showed an overall increase by 4.2 per cent per annum. On a sectoral basis, the maximum growth in emissions is from the industrial process sector (21.3 per cent per annum), followed by the emissions from the waste sector (7.3 per cent per annum). The energy sector emissions have only grown by 4.4 per cent per annum with almost no increase in emissions registered from the agriculture sector. Significant increase in emissions from the industrial process sector can be attributed to the growth in cement and steel production in India over the decade. Similarly, increase in emissions from the waste sector can be attributed to increase in quantity of waste generated due to the large influx of population from villages to cities in 2000 with respect to 1990, where because of systematic waste disposal practices; anaerobic conditions are created leading to CH_4 emissions.

Data from some of the developed countries indicate that between 1990 and 2000, there has been a decline in the compounded annual growth rates of GHGs such as in the case of Russian federation, Germany and UK were the growth rates have decreased by –2.8, –2.0 and –1.4 per cent per annum respectively. In comparison, the emissions from Japan, USA and India have grown by 1.6, 2.0 and 4.2 per cent per annum respectively within the same period. Even the emissions from China and Brazil for the period 1990–1995 show a high compounded annual growth rate of 5 and 6 per cent respectively. Though the compounded annual growth rates of CO_2 equivalent emissions from India are on a higher side (4.2 per cent per annum), the absolute value of these emissions is still 1/6th of that of USA. Also, the per capita GHG emissions from India are one of the lowest. In the year 2000, the US per capita CO_2 equivalent emission was 15.3 times more than that of India. The German per capita emissions were 8.0 times higher. Similarly, the Japanese per capita CO_2 equivalent emissions were 6.7 times higher than that of India. Even when compared with developing countries such as China and Brazil, the Indian per capita emissions were 2.2 and 1.3 times lower respectively.

For almost all the countries, the share of CO_2 emissions is actually increasing continuously between the period 1990 and 2000 and it is the CH_4 and N_2O emissions which have decreased in this period, resulting in an overall decrease in the growth rates of the CO_2 equivalent emissions. Exceptions are in the case of India, where the N_2O emissions are also increasing, and in the case of UK and Germany, where all three emissions are declining. Further the decrease in emission trends in Germany and the UK, is due to the fact that the solid and liquid fuel use in these countries is on the decline and the natural gas consumption is increasing. Japan is the only country amongst all the countries considered, where the solid fuel use has increased between 1990 and 2000. In the USA, the fuel mix has remained same between 1990 and 2002, with maximum use of liquid fuel, followed by gaseous and solid fuel. In India too, the commercial fuel mix has remained almost the same between 1990 and 2002, wherein 10 per cent of the fuel used is solid fuel, 81 per cent is liquid fuel and the rest is gaseous fuel. Penetration of commercial biomass as a main fuel source is still very low.

Indian climate-friendly initiatives

The GHG intensity of the Indian economy in the year 2000, in terms of the purchasing power parity, is estimated to be little above 0.4 tonne CO_2 equivalent per 1000 US dollars, which is lower than that of the USA and the global average. The Indian Government has targeted an 8% GDP growth rate per annum for 2002–07 to achieve its development priorities. In order to achieve these developmental aspirations, substantial additional energy consumption will be necessary and coal, being the abundant domestic energy resource, would continue to play a dominant role. Since GHGs emissions are directly linked to economic growth, India's economic activities will necessarily involve increase in GHGs emissions from the current levels. The CO_2 equivalent emissions from India are set to increase up to 3000 million tonnes by 2020. Energy and power sector reforms, for instance, have helped to enhance the technical and economic efficiency of energy use. Policies adopted by India for a sustainable development, such as energy efficiency, improvement measures in various sectors, increasing penetration of cleaner fuels. And a thrust for renewable energy technologies have all contributed towards GHG emission reduction since the last decade. Past few years have also witnessed introduction of landmark environmental measures that have targeted cleansing of rivers, enhanced forestation, installed significant capacity of hydro and renewable energy technologies. The Indian government has simultaneously introduced clean coal technologies like coal washing and introduced the use of cleaner and lesser carbon intensive fuel, like introducing auto LPG and setting up of Motor Spirit-Ethanol blending projects in selected states.

Climate Change Effects

Sea level and climate change

One quarter of the Indian population live along the country's coasts, and are largely dependent on coastal livelihoods. Climate change effects on sea level can impact coastal areas in two ways – through increase in mean sea level, and through increased frequency and intensity of coastal surges and storms. Climate change is of concern to India in view of the damages that occur along the east coast of India from the cyclones that form in the Bay of Bengal. Any increase in the frequency or intensity of tropical disturbances due to climate change in the future could cause increased damages to life and property in the coastal regions. The National Institute of Oceanography (NIO) and the Indian Agricultural Research Institute (IARI) conducted a study on the impacts of climate change on sea level to assess the degree to which mean sea level and the occurrence of extreme events may change.

The National Institute of Oceanography

The National Institute of Oceanography (NIO) is a research organization of the Council of Scientific and Industrial Research (CSIR), Government of India. NIO is a large oceanographic laboratory with a focus on the oceanography of the seas around India. Their core areas of study are ocean processes, coastal studies, resource surveys, conservation, and ocean engineering.

Predicted climate change impacts on sea level

As a result of the study, the following changes due to climate change were predicted for sea level:

Mean sea level: Mean sea level rise estimates (using past tide gauge data) were found to be slightly less than 1 mm/yr for most of the stations analyzed along the Indian coast. However, data on vertical land movements was not available, and will need to be incorporated in order to obtain net sea level rise estimates.

Storm surges: The study showed a greater number of high surges under climate change. In addition, the model showed an increased occurrence of cyclones in the Bay of Bengal, particularly in the post-monsoon period, along with increased maximum wind speeds associated with cyclones.

Agriculture and climate change

The agricultural sector represents 35% of India's Gross National Product (GNP) and as such plays a crucial role in the country's development. Food grain production quadrupled during the post-independence era; this growth is projected to continue. The impact of climate change on agriculture could result in problems with food security and may threaten the livelihood activities upon which much of the population depends. Climate change can affect crop yields (both positively and negatively), as well as the types of crops that can be grown in certain areas, by impacting agricultural inputs such as water for irrigation, amounts of solar radiation that affect plant growth, as well as the prevalence of pests. The Indian Agricultural Research Institute (IARI) examined the vulnerability of agricultural production to climate change, with the objective of determining differences in climate change impacts on agriculture by region and by crop.

Models used to predict climate change impacts on agriculture

The following models were developed to evaluate the impacts of changes in temperature and carbon dioxide on crops:

1. INFOCROP, a generic growth model for various crops, was developed by IARI for optimal resource and agronomic management options.

2. INFOCANE, a simple sugarcane growth model, was developed by IARI to measure effects on cane yield.

Human Health and climate change

Both climatologically and medical communities are increasingly concerned that climate change is likely to have wide-ranging impacts on health. The poor, as well as the elderly, children, and the disabled are likely to be most vulnerable to these changes, as they already face limited access to health facilities. Among vector-borne diseases in India, malaria is of considerable concern. Periodic epidemics of malaria occur every five to seven years, and the World Bank estimates that about 577,000 DALYs (disability-adjusted life years) were lost due to malaria in India in 1998. Climate change could increase the incidence of malaria in areas that are already malaria-prone, and also introduce malaria into new areas. The National Physical Laboratory (NPL), New Delhi undertook a study of the impacts of predicted climate change on human health in India, with a particular focus on malaria.

Health concerns and vulnerabilities due to climate changes

1. **Temperature related morbidity**
    - Heat and cold related illness
    - Cardio vascular illnesses

2. **Vector borne diseases**
    - Changed patterns of diseases by region and by climate parameter
    - Malaria, Filaria, Kala-azar, Japanese Encephalitis, and Dengue caused by bacteria, viruses and other pathogens carried by mosquitoes, ticks, and other vectors.

3. **Health effects of extreme weather**
    - Diarrhoea, Cholera and intoxication caused by biological and chemical contaminants in water.
    - Damaged public health infrastructure due to cyclones / floods
    - Injuries and illness
    - Social and mental health stress due to disasters and displacement

4. **Health effects due to insecurity**
    - Malnutrition, hunger, particularly in children in food production

Mitigation strategies

CARBON REDUCTION

India's Initiatives

India has undertaken numerous response measures that are contributing to the objectives of the United Nations Framework Convention on Climate Change (UNFCCC). India's development plans balance economic development and environmental concerns. The planning process is guided by the principles of sustainable development. Reforms in the energy and power sector have accelerated economic growth and enhance the efficiency of energy use. These have been complemented by notable initiatives taken by the private sector.

In the last few years several measures relating to environmental issues have been introduced. They have targeted increasing significantly, the capacity of renewable energy installations; improving the air quality in major cities (the world's largest fleet of vehicles fuelled by compressed natural gas has been introduced in New Delhi); and enhancing afforestation. Other similar measures have been implemented by committing additional resources and realigning new investments, thus putting economic development on a climate-friendly path.

Sectoral initiatives

Coal : Coal is and will remain the mainstay of commercial energy production. To ensure more efficient use of coal the following measures have been taken:

- Rationalization of coal use
- Participation of private sector encouraged
- Reforms in pricing
- Technology upgradation involving: coal-washing, improvements in combustion technology and the recovery of coal-bed methane.

Oil : To promote fuel efficiency and conservation, the following measures have been undertaken.

- Reduction of gas-flaring
- Installation of waste heat-recovery systems
- Energy audits
- Equipment upgradation
- Substitution of diesel with natural gas. Establishment of PCRA (Petroleum Conservation research Association) to increase awareness and develop fuel-efficient equipment.

Gas : This source of energy is the preferred substitute for coal and oil. In the residential sector, gas has replaced coal and kerosene. CNG has been introduced in the place of petrol and diesel in the transport sector. Major investments have been made in developing infrastructure for long distance and local distribution. Import options are under consideration. The share of gas in the power sector has increased from 2-8%.

Hydropower : The government's policy objective is to exploit the huge potential in India's northeast. At present, about 25% of the total installed capacity is accounted for by hydro.

Renewables : India has a very active programme to promote the use of renewable energy. Some salient features of the current renewables situation are given source-wise

Solar : Photovoltaic system based on solar energy have been put to a variety of uses in rural electrification, railway signalling, microwave repeaters, power to border outposts and TV transmission and reception. Grid-connected PV power plants with an aggregate capacity of 1900 kWp have been set up for demand-side management or tail-end voltage support. A 140 MW integrated solar combined cycle (ISCC) plant is being set up based on solar thermal technology and liquified natural gas. Solar lanterns, home- and street-lighting systems, stand-alone power plants, and pumping systems are being promoted. So far, 9,20,000 SPV systems with an aggregate capacity of 82 MWp have been installed in the country.

Wind Energy : India is among the five leading nations in wind power generation. The installed capacity is 1507 MW, and generators of capacity 250-600 kW are manufactured here. 95% of installed wind power capacity is in the private sector. State-of-the-art wind power systems are also being manufactured in the country. In fact, wind turbine equipment is also being exported to other developing and developed countries.

Biogas : Biomass power generation plants of a total capacity of about 358 MW have been installed and gasification systems of a total capacity of 42.8 MW have been set up for decentralized energy application. In rural areas, over 3.2 million biogas plants and 33 million improved stoves have been installed.

Agriculture : Some efforts to mitigate climate change in the agricultural sector have also been undertaken. They are:

- Standardization of fuel-efficient pump sets, rectification of existing pump sets.
- Rationalization of power tariffs.
- Better cultivar practices which will help in reducing N_2O emissions.

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Residential: Fuel-efficient equipment/appliances such as kerosene and LPG stoves, compact fluorescent lamps, pump sets for lifting water in high-rise buildings are being promoted in the residential sector.

Afforestation and land restoration

The basic components of India's forest conservation efforts include protecting existing forests, putting a check on the diversion of forest land for non-forestry purposes, encouraging farm forestry/private area plantations, expanding the protected area network and controlling forest fires. Forests cover 19.4% of the country's landmass. Forests with a crown cover of more than 40% have been increasing. The National Forestry Action Programme has been formulated for sustainable forest development and to bring one-third of the country's geographical area under forest/ tree cover as mandated in the National Forest Policy, 1988.

A major programme of afforestation is being implemented with the people's participation under the Joint Forest Management. The National Forest Policy envisages the participation of people in the development of degraded forests to meet their requirements of fuel wood, fodder and timber. Twelve biosphere reserves have been set up to protect representative ecosystems. Management plans are being implemented for 20 wetlands with coral reefs and mangroves being given a priority. The National Wasteland Development Board is responsible for regenerating private, non-forest and degraded land. The National Afforestation and Eco Development Board is responsible for regenerating degraded forest land, land adjoining forests and ecologically fragile areas.

Role of Methanotrophs and Methylotrophs

The atmospheric concentration of methane, a green house gas, has more than doubled during the past 200 years. Consequently, identifying the factors influencing the flux of methane into the atmosphere is becoming increasingly important. Methanotrophs, microaerophilic organisms widespread in aerobic soils and sediments, oxidize methane to derive energy and carbon for biomass hence, they play an important role in mitigating the flux of methane into the atmosphere. Several physico chemical factors influence rates of methane oxidation in soil including soil diffusivity, water potential and levels of oxygen, methane, ammonium, nitrate, nitrite and copper. Most of these factors exert their influence through interactions with methane monooxygenase (MMO), the enzyme that catalyzes the reaction converting methane to methanol, the first step in methane oxidation. Although biological factors such as competition and predation undoubtedly play a role in regulating the methanotroph population in soils, and thereby limit the amount of methane consumed by methanotrophs.

Methane, is second only to carbon dioxide in its importance as a green house gas. The ability of microorganisms to oxidize methane has been known since 1906, when **Sohngen** first isolated an organism capable of growing on methane as a carbon source and named it ***Bacillus methanicus***. Since that time, methane oxidizing microorganisms (methanotrophs) have been found in a variety of soil and aquatic environments. Oxidation of methane to carbon dioxide in soil occurs primarily as part of aerobic metabolism in methanotrophic bacteria. The net reaction of methane oxidation under aerobic conditions can be described as:

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

Methane oxidation can also be linked to the reduction of sulphate in anaerobic metabolism. Anaerobic methane oxidation has not been detected in environments lacking sulphate and appears to be most prevalent in aquatic environments.

Methanotrophs, are a subset of the larger group of organisms that utilize one – carbon compounds, the methylotrophs. Classically, the methanotrophs have been divided into a few main genera: *Methylococcus*, *Methylomonas*, *Methylobacter*, *Methylosinus*, *Methylocystis, Methylobacterium* and *Methylosporovibrio.*

From a functional standpoint, methanotrophs can be divided into three types based on their carbon –assimilation pathway or pathways, as well as intra cytoplasmic membrane arrangement, cell morphology and their guanine and cytosine content of their DNA. Type I methanotrophs possess the ribulose monophosphate pathway, Type II the serine pathway, and Type X both the pathways.

CARBON SEQUESTRATION

Global warming is amongst the most dreaded problems of the new millennium. Carbon emission is supposedly the strongest causal factor for global warming. So, increasing carbon emission is one of today's major concerns, which is well addressed in Kyoto Protocol. Trees are amongst the most significant elements of any landscape, both due to biomass and diversity. Their key role in ecosystem dynamics is well known. However, it is paradoxical that the vegetation has undergone destruction and degradation in the modern times due to industrial and technological advancement achieved by human society. This advancement has resulted in emission of carbon in the ecosystem. Therefore, there is need to address environmental issues related to them. Trees are important sinks for atmospheric carbon i.e. carbon dioxide, since 50% of their standing biomass is carbon itself.

Nearly half the Indian population will soon be living in urban areas. And urbanization is vigorously promoted both politically and socially as a means to enhance average living standards. However, the ever-growing urbanization threatens escalating of carbon emission due to higher consumption of goods and services compared to the rural sector. Hence, it is crucial that the balance be maintained between the carbon emission and carbon sequestration to achieve sustainability.

Global Carbon Sinks

Global carbon is held in a variety of different stocks. Natural stocks include oceans, fossil fuel deposits, the terrestrial system and the atmosphere. In the terrestrial system carbon is sequestered in rocks and sediments, in swamps, wetlands and forests, and in the soils of forests, grasslands and agriculture. About two-thirds of the globe's terrestrial carbon, exclusive of that sequestered in rocks and sediments, is sequestered in the standing forests, forest under-storey plants, leaf and forest debris, and in forest soils. In addition, there are some non-natural stocks. For example, long-lived wood products and waste dumps constitute a separate human-created carbon stock. A stock that is taking-up carbon is called a "sink" and one that is releasing carbon is called a "source." Shifts or flows of carbon over time from one stock to another, for example, from the atmosphere to the forest, are viewed as carbon "fluxes." Over time, carbon may be transferred from one stock to another.

How Forest Ecosystems Act as Sinks: A sink is defined as a process or an activity that removes greenhouse gases from the atmosphere. Carbon sequestration is the extraction of the atmospheric carbon dioxide and its storage in terrestrial ecosystems for a very long period of time - many thousands of years. Forests offer some potential to be managed as a sink, that is, to promote net carbon sequestration.

Carbon Reduction Credits:

The cost aspect of forest based carbon sequestration, as an offset mechanism is particularly important. It determines how carbon sequestration compares with other potential carbon offset mechanisms in the broader scheme of greenhouse gas reduction policies. According to the protocol, each country will be given carbon credits based on the carbon emission and sequestration scenario. If developing countries like India has to improve on the issue of carbon credits, then role of vegetation patches in carbon sequestered should be considered.

Indian Scene

According to Ravindranath *et al.* (1997) the standing biomass (as above and below ground biomass) in India is estimated to be 8,375 million tons for the year 1986, of which the carbon storage would be 4,178 million tones. The total carbon stored in forests, including soil is estimated to be 9578 m t. On the other hand, carbon emissions from fossil based energy production and consumption activities in India have been estimated at 152-205 m t per year. The corresponding estimate from agriculture activities including fuel burning ranges from 43 m t to as high as 115 m t. The current rate of carbon emission from agricultural and forestry sectors are just about being balanced by the current rate of reforestation.

Plant roots and carbon sequestration

Carbon management is a serious concern confronting the world today. A number of summits have been organized on this subject ranging from the Stockholm to Kyoto protocol. The current level of carbon in the atmosphere is about 375 ppm. It is estimated that if the carbon increases in the atmosphere at the present rate and no positive efforts are pursued, the level of carbon in the atmosphere would go up to 800–1000 ppm by the end of current century, which may create havoc for all living creatures on earth. Soil may be an important sink for the carbon storage in the form of soil organic carbon. This form of carbon is also a matter of serious concern for agricultural scientists across the globe because various researches reveal that the soil under intensive cultivation results in the increase.

Since the beginning of the industrial revolution, carbon dioxide concentration in the atmosphere has been rising alarmingly. Plant roots have ability to synthesize, accumulate and secrete a diverse array of compounds. More than 200 carbon compounds released from plant roots in the form of exudates are reported, which is termed as rhizodeposition. These exudates contain simple water-soluble compounds such as amino acids, organic acids, sugar and various plant secondary metabolites to complex polymeric compounds such as polysaccharides, polypeptides and enzymes.

Soil carbon sequestration

Soils are the largest carbon reservoirs of the terrestrial carbon cycle. Soils contain about three times more C than vegetation and twice as much as that present in the atmosphere. Soils contain much more C (1500 Pg of C to 1 m depth and 2500 Pg of C to 2 m; 1 Pg = 1 ´ 1015 g) than is contained in vegetation (650 Pg of C) and twice as much C as the atmosphere (750 Pg of C). Carbon in the form of organic matter is a key element to healthy soil. It is estimated that each tonne of soil organic matter releases 3.667 tonnes of CO_2, which is lost into the atmosphere. Similarly, the build-up of each tonne of soil organic matter removes 3.667 tonnes of CO_2 from the atmosphere. The conversion of natural habitats to cropland and pasture, and unsustainable land practices such as excessive tillage frees carbon from organic matter, releasing it to the atmosphere as CO_2. Depletion of organic carbon, soils develop a carbon deficit. Soils can regain lost carbon by reabsorbing it from the atmosphere. This process is called carbon sequestration.

Agricultural practices for carbon sequestration

The carbon content of most agricultural soils is now about one-third less than that in its native condition as either forest or grassland. Fortunately, modern agriculture has stopped this net loss to the atmosphere. This has come about through higher levels of biomass production, the return of greater proportions of crop residue to the land, use of cover crops and conservation tillage such as reduced and no till. Simultaneously, better fertility management through soil testing, precision farming and proper nutrient application can also lead to lowering of greenhouse gas emissions. Irrigation waters trap some CO_2 because irrigated soils produce high crop residues which sequester carbon at a rate of 0.16 to 0.27 Pg per year.

Carbon and soil organic matter

Carbon is a key ingredient in soil organic matter (57% by weight). Plants produce organic compounds by using sunlight energy and combining carbon dioxide from the atmosphere with water from the soil. Soil organic matter is created by the cycling of these organic compounds in plants, animals, and microorganisms into the soil. Well decomposed organic matter forms humus, a dark brown, porous, spongy material that provides a carbon and energy source for soil microbes and plants. When soil is tilled, organic matter previously protected from microbial action is decomposed rapidly because of changes in water, air, and temperature conditions, and the breakdown of soil aggregate accelerates erosion.

What still needs to be known?

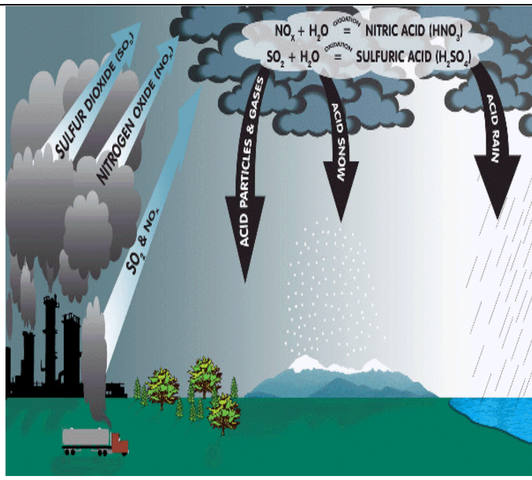
Improvement in monitoring and verification protocols for carbon sequestration in soil plant ecosystems is needed for quantitative economic and policy analyses. Such protocols must be acceptable, both domestically and internationally, to scientists, policy makers, landowners, and business groups. These protocols must be suitable for use by employees of government agencies and licensed professionals. Practical techniques to quantify the overall net beneficial impact of agricultural and silvicultural practices on all greenhouse gases, including methane (CH_4) and nitrous oxide (N_2O) are needed. Other beneficial services derived from improved land practices, such as changes in soil quality, productivity, water and air quality, and erosion must also be recognized and evaluated. Recommended carbon sequestration practices must show benefit for the total environment from a whole ecosystem accounting perspective. Long term studies are needed to insure that current effective carbon sequestration practices result in stable carbon forms for the long term (at least 20-50 years).

Acid deposition/Acid rain

The presence of excessive acid in rain water is called Acid rain. It is a mixture of nitric acid , sulphuric acid and carbonic acid. Since the early 1970s, problems associated with acidic precipitation have gained worldwide attention. Acid rain have damaged or destroyed fish and plant life in thousands of lakes throughout central and northern Europe (especially in Scandinavia), the north east United States, south east Canada, and parts of China. Many species of trees in forests throughout these regions have been in decline, largely due to soil acidification. Acid rain also causes pitting and corrosion of metals and the deterioration of painted surfaces, concrete, limestone, and marble in buildings, monuments, works of art, and other exposed objects.

Acid rain is caused by the emission of sulfur and nitrogen oxides into the atmosphere, mostly from the burning of fossil fuels for electric power. Other sources from human activities include certain industrial processes and the gasoline powered automobile. Sulfur dioxide reacts with water vapor in the air to form sulfuric acid; nitrogen dioxide reacts with water vapor to form nitric acid. It has been found that the contribution of sulfur dioxide to acid rainfall is more than twice that from nitrogen oxides. Contribution of these gases from natural sources, such as from swamps and volcanoes, are small in comparison to human sources.

A major environmental impact of acid deposition is the lowering of pH in lakes and rivers. Most aquatic life is disrupted as the pH drops. Phytoplankton populations are reduced, and many common water – dwelling invertebrates, such as may flies and stone flies, cannot survive when the pH falls below about 6.0. Some sensitive species of fish, including trout and salmon, are harmed when pH levels fall below 5.5. Acidity has a deleterious effect on the reproductive cycle of fish; when the pH is less than 4.9, reproduction of most fish species is unlikely. Acid dead lakes have pH below about 3.5.



Changes In Stratospheric Ozone

Ozone is continuously being created in the stratosphere by the absorption of short-wavelength UV radiation, while at the same time it is continuously being removed by various chemical reactions that convert it back to molecular oxygen. The rates of creation and removal at any given time and location dictate the concentration of ozone present. The balance between creation and removal is being affected by increasing stratospheric concentrations of chlorine, nitrogen and bromine, which acts as catalysts, speeding up the removal process. CFCs are predominant.

The Ozone layer as a protective shield

- Ozone formation in the stratosphere can be described by the following pair of reactions.
- In the first, atomic oxygen (O) is formed by the photolytic decomposition of molecular oxygen (O_2)

$$O_2 + h\nu \longrightarrow O + O,$$

where UV radiation in this case has wavelength <242 nanometers (nm)

- The atomic oxygen, in turn, reacts rapidly with molecular oxygen to form ozone.

$$O + O_2 + M \longrightarrow O_3 + M,$$

where M represents a third body (N_2 or O_2) necessary to carry away the energy released in the reaction.

- Opposing the above formation process is ozone removal by photodissociation

$$O_3 + h\nu \longrightarrow O_2 + O,$$

where in ozone absorbs UV radiation in the 200 – 320 nm wavelength region.

- The above combination of reactions form a long chain, in which oxygen atoms are constantly being shuttled back and forth between the various molecular forms.
- The net effect of the above reactions is the creation of a layer of ozone in the stratosphere that absorbs biologically damaging UV radiation.
- In addition, the heating that results from this UV adsorption is what creates the temperature inversion in the stratosphere, which produces stable conditions that lead to long residence times for stratospheric pollutants.
- As can be seen, the radiation reaching the earth's surface is rapidly reduced for wavelengths less than about 320 nm.
- The UV wavelength have been divided into two bands designated as UV-A and UV-B, where UV-A corresponds to wavelengths less than 320 nm.
- The UV-A portion of the spectrum is not carcinogenic at usual exposure levels on the earth's surface. The crucial role played by ozone in reducing UV-B is apparent.
- CFCs are very stable compounds in the troposphere. When they drift to the stratosphere, CFC molecule can be broken by UV radiation, freeing the chlorine, that is then available to destroy ozone.
- The reaction involving CFC-12 for example is $CCl_2F_2 + h\nu \longrightarrow Cl + CClF_2$, where $h\nu$ represents solar radiation.
- The chlorine freed acts as a catalyst in the ozone removal process i.e. it contributes to the reaction, but is unaffected by it.
- A single chlorine atom may break down 1, 00,000 ozone molecules, before it returns to the troposphere, where it is rained out as hydrochloric acid.
- Concern over possible destruction of stratospheric ozone first expressed in the early 1970's (Molina and Rowland, 1974), but it was not until 1985, with the dramatic announcement of the discovery of a 'hole' the ozone layer over Antarctica, the size of the continental US, that the world began to acknowledge the seriousness of the problem.

The following set of reactions has been proposed to describe the role of chlorine and CFCs in the creation of the Antarctic ozone hole.

$Cl + O_3 \longrightarrow ClO + O_2$, which reacts with nitrogen dioxide (NO_2), to form a relatively inert molecule of chlorine nitrate ($ClONO_2$) :

$$ClO + NO_2 \longrightarrow ClONO_2$$

- All this point, the chlorine is effectively stored in an inactive form, unable to destroy more ozone.
- In the Antarctic winter, however, a unique atmospheric condition known as the *polar vortex* traps air above the pole and creates conditions that eventually allow the chlorine to be released.
- The polar vortex blocks warmer mid-latitude air from mixing with the air above the pole, creating extremely cold polar air temperature.
- Stratospheric temperatures may fall below – 90°C, which is cold enough to form polar stratospheric clouds even though the air is very dry.
- The ice crystals that make up polar clouds play a key role in the Antarctic phemomenon.
- By providing reaction surfaces, these ice crytals allow chlorine nitrate to react with water to form hypochorous acid (HOCL)

$$H_2O + ClONO_2 \longrightarrow HOCl + HNO_3$$

- As soon as the Sun rises in Antarctic in August, the chlorine stored in HOCl is freed dry photolysis

$$HOCl + H\upsilon \longrightarrow Cl + OH$$

- As number of possible catalytic reactions have been proposed, whereby the freed chlorine can proceed to destroy ozone.
- As described by Rowland (1989), the chlorine formed can destroy an ozone molecule, creating chlorine monoxide.

$$Cl + O_3 \longrightarrow ClO + O_2$$

and the OH radical can destroy another ozone

$$OH + O_3 \longrightarrow HO_2 + O_2$$

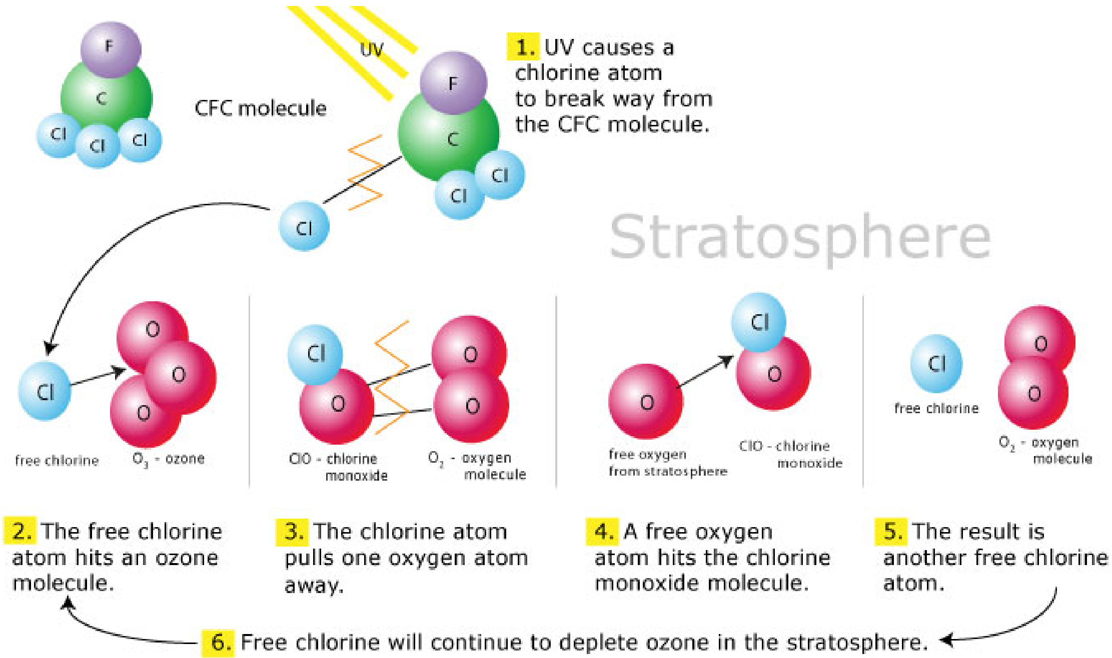
- The ClO and H_2O formed thus, can react with each other to form HOCl.

$$ClO + HO_2 \longrightarrow HOCl + O_2$$

Which ca be photolysed, releasing chlorine once again

$$HOCl + h\upsilon \longrightarrow 3O_2$$

- The destruction of ozone, as the sun first appears in the Antarctic spring, proceeds as described until the nitric acid formed ($H_2O + ClO_2 \longrightarrow HOCl + HNO_3$) photolyses, creating NO_2 that ties up chlorine. ($ClO + NO_2 \longrightarrow ClONO_2$), stopping the ozone destruction.



Since ozone absorbs biologically damaging UV radiation before it can reach the earth's surface, ozone destruction increase the risks associated with UV exposure. UV radiation is linked with human skin cancer, cataracts and suppression of immune system response. Moreover, many plants and aquatic organisms have been shown to be adversely affected by increases in UV exposure. And finally, increases in terrestrial UV flux could increase urban air pollution through the photolysis of formaldehyde, a common component of photochemical smog. Sunburn, Cataract, aging of the skin and skin cancer are caused by increased UV radiation. It weakens the immune system by suppressing the body's resistance to certain infections like measles, chicken pox and other viral diseases that elicit rash and parasitic diseases such as Malaria introduced through skin. It affects the ability of plants to capture light energy during the process of photosynthesis. This reduces the nutrient content and the growth of plants. This is especially seen in legumes and cabbage. Zooplanktons and phytoplanktons are damaged by UV. UV exposure shortens the breeding period of Zooplanktons. As planktons from the basis of the marine food chain, any change will influence the fish and shellfish production.

Lecture 8 Global warming and climate change : GHG emission, GH effect, impact on environment and agriculture – mitigation strategies

1.	IPCC is concerned with	
	a)Heavy metal	**b)Ozone depletion**
	c)Biodiversity	d)Nitrate pollution
2.	Sulfuric acid is a secondary pollutant	
	a)True	b)False
	Acid rain is	
3.	**a) Rainfall with a pH of <5.6**	b) Rainfall with a pH of >5.6
	c)Rainfall with a pH of >7.6	d)Rainfall with a pH of <2.6
4.	Reddish brown flecks on leaves, bleaching , premature aging, in plants is caused by	
	a)Nitrate	b)SO2
	c)Lead	**d)Ozone**
5.	Which one of the following is a Ozone depleting compounds	
	a)CFCs,	b)methane
	c)nitrous oxide	**d)All the above**
6.	A single chlorine atom can destroy up to	
	a)10,000 ozone molecules in the stratosphere.	**b) 100,000 ozone molecules in the stratosphere.**
	c)100,000 ozone molecules in the Troposphere.	d)10,00,000 ozone molecules in the stratosphere.
7.	Ozone hole was first observed in	
	a)Africa	**b)Antartica**
	c)Asia	d)Latin America
8.	Microbes involved in methane oxidation are	
	a)Methhanotrophs	b)Methanogens
	c)Acidophiles	d)Methanococcus
9.	The Scientist who detected acid in rainwater for the first time	
	a) Ravish Malhotra	b) Yuri Gagarin
	c) Henry Becquerel	**d)Robert Angus Smith.**
10.	A generic growth model for various crops was developed by IARI for optimal resource and agronomic management options.	
	a) Inforesource	**b) Infocrop,**
	c) Infomap	d)Infoagron
11.	A simple sugarcane growth model, to measure effects on cane yield is	
	a) Infosys	b)infocrop
	c) Infocane	d) none of the above
12	The main culprit in photochemical smog is	
	a)NO_X	b)Ozone
	c)PAN	**d)all the above**
13	The main pollutant in reducing smog is	
	a)SO_2	b)Moisture
	c)Soot particles	**d)all the above**
14	In the total warming effect CO_2 alone contribute	
	a)30%	b)25%

	c)60 %	d)40 %
15	The important replacement for CFC's are	
	a)HFCs	b)HCFCs
	c)Halogenated CFC's	d) all the above
16	Atmosphere residence time for methane is around	
	a)10-12 years	**b)8 -11 years**
	c)5 – 6 years	d)More than 20 years
17	Ozone layer is ------------------	
	a)Protective layer when it is in mesosphere	b) Protective layer when it is in troposphere
	c)Destructive layer when it is in troposphere	d)all the above
18.	___________ is the predominant inorganic oxidant in atmosphere **(Ozone)**	
19.	Electrostatic precipitators are used to remove ____________________**(Particulate Matter)**	