UNIT 18 CLIMATE CHANGE: GLOBAL WARMING

Structure

18.0 LEARNING OUTCOME

After studying this Unit, you should be able to:

- imbibe the concepts of weather, climate and climate change;
- understand the threat posed to climate by human activities;
- describe the interacting components of the earth's climate system having different scales of responses to external forcings;
- appreciate the importance of monitoring of the climate system;
- **explain** greenhouse effect in relation to climate change, and the use of clirnate models for making projections about future greenhouse gases induced global warming which is the most perceptible manifestation of the ongoing man-made climate change;
- learn about climate change studies done in India;
- highlight the role played by oceans in modulating global warming and its impact on clirnate-related disasters; and
- describe probable biological impacts of global warming / climate change on agriculture **and** terrestrial ecosystems.

18.1 INTRODUCTION

Weather and climate have the inherent characteristic of change. Weather refers to the day-to-day state of the atmosphere, characterised by meteosotogical variables like rainfall, temperature, wind etc. Climate refers to the normal / long term average conditions of weather variables over a specified period, like month, season or year and may also provide information on the frequency and intensity of extreme events and other statistical properties of weather elements. Both weather and climate vary over a wide range of spatial and temporal scales. Weather is variable due to the dynamic nature of atmospheric disturbances. Earth's climate is fundamentally controlled by its orbital parameters, the chemical composition of the atmosphere and feedbacks within these components of the climate system. Climate varies because of latitudinal and altitudinal temperature gradients, nearness to sea, presence of mountains, forests and deserts, etc. Superposed on these large-scale factors, which determine regional climate, more complex sub-regional and local factors such as river valleys, large lakes, character of soil may modulate local climate on fine geographic scale. The amplitudes of climate variability differ considerably from global, regional and local spatial scales, such as inter-centennial, inter-decadal, inter-annual, seasonal and sub-seasonal scales. Climate variability on sub-seasonal scale is reflected as variability in the occurrence of normally expected large-scale weather events. Finally, even long-term climatic normal cannot be considered to be fixed and the climate itself varies and changes over medium to long-term scales.

Climatic variability refers to year-to-year and decade to decade patterns of weather. Climate change refers to long term trends. Climate changes have occurred on the Earth due to a variety of factors like evolution of the chemical composition of the atmosphere, geological changes in the Earth, slow changes in the Sun-Earth geometry etc. These climatic changes are related to natural causes and man has no control over them. For example the cycle of glacial cold and interglacial warm epochs on the Earth that have been inferred through proxy climate records, have resulted in catastrophic changes in the Earth's climate. The amplitudes of these transitions in terms of temperature are of the order of 5-1OC. Within the interglacial periods, known as little Ice Ages, global and regional climates may fluctuate to an extent of 2 to 5°C accompanied by extension and retreat of glacial ice cover on the surface of the Earth. History tells us that impact of such naturally caused climate change have devastated human societies and cultures in different regions of the world. The present day scientific - technological society is considered more vulnerable as even small aberrations like flood / drought in a year or more frequent intense tropical stonns along the coastal belt disrupt regional and national economies for years.

We are aware that the present society has acquired the capacity to affect and even alter the Earth's physical, chemical, biological and geological environments on all scales (global, regional and local) by excessive use of energy, fertilizers, water, etc. Human impacts on atmospheric composition, global climate, landscape etc. are growing. Threat of human induced climate change has attracted the attention of scientists and policy makers in the last three decades. The effectiveness of response to extreme weather events and to decadal scale climate variability is an indicator of the abilities of societies to adapt to future climate change whether it is caused by natural or man made factors. Because of our increasingly complex and interactive social and technological structures, we ace more vulnerable to climate related disasters. Developing nations are even more vulnerable to climate-related natural disasters and environmental degradation.

In this Unit we will focus on the climate system, climate monitoring and records, human induced climate change through green house effect on global and regional scales, difference between climate change and global change, global warming and ocean response to global change and impacts of global wanning on agriculture and terrestrial ecosystem, etc.. These themes are very complex and authoritative books are available on each theme. Our attempt in the Unit is to provide only the salient features about them and to build interest among learners for acquiring more comprehensive information on the desired theme.

18.2 EARTH'S CLIMATE SYSTEM AND ITS MONITORING

18.2.1 Earth's Climate System and its Components

The Earth is unique in our solar system as it alone seems to have the capacity to sustain such a vast vaiiety of evolving life. Earth is a complex system of interacting, physical, biological and geological processes in which humans interact and influence the environment. In modern context, the Earth's climate system is considered to be composed of four interacting coinponents like the atmosphere, the hydrosphere (ocean and water bodies), the'biosphere and the geo-sphere (cryosphere and the land surface). Growing understanding of the linkages within different components of the Earth's Climate System is enabling the development of observational studies through global and regional monitoring of each component and maintenance of appropriate data bases at international and national levels along with developments of comprehensive mathematical inodels of the colnponents and the total climate system. Such climate models have the capabilities of predicting large scale climate events on aglobal scale with more certainty than was feasible before in comparison to regional scale events. Significant advances in observing, modeling and understanding of the complex climate system are being made now a days when society is in need of some scientific advice on how to cope with or adapt and mitigate changes in the Earth's habitat which may result from climate change.

The atmosphere is an envelope of gases over the earth's surface with different layers, such as troposphere and stratosphere with their characteristic thermal and dynamical structures. The earth's atmosphere system is in radiative balance in which wind circulation and ocean currents are important. The oceans cover up to 70 percent of the earth's surface and play a critical role in regulating climate because of their huge thermal inertia. The ocean currents also contribute substantially towards maintaining thermal equilibrium in the earth atmosphere system. The oceans also sequester about 30percent of atmosphere carbon dioxide and thus play an important role in the earth's carbon cycle. Oceans also play an iinportant role in the hydrological cycle, as they are the source of most of the moisture in the earth-atmosphere system. Oceans are also crucial in the process governing the cycling of the nutrients and dissolved organic matter in them which function as marine food web. Thus oceans are involved in long- term variations in climate and in turn in maintaining the biodiversity and productivity of species living within them.

The biosphere and the land surface exchange materials, heat and moisture with the atmosphere. Interactions in the boundary layer between biosphere, land and atmosphere are crucial for hydrological cycle, weather and climate, run-off, water quality, air quality etc. Humans by acquiring the ability to alter the planet's biosphere (deforestation) and land surface now stand in nature's way of exchanging materials and the energy with the atmosphere and even altering the trace gas coinposition of the atmosphere which has serious implications for climate and climate change. As the climate system evolves in response to changing concentration of atmospheric gases, the terrestrial and marine bio-systems also evolve in order to adjust to the climate change.

The geosphere consists of the interior of the Earth, land surface and cryosphere, (polar ice caps, the permafrost, and the glaciers and snow accumulation on mountains). Cryosphere also contributes to the maintenance and modulations of the climate on the Earth. Slow variations in this sub-coinponent contain the history of the climate of the planet.

Components of the climate system react to the external forcings on considerably different time scales. Atmosphere is the fast component of climate system as it responds rather fast to different forcings. Ocean is a slow component and land surface and biosphere are slow as well as fast responding components to different forcings. Cryosphere and the interior of the Earth are the slowest responding components to different forcings. The atmosphere, ocean, biosphere, and geosphere are connected to climate, climate variability and climate change from minutes to decades, centuries, and millennia scales. Climate system integrates variations in the components and feedbacks on terrestrial biomass / ecosystem.

18.2.2 Climate Monitoring and Climate Records

A knowledge of the history of climate is important for studying climate change. Climate history is studied by collecting information about relevant parameters of the different components of climate system. Most of the modern national weather services including India's were established between the middle of the 19th century and beginning of the 20th century. Therefore, the instrumental records on global and regional climates are available for nearly 100-150 years only. They are useful in understanding climate variability more precisely. They also help in diagnosing whether any slow changes or trends and fluctuations which have taken place on different spatial and temporal scales, and keeping vigil on the anthropogenic (man-made) changes in climate on global, regional and the local scales. International mechanisms have been established for monitoring the climate system under the aegis of the World Meteorological Organization (WMO) of the United Nations System, and other scientific agencies.

Global Climate Observing Systein (GCOS) and special research programs like the World Climate Research Program, World Ocean Circulation Experiment, International Geosphere–Biosphere Program, the Global Change Program, Climate Variability Program, Global Energy and Water Cycle Experiment etc. are in place to understand climate variability as well as natural and anthropogenic induced climate / global change,

Past climate is studied by using proxy records based on a variety of factors such as width of tree rings, extent of glaciers, pollens, cores and sediments from deep-ocean and polar ice caps. These records have shown that the earth's climate system has passed through different epochs as a result of natural causes. For example, climate of the last ice age 18000 years before the present was very cold as the ice sheets had extended down upto about 30°N in the Northern Hemisphere which had made the Indian summer monsoon very weak. Similarly, in the present interglacial during 10000- 6000 years before present, the earth has passed'through a warm period resulting in more poleward movement of the northern hemisphere forests and greatly expanded African and Asian monsoon systems, which had made the Sahara and the Rajasthan deserts rather green with vegetation and scattered with fresh water lakes. During this Holocene period, the orbital configurations of the Sun-Earth geometry were different:than the present:and the coupled climate –vegetation converged to produce a different terrestrial ecosystem. Similarly global carbon cycle provides another example of the links between the planetary ecology and the Earth's Climate System. Whereas past climate changes were caused by natural factors, there is threat **now** that climate may change in the next century due to man's activities.

Among the most perceptible manifestations of the on-going climate change is the phenomenon of Global Warming on account of enhanced greenhouse effect resulting from man-made causes. We shall concentrate on global warning in the subsequent sections of this Unit.

18.3 GREENHOUSE EFFECT, CLIMATE CHANGE AND GLOBAL WARMING

18.3.1 Green House Gases, Green House Effect and Global Warming

Green house effect on the Earth is identified by the difference between the effective radiating temperature of the planet and its surface temperature. Naturally occurring green house gases (GHGs) such as water vapor, carbondioxide (CO,) , tropospheric ozone (0,), oxides of nitrogen (NO_x) and methane (CH4) bring about the green house effect through the property that they strongly absorb the radiation emitted by the Earth in the infrared region of the spectrum. Greenhouse effect changes the global energy balance which would otherwise have been without the presence of these gases. This keeps the global average temperature warm and makes it possible for all kinds of life to thrive on the Earth. Human activities such as industrialisation, intensive agriculture, excessive use of fossil fuel etc. are disturbing the composition of natural green house gases as several anthropogenic gases like CO_2, CH_4, NO_x, chloro-fluoro-carbons (CFCs) are being added to the atmosphere at increasing rates which is beginning to make an impact in tenns of climate change. For example, CO, has gradually increased from about 270 ppmv in pre-industrial era in the 18th century to about 370 ppmv at present, with án annual increase of about 1.8 pprnv. CH_4 has increased from 700 ppbv to 1750 ppbv. Chloroflurocarbons which have a residence time of almost 100 years, have also increased considerably from nil in pre-industrial era to about 400 X 10^{-6} ppmv in 1990 till an international protocol, known as, Montreal Protocol, was introduced in 1987 to regulate and curb the use of CFCs. In addition to disturbing the Earth's radiation balance, greenhouse gases also perturb the chemical balance. Some of the man-induced gases like CFCs and CH_4 have much higher global warming potential relative to CO, (30 to 25000 for CH, and CFCs respectively in relation to CO,). Even though their concentrations in the atmosphere are much smaller than CO,, their contributions to global warming could be very significant.

The present threat of warming of the surface temperature of the Earth is resulting from an increase of greenhouse gases in the atmosphere. It has been under study for two decades by the Intergovernmental Panel on Climate Change (IPCC), under the aegis of WHO and UNEP. These studies have evolved different scenarios for the emissions of greenhouse gases by human activity ranging from no change in the present emission rates to highly controlled emissions. Each scenario leads to different magnitude of global warming/ cl imate change as inferred from the results of climate models of different complexities. The consensus in magnitude of changes of wárming on global scale is better than on a regional scale. Some of the indicators of global warming are:

- Climate change is a direct consequence of unsustainable consumption driven by energy intensive production and consumption systems including the unbridled use of fossil fuels.
- Increasing concentrations of greenhouse gases, some of which remain in the atmosphere for centuries, has already resulted in global warming by 0.6^0 C in the last 100 years and will result in increase in average global temperature by 1.5 to 5.8°C by the end of 21st century as per different scenarios of GHG emissions.
- Sea level has risen by 10 – 20 cm in the 20th century and will further rise in the 21" century by even higher magnitude (50-88 cm) by the end of 2100. (This is a very serious threat and we shall discuss Sea level Rise in detail in the next Unit).
- Manifestation of climate change on regional scale remains a grey area with several uncertainties Polar temperature will rise more than tropical temperatures. Regional difference will be also present as the warming will not beuniform, globally.

- There would be direct and indirect sectoral impacts on different sectors of human activity as anthropogenic clitnate changeemerges in the next 20 years and beyond unless the emission of GHGs is controlled on a global scale.
- There are some barriers lo effective adaptation and mitigation strategies on global and regional scales due to scientific uncertainties, absence of sufficient information base, inadequate science and technology inputs for policy formulation, lack of trained manpower, inadequate coordination mechanisms and resistance of some countries with high per capita emission to reduce their greenhouse gas emissions by becoming partners in the international protocols for climate change.
- Reacting to climate change is more difficult for developing countries without necessary financial and technical resources to adopt cleaner technologies while continuing their development. Thus the fight against climate change is also about sustainable development with clean technologies and developing countries are more vulnerable in this context. The challenge of climate change is such that both the developed and developing nations have to adopt a pragmatic, cooperative and a holistic view balancing the best interests of the genuine needs of a dignified human society and high consumption life styles.

18.3.2 Climate Change and Global Warming

Some of the predictions about anthropogenic climate change are virtually certain; others are very probable. Regional scale changes and changes in climate variability are uncertain. Scientists are still discussing why and by how much the climate is changing in response to greenhouse gas emissions. Obviously, there is no simple answec Climate models, on which the predictions about climate change/global warming are made, are of different vintage. However all models, converge to indicate that the annual average global temperature of earth's surface would increase between 1.5 to 5.8°C over the next 100 years, the increase being more in higher latitudes than near the equator. Furthermore, the increase would be higher in winter than in summer.

Thus global warming encapsulates for the public all complex issues in anticipated future climate change associated with observed greenhouse gases increase. It refers to a clear symptom of climate change hut it is not the only aspect of climate change that concerns mankind today. The attributes of climate change are many, e.g., change in the frequency of extreme weather and climatic events like heavy rainfall spells, tropical cyclones, storm surges, floods and droughts, rise in soil temperatures, sea level rise, alterations in the working of the global carbon cycle and the bio-geo-chemical cycle, etc. The fundamental problem is that the present day human activity is changing the way the atmosphere absorbs and emits solar radiation, i.e., the energy received from the sun. Global warming is the most obvious way in which the climate change is predicted and is detected. The potential consequences of this warming may lead to other changes by modulating the energy source of the climate system which may induce changes in other climatic parameters, thus impinging seriously on society and human life in general.

Scientific dataevaluation of the past 100 years or so on surface air temperature records indicates global warming of about 0.6°C in 100 years with the 20th century being the warmest in the last 1000 years and the decade of 1990's being the warmest in the 20th century. However, substantial fluctuations have occurred in theunderlying trend with the warming having been arrested between 1940 – 1970. A few consecutive years of higher / lower globally or regionally average temperature would not mean global warming /cooling. Similarly, more frequent heat / cold waves may not be the sign of global warming / cooling though such extreme events, if found to be statistically significant, may cause alarm about warming / cooling trends.

General Circulation Models (GCMs) of the atmosphere and the ocean are the only quantitative tools for predicting future climate. These mathematical models are solved on ever-faster super computers simulating the Earth's climate over hundreds and thousands of years under controlled and simulated conditions under different greenhouse gases scenarios. The models also include explicitly coupled processes in the land, atmosphere and ocean components of the climate system and projections or predictions are made on global mean parameters like temperature, rainfall, soil moisture, etc. However in all models these projections represent a substantial warming of global climate (global warming) by the end of the 21" century. Uncertainty is getting reduced but still exists, as the global climate is sensitive to radiative forcing by greenhouse gases and other perturbations in the climate system, which in turn depend on different scenarios.

Spatial patterns of global warming or climate change on continental scale emerge with increase in greenhouse gases, the warming over the land (continents) is more than warming over the ocean. There is minimum warming in the Southern Hemisphere as it is mostly ocean-covered. Less warming is predicted for the Antarctica and the North Atlantic, which is due to deep oceanic mixing in these areas. Maximum warming is predicted in high latitudes of the Northern Hemisphere. There is little seasonal variation in the wanning at low latitudes and the magnitudes are also less compared to high latitudes. The following major results have emerged about anthropogenic global warming and its major impacts:

- CO, emissions alone account for 64 percent of the global warming.
- Snow cover has decreased by 10 percent since 1950s.
- Frequency of extreme events like floods and droughts is expected to increase.

18.3.3 Climate Change: Studies in India

Several studies have been made about climate change over India in the past by using proxy data (pollens, lake levels, ocean core / sediments, corals, tree rings etc.), Holocene changes, instrumental data and climate model-based projections of possible changes under green house gas forcings have also been investigated. Holocene changes are the best among those identified which showed more vigorous monsoon rainfall regime extending up to the Rajasthan desert making it much greener during 1000-6000 years before present than what it is today. Similarly, tree ring data from western Himalayas also indicate cold/warm spells lasting several years in the last 400 years or so. Instrumental records of temperatures in the last 100 years show large overall warming of about 0.6^0 C / 100 years (as in the global average temperature) with patches of cooling on sub-regional scale. The data with respect to annual or seasonal summer monsoon rainfall do not show any definite trends on All India or Indian Regions scales though individual stations do indicate rising or falling rainfall trends lasting 2 or 3 decades. With regard to changes in the frequency of tropical disturbances forming on the Indian seas, there is no trend in the high intensity cyclonic systems though number of monsoon depressions have shown a decrease in the last 30 years or so. Similarly, there is no clear-cut trend in the frequency of drought or excess monsoon season rainfall as an oscillatory behaviour on multi-decadal scale (about 30 years) is only identifiable with respect to the occurrence of drought/excess monsoon years. More detailed studies with regard to occurrence of extreme weather events on long-term basis such as intensity of heavy rainfall spells, sequences of dry days, heat and cold waves etc,. are still needed.

Atmospheric and coupled ocean-atmospheric models have been used to determine the magnitude of anthropogenic climate change in the summer monsoon rainfall over south Asia under double CO, and other scenarios. Different models suggest different magnitudes of simulated monsoon (June to September) rainfall in such scenarios, the differences being within ± 10% among different models. Also the models show warming over India by about 1^o to 2^0C in summer and winter seasons. Efforts have also been made to use regional models, embedded within the global models, and to use down-scaling techniques to improve the model predictions on a regional basis. However no clear cut (certain) results with regard to predictions on regional climate change over India seem to be available from these model studies so far. The science of the models is changing fast and as such the results of the modeling studies evolve with changes in the modeling physics and coupling strategies. It is expected that modeling uncertainties would decrease as the state-of the-art techniques tools are used for understanding the Earth's present climate, and for estimating the effects on past and future climates due to various natural and human factors.

The access to model outputs from sophisticated models run in Europe, North America and Japan for the South Asian part has also increased amongst scientists in India. Besides Indian research centres have also developed computing facilities and other infrastructures to integrate global climate models within their institutional environments. These have enhanced our capabilities to use global model predictions for policy formulation to adapt to future anthropogenic climate change. Within the south Asian Region, India can provide a lead to other countries on climate modeling and related policy issues and promote regional cooperation on science of climate and climate change as well as on capacity building issues to mitigate climate change. Several of the South Asian countries are already signatories to the United Nations Frame work Convention on Climate Change (UNFCCC), acknowledging that change in the Earth's climate may adversely affect mankind and the terrestrial and marine ecosystems.

There is a need to quantitatively asses the sensitivity and vulnerability of natural and human systems to climate change over different countries of the South Asian region. This is specially important for India because of its dependence on monsoon rains. Assessment of sensitivity and vulnerability of monsoon on climate change would help in identification of adaptation and mitigation strategies as well as improvements of long-term monitoring of the regional land-atmosphere–ocean system. Keeping inventories of the regional greenhouse emissions is equally important in spite of the fact, that at present, South Asia contributes only about 3% of the global greenhouse gas emissions. These emissions are bound to increase as the region marches on the path of development.

18.4 GLOBAL WARMING AND OCEAN

Ocean, because of its thermal inertia is a regulator and modulator of global and regional climates on different scales. Tropical oceans are the source of moisture which is essential for rain and snow. Warm tropical oceans like the Indian ocean and the western Pacific ocean exercise great control on the Asian monsoon and are the regions of organised convection which helps in the formation of tropical disturbances (depressions, tropical cyclones, typhoons). Climate models predict that the sea surface temperature (SST) may further warm by 1 to 2°C in the already warm pools of the tropical Indian ocean and the Pacific ocean. This would have the following implications:

- Since the formation of tropical cyclones depend on SST, rise in SST may lead to higher frequency and more intense tropical cyclones. As a result risk of devastation along the coastal belts by the striking of tropical cyclones could increase. Also higher intensity cyclones would result in higher storm surges near the zones where the cyclones would hit the coast resulting in greater damage to life and property.
- Warming of the global ocean would lead to rise in the sea level as a result of thermal expansion of the waters. As already stated, sea level rise will be discussed in detail in the next Unit.

Unusual warming of the sea surface water in the equatorial central and eastern Pacific ocean is called the El-Nino phenomenon which has been recognised as a global signal on inter-annual and decadal scale climate variability across many countries. El-Nino leads to warming of the central and eastern equatorial Pacific ocean above the threshold value of convective formations *(26.5" C)* and eastward shift of convection over the Indo-Pacific region. It was stated in the Unit on Cyclone that the temperature of sea surface water should be around 26-27 degree celsius for a cyclone to form and strengthen. Climate models indicate that in the climate change scenario, there may be changes in the frequency and intensity of El-Nino events which would modify the frequency of cyclones, droughts & floods across several countries.

Oceans sequester nearby **30** percent of atmospheric CO, and thus are storehouses of excess CO, Changes in sequestering of CO, in the oceans may change global warming. It must be emphasised that the ocean modeling and the coupled atmosphere ocean modeling are still under development and hence their results on climate change issues have to be taken with caution. In spite of great progress in climate modeling, there is no doubt that many of the major issues linking climate change and oceans are still not fully understood and hence the challenge of modeling and prediction of the coupled climate system is still formidable.

18.5 IMPACTS OF GLOBAL WARMING/CLIMATE CHANGE

Our global, regional and local environments are changing from many kinds of human activities e.g. greenhouse gas emissions, changes in land surface use, deforestation, desertification, coastal zone activities, intensive agriculture and several others. Climate warming by increasing greenhouse gas emissions is but one, perhaps the most complex, of these issues. These environmental changes may cause climate changes on corresponding scales in different measures. The likely consequences an different sectors of society need to be understood. Our response to these changes should be to promote suitable policies to remedy the possible adverse effect on specific sectors. There are several reasons for conducting climate change impact assessment e.g. modern society's increasing vulnerability to adverse climatic events (vulnerability to water stress, geological stress, human health problems, economic development).The simple approach for assessing climate change impact follows the cause and effect pathway. At the same time, interactions of the society to meet climate change threat also need to be examined for realistic assessment. For example, at the global level, changes in climate may lead to a shift in natural vegetation zone and this shift in itself may feedback on the climate. An integrated approach to climate impact assessment therefore, involves:

- Building of climate scenarios in relation to land, atmosphere, ocean, water resources etc. using sector specific models; e.g., energy sector, transportation sector, agriculture sector, etc.
- Integrated assessment of impacts on regional/national level for each sector such as agriculture impact assessment, water resources impact assessment, etc.

More precise projections of impacts using mathematical models to extrapolate into the future is needed for policy formulation. Impact models are different than the climate models which predict climate changes with regard to temperature, precipitation, frequency of extreme climate events etc. Impact models use these climate scenarios to project the future impacts of climate change in specific sectors. Econometric models are also applied to determine the probable losses to the economy and make cost-benefit estimates for possible remedial actions. Use of such models would also need selection of a climatological base line e.g. the presently available long-term averages or normals of the climate on different spatial scales. Similarly appropriate environmental base-line would be used for assessing biophysical impacts.

Selection of thresholds for response that may occur, under a given magnitude or rate of climate change e.g. warming, may enhance plant growth in high latitudes but high temperature in the tropics/ subtropics may cause heat stress or water stress to plant growth. Thus limits of tolerable climate change without major disruptive effects on different scales are to be assessed and defined. Threshold limits of climate change acceptable in different sectoral assessments must be chosen carefully before geographical area specific impacts are quantitatively assessed. Thus techniques for assessing climate change impacts have to be carefully developed using historical records, climate models and impact models. We will now examine the potential impacts of climate change on two specific areas viz. agriculture and terrestrial ecosystems while focusing our discussion on India.

18.5.1 Impact of Climate Change on Agriculture

Agriculture's dependence on climate makes this sector an ideal one for examining potential impacts of climate change. It has aleady been explained that increase in greenhouse gases has the potential of global warming. The global and regional warming estimates differ from model to model and scenario to scenario for the increase of green house gases. Therefore for assessing the impact on agriculture, the following have to be kept in view:

- Increase in the concentration of CO, would affect photosynthesis by agricultural plants, increasing the foliage and the biomass of plants and vegetation.
- Increase in temperature may cause-thermal stress.
- Changes in rainfall, cloudiness (changes in solar radiation), storm activity, run-off, and extreme rainfall events may cause changes in agricultural production mostly detrimental.

During the last decade, there has been rapid increase in public awareness of global warming. This has encouraged several scientists in India to study the impacts of climate change on India's agricultural production. Agriculture provides not only food security to vast Indian population but is also a major source of direct and indirect employment in rural and urban India. The salient features of the impacts of climate change on agriculture in India, as brought out by several studies are summed up below:

- The Indian rainfall data of over 130 years does not show any definite trend in summer monsoon and annual rainfall. Also there is no significant change in the incidence of extreme rainfall spells or frequency of droughts/floods on multidecadal scale. Unlike predictions by the models, the number of monsoon depressions have decreased in the last two decades.
- Since CO, is an essential factor in photosynthesis by plants, its increasing trend due to anthropogenic activity is likely to cause a benevolent effect on plants and hence improve their crop yield. These prospects have been well simulated in plants grown in controlled CO, chambers and also through crop models.
- Increase in temperature under global warming is of modest extent (about 2^0 C only during the next 100 years) for the Indian region. The increased temperature may be advantageous for agriculture in hilly regions of India but may be marginally detrimental to crops grown in the hot plains. Wheat, which is a winter crop in India, may somewhat benefit but it would also reach mature stage early. Therefore to obtain optimal use, its sowing schedules may require some minor adjustments in different wheat growing areas of India.
- Overall, due to climate change a decrease in agricultural output for India as a whole is predicted after 2050, the estimates varying between 13 to 25 percent is loss both for rice and wheat.
- Provided no water stress is caused, higher temperatures in main Kharif rice growing season inay be beneficial to yield.
- Increased rainfall (even by 5%) may be beneficial to Kharif crops but lower rainfall (even by 5% as predicted by certain models) may decrease rice yield by about the same percentage. However, higher monsoon rainfall may make Kharif crops more vulnerable to pests and diseases.

- Higher (lower) cloudiness associated with higher (lower) monsoon rainfall may have negative (positive) effect on photosynthesis and influence output of Kharif crops.

The Indian Council of Agricultural Research (ICAR) is aware of the potential impacts of climate change on Indian agriculture. They have launched a major research programme of assessing the impacts of climate change and climate variability on crops within the huge network of their research institutes. Most of the crop models used by them are adapted from models developed in other countries and hence their projections over specific region are under certain assumptions. Assessing the magnitude of impacts on higher spatial scales is needed. Also the impacts may change as new cultivars are introduced. Hence evaluation of global warming impacts on Indian agriculture has to be an on-going process so that in future those cultivars are introduced which are tolerant to increased temperature. Creation of long-term data bases on climate and crop yields of major rainfed regions of the country would also be needed along with identification of areas which could be more vulnerable to climate change scenarios. Base line agricultural scenarios for different crops and different crop belts of India ought to be developed for the next 20 to 50 year period.

18.5.2 Impacts on Terrestrial Ecosystem

Terrestrial ecosystems and climate have very close links. The natural vegetation in different climatic zones of India, like Himalayas, grass lands, sub-tropical dry lands/arid belts and tropical evergreen forests etc, is affected by climate and CO, concentration. Similarly other ecosystems like animals, microbes also exists in different climatic zones in India. The biological richness (biodiversity) of plants and other terrestrial ecosystems is characterized by the magnitude of flow of energy and material between their constituent species and their physical environments. The interactions among biological species and the competitions among species are also influenced by climate. Therefore the term ecosystem is used not only to describe natural systems (such as corals, evergreen forests, grasslands) but also for managed systems like plantation forests and agricultural crop lands although these managed ecosystems are different from the natural ecosystems they have replaced. Both natural and managed ecosystems produce a variety of goods and services that benefit humans in direct and indirect ways. They also regulate rain run-off thus providing defences against floods and even improve water quality. Ecosystems are also used by man for recreational purposes. They are also our natural regional heritages in different ways. Climate conditions determine the performance of individual species of plants and animal that live, grow and reproduce in different ecosystems. The species in some ecosystems are strongly adapted to their environmental climate and even modest climate change would make them vulnerable. For example, the wild life in tropical deciduous forests and the desert vegetation in western India is adapted to high temperature and dry conditions. Forests in northeast India and Kerala are adapted to heavy rainfall and high soil moisture regimes. Region specific studies are needed in order to throw more light on possible impact of climate change which in turn would lead to specific responses.

Plants and animal life in the marshy areas and mangroves of Sundarbans are unique and would be severely damaged if their ecosystem is destroyed by climate changes. In aquatic ecosystems in the coastal belts of India, many fish can breed in waters that fall within a narrow range of sea temperature and salinity. Rapid sea level rise resulting from global warming accompanied with climate change would surprise corals and plants existing in coastal wetlands of India making them unfit to re-establish themselves.

Ecosystem models over a specific system when linked with the climate models provide information about the likely influence of changed climate conditions in the natural ecosystems. Thus the monsoon forests of NE India are likely to retain robust growth as the climate models predict higher rainfall and higher soil moisture for that belt. The Himalayan forest belt which is adapted to present cold temperature may be somewhat adversely affected as the climate models predict rise in winter temperature by about 2° C over the next 100 years. Similarly, rise in temperature may also affect the habitat of the Himalayan wild life and some species may be severely affected. Again higher temperatures in Himalayas may trigger more forest fires in summer thus impinging adversely on Himalayan ecosystein. Snowmelt in the Himalayas may begin earlier and upset the habitat of plants and other species. There are different uncertainties resulting from uncertainty in climate projections and inadequacies of ecosystem, biophysical, biogeochemical and bio-geographical models. These uncertainties would not allow at this stage of the development of different disciplines to make categorical impact assessments. Since climate change predictions for the Indian region are modest, much also depends upon the adaptability of the natural ecosystems (terrestrial or aquatic) over India to withstand regular or episodic small/modest climate changes. The data bases on the ecosystems in India are inadequate at present and the ecosystem specific climatic records have to be examined in detail to validate predictions of ecosysteln models with respect to historical records. The dynamics of the ecosystems in the Indian context has also yet to be fully understood.

Vegetation helps in the exchange of water and energy between land surface and atmosphere, Therefore surface processes affect climate. As natural vegetation shifts due to climate change, it would further affect climate. For example, if global warming would damage Himalayan forest belt, this change would tend to further increase the warming because of absence of forest particularly in winter. Similarly land use changes being affected by increased urbanisation, higher land use for industry, agriculture and transportation sectors, deforestation etc., would further modify the feedbacks between the climate and ecosystems on regional and sub-regional scales. In summary, the natural terrestrial and aquatic ecosystems are affected by climate and in turn provide feedback to climate. For India, the priority is to build ecosystems data bases and validate ecosystem models to understand the role of climate variability and climate change on ecosystem dynamics.

18.6 CONCLUSION

This Unit dealt with climate change related Global Warming, The terms weather, climate, climate variability andclimate change have been explained. Factors controlling global, regional and local climates have been described. Climate affects human or societal activity and is in turn affectedby societal activity. Modern society has become more vulnerable to climate variability while also changing the clitnate by authropogenic activity. Thus it is ironic that mankind is the perpetrator as well as the sufferer of/from this problem. Four interacting components of the Earth's climate system, each having different time scales for responding to external forcings, are pertinent. Man has acquired the ability to change the composition of the atmosphere by addition of greenhouse gases to the atmosphere through fossil fuel burning and other activities. This has produceda threat to climate particularly in respect of producing global warming. Climate models have been used to project future global warming and climate change scenarios under different emission rates of the greenhouse gases. Global warming is a symptom and an obvious way in which predicted climate change can be assessed. There are other indicators and attributes of climate chauge too. Mathematical models of climate have been used as tools in the last two decades to give an estimate of global warming and climate change. Different models produce different projections of climate change because of differences in the resolution of the models, model physics and coupling strategies to link different components of the climate system. Climate variability/change aspects over India as evidenced by proxy data studies for past climate are discussed. Observation data studies for recent climate projections based on models for future scenarios are also discussed. Global warming may impact on oceans too and produce changes in El Nino phenomenon (in its intensity and frequency). Ocean warming may lead to more intense tropical cyclones, higher storm surges and rise in sea level. Impacts of global warming/climate change on two sectors viz agriculture and terrestrial ecosystems are discussed placing more focus on India. Need for creation of base-line databases for different societal sectors and terrestrial and aquatic ecosystems over different regions of India is stressed.

18.7 KEY CONCEPTS

Climate change scenarios	: Estimates of global warming/climate change predicted by models under different emission rates of green house gases in the future.
Climate change	: Change in climatic parameters from their long-term normals from one epoch to another epoch due to anthropogenic causes.
Climate impacts	: Adverse consequences on the bio-geophysical and socio-economic systems and human health due to anthropogenic global warming/climate change
Climate model	: Mathematical model of the Earth's climate system solved on computer to predict magnitude of climate change.
Climate variability	: Variations of climate parameters on seasonal, interannual and inter-decadal scales from the respective averages
Earth's climate systtem	: Interacting components like atmosphere, hydrosphere, geosphere and biosphere influenced by external forcings on different time scales for controlling climate.
Global warming potential	: Relative warming caused by different greenhouse gases in relation to atmospheric carbon dioxide.
Global warming	: Increase in average surface temperature of the Earth being caused by increase in greenhouse gases emissions.
Greenhouse effect	: Trapping of Earth's thermal emission by natural and man-made gases in the atmosphere causing increase in surface temperature of the Earth. It should be noted that greenhouse effect results in the increase in the morning temperature (technically termed the Minimum Temperature) and this leads to an increase in the mean temperature of the day.
Holocene	: Most recent of the geological epochs.
Inter-glacial warm epochs	: Warm periods between two glacial ages or ice ages.
Ppmv	: Parts per million by volume
Pppv	: Parts per billion by volume
Proxy records	: Inferences drawn from evidences such as tree rings, ice cores to compile climate data of the past when there were no scientific observations.
Regional warming	: Different magnitudes of anthropogenically caused temperature changes on regional scales as global warming is not expected to occur uniformaly in all regions of the world.

Terrestrial ecosystems	:	Alignments of different natural distribution of vegetation, animal species, organisms etc on the Earth which have close links with climate and are characterised by flow of energy and materials between constituent species and environments.
UNEP	:	United Nations Environment Programme.
WMO	:	World Meteorological Organization.

18.8 REFERENCES AND FURTHER READING

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18.9 ACTIVITY

1) Identity and explain the interacting components of the earth's climate system.
2) Write a note on the basis of your experience/study on climatic records and monitoring of the climate system.
3) Prepare a list of the impacts of global warming on climate related disasters. Also explain the role played by oceans in modulating global warming.
4) Observe and explain the probable biological impacts of global warming/climate change on agriculture and terrestrial ecosystems.