DISTANCE LEARNING MATERIAL



VIDYASAGAR UNIVERSITY

DIRECTORATE OF DISTANCE EDUCATION

MIDNAPORE - 721 102

M. A. / M. Sc. in Geography

PART - I

Paper : II • Module No. : III • Unit : 1, 2, 3 & 4
Paper : II • Module No. : IV • Unit : 1, 2, 3 & 4

DIRECTORATE OF DISTANCE EDUCATION

VIDYASAGAR UNIVERSITY, MIDNAPORE

M. A. / M. Sc. in GEOGRAPHY

PART – I

Paper – II
Module No. - III ★ Unit – 01, 02, 03, 04 & 05
Module No. - IV ★ Unit – 01, 02, 03 & 04

M.A. / M. Sc. in Geography

Part - I

Paper -II

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PART - I
Paper-II : Module-III
Unit-01

Module Structure

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Paper-II : Module-III
Unit-01

1. Scope and nature of Climatology; Climatology and Meteorology
2. Atmospheric composition-its evolution through phases, changes with height; hydrostatic equation
3. Greenhouse gases- sources and characteristics

■ 3.1.0 Introduction

Climate is perhaps the most important single factor that has universal effect on almost everything on the surface of the earth. Although a different kind of climate can be found in other celestial bodies. the very special type of climate we use to come across is the climate of the earth's atmosphere (<Greek ***atomo***= **air** + ***sphere***). Broadly speaking, geography deals with the study of time-space interaction of five important spheres, namely lithosphere, hydrosphere, atmosphere, biosphere and noo-sphere (related to brain work of human beings); and climate interlinks all these spheres through a system, may be called climate system (Critchtfield, 2004). It is a very dynamic system, and is quite sensitive to any kind of change occurring at any point of this gigantic system having regional or local sub-systems according to various local factors.

■ 3.1.1 Objectives

The main objectives of this unit are to identify the very basic principles of this climate system in relation to the nature of the atmosphere; and Climatology-as a discipline to study climate. The objectives can be outlined as follows:

1. To study the importance of climate and more specifically its constituent, weather;
2. To define Climatology in relation to its area of study and also its relation with other branches of knowledge dealing with weather and climate;
3. To describe the nature of the atmosphere and its brief history of evolution, especially in regard to the changes in the composition of the atmosphere over time and space;
4. To discuss the changing character of atmospheric composition, particularly during the recent past, and its impact on the change of climate system;
5. To have an idea about the role of human beings in the recent change in the composition of the atmosphere with a brief outline of current developments.

3.1.2 The climate system and its importance

Weather and climate are two basic terms used in atmospheric sciences including climatology and meteorology, although they are defined variously. However, the elements of weather and climate are more or less the same. The commonly observed atmospheric variables constituting both weather and climate are- sunshine, atmospheric temperature, dew point temperature, pressure, cloud conditions, precipitation, wind characteristics and prevailing weather like visibility, thunder storms, cyclones etc. The basic relation between weather and climate can be stated by the fact that 'climate is the integration of weather, and weather is differentiation of climate' (G. F. Taylor), meaning a composite of weather conditions including departures of normal conditions, for over a long period of time constitutes a climate. So the difference between the two is mainly a matter of time.

In a rather simple sense, weather can be defined as the over-all condition of the atmosphere of a locality in a specific time; and climate is the nature of change of weather throughout the year in that locality. Barring few extreme conditions, called departures from the normal, climate of a locality usually remain the same for a long period of time, say three to four decades, unless and until there is any sudden or repaid intervention acting adversely in that climate system, resulting in appreciable change in it.

The study of climate essentially encompasses three basic aspects, especially in geo-sciences, namely processes, patterns and applications of climate (or weather). The importance of weather and climate can be outlined as follows:

- They are active factors to influence the physical environment of all living and non-living things.
- They play significant role on development of landscape features, including landforms, soil, vegetation, organisms etc.
- To human beings there are immediate effects of weather events to long term consequences of climate change.
- Although there have been some modifications of local weather, and also of climate, through technological advancements for adjustment in man-climate relationship, still human civilization is largely influenced by the whims of climate, especially its extreme conditions.
- The man-climate relationship is a both way interaction and, therefore, it is the duty of man to understand the nature of this relationship and act accordingly.

3.1.3 Climatology and Meteorology

According to Critchfield, 'climatology (<Greek *klima*= slope or inclination of the earth's axis, i.e. related to latitude + *logos*= discourse or study) is the science that seeks to describe and explain the nature of climate, why it differs from place to place, and how it is related to other elements of the natural environment and to human activities'. Two important disciplines related to Climatology are aerology (or aeronomy) and meteorology. The former one deals with physical and chemical properties of the atmosphere, particularly of its different layers, and is relevant to aviation, astronomy, space sciences etc. The latter one, that is meteorology (<Greek *meteor*= things above) is more closely related to climatology, as it explains relatively short period status of the atmosphere, and the process responsible for the making of weather and climate. Climatology is primarily a part of meteorology, but it does not entirely belong to meteorology, as some of it is geographical. According to E. T. Stringer, climatology is an applied science- whose methods are strictly meteorological, but its aims and results are geographical.

3.1.4 Nature and scope of climatology

Simply to say, climatology is the study of earth's climates. A related branch of knowledge called *climatography* consists of the basic presentation of climatic data in written or map form. Based on the approaches of study climatology may include five important branches, namely physical, dynamic, synoptic, historical and applied. *Physical climatology* deals largely with physical processes in terms of energy exchange in the earth-atmospheric system. *Dynamic climatology* is primarily concerned with the atmospheric motions and their effects. *Synoptic climatology* studies regional (i.e. regional climatology) or local (local climatology) atmospheric circulations and related weather and climatic conditions. *Paleo-climatology* or *historical climatology* is the study of development of climate trough time, for instance study of climate change on the basis of geologic or historical records. *Applied climatology* seeks to explore the interactive relation between climate and other elements of the earth, more specifically various aspects of human activities. Knowledge of *general climatology* (i.e. theoretical aspects) in combination with other branches of knowledge has evolved new investigations in application of climatology in the form of, for example, bio-climatology, agro-climatology, urban climatology etc.

M. M. Yoshino has classified four groups of regional or local climates on the basis of spatial scale, such as micro-climate, local climate, meso- climate and macro-climate, and accordingly their studies involve classification of climatology, e.g. micro-climatology, local climatology etc.

Time-space dimensions of weather systems				
Motion system	**Horizontal Scale (Km)**	**Vertical Scale (Km)**	**Time Scale (Hour)**	**Example**
Planetary Scale	$5x10^3$	10	$2x10^2$ to $4x10^2$	Monsoon circulations
Macro Scale	$5x10^2$ to $2x10^3$	10	10^2	Mid-latitude or tropical cyclones, depressions
Meso Scale	1 to 10^2	1 to 10	1 to 10	Thunderstorms
Micro Scale	$<10^{-1}$	$<10^{-2}$	10^{-2} to 10^{-1}	Small-scale wind eddies, Urban heat-island
				Source: After Barry, 1970

Tools and techniques of analysis of climate systems have given a separate way of classification of climatology, like: (a) *descriptive climatology*- involving description of climatic elements of a place; (b) *statistical* or *mathematical climatology*- involving statistical or mathematical techniques and formula for analysis and interpretation of climatic data, (c) *synoptic climatology*-involving a condensed view of local or regional atmospheric elements and circulation patterns in a chart form, called synoptic chart, and (d) *satellite climatology*-involving acquisition of weather or climatic data from weather satellites, like TIROS, GOES, INSAT, METEOSAT etc. *Radiosondes* or *Rawisondes* involving balloon carried instruments and other forms of remote sensing data are also included in this category.

In brief, following are some of the <u>important characteristics of climatology</u>:

i. It is a branch of atmospheric science and it has very close relation to meteorology and geography.

ii. It involves dimensions of both time and space, and classification of climatology incorporates the elements of these two dimensions.

iii. Climatology includes both theoretical and applied aspects of studies involving various branches of knowledge of science, mathematics, technology, agriculture etc.

iv. Application of climatology has resulted in emerges of new sub-disciplines like agro-climatology, urban climatology etc.

v. Recent climate change and its consequences have a positive outcome of climate studies, in these days, leading to a renewal of importance to the study of climatology.

vi. It is possible to find out tremendous scope of works to be done in climatology in respect to its academic importance as well as various fields of application.

Section-II: The Earth's Atmosphere

■ 3.1.5 The atmosphere of the earth and the standard atmosphere

Although many planets in the solar system posses different kinds of gaseous layers surrounding them, the earth's atmosphere is quite unique and essential not only for the climate system of the earth, but for other systems like hydrosphere, bio-sphere, etc. The structure and properties of the atmosphere are determined by the interplay of physical and chemical processes. Therefore, overall character of the earth's atmosphere is constantly in change and never exactly the same at two different points over time and space. The most frequent condition of the atmosphere in a vertical column represents an idealized, steady- state (*not average*) condition, where the atmosphere is in balance with the processes that govern it, is called (in the USA) the *standard atmosphere* (Oliver and Hidore, 2003). This is a model atmosphere in terms of its physical, chemical and other properties, and when we take into account any aspect of the earth's atmosphere, it is the standard atmosphere.

■ 3.1.6 Evolution of the earth's' atmosphere

The earth was believed to be originated some 4.5 billion years ago. But its atmosphere was created much later due to various physical and chemical processes of gassing (i.e. addition of gases) and degassing (i.e. removal of gases). According to Critchfield (2004) 'the gases of the present atmosphere are not a direct residue of the earliest form of the planet; rather they are the evolutionary products of volcanic eruptions, hot springs, chemical breakdown of solid matter, and contribution from the bio-sphere, including photosynthesis and human activities'. The early atmosphere was believed to be devoid of oxygen. Later on splitting of water in plant cells formed molecular oxygen. The interaction between land, water, air, plants and animal are still quite active in modifying the atmospheric composition, although the process is very slow.

■ 3.1.7 Importance of the earth's atmosphere and its composition

The earth's atmosphere is the environment for most of the biological activities and the atmosphere also exerts a considerable influence on the ocean and lake environment. The day-to-day fluctuations of environmental variables depend considerably on weather elements and ultimately the overall climatic condition of a locality. The atmosphere protects earth's life forms from harmful radiations and cosmic debris. For instance, the ozone layer protects the

arth from the sun's harmful ultraviolet rays. Meteors strike the thermosphere and mesosphere and burn from the heat generated by air friction; otherwise they could come down to the earth's surface resulting in considerable damages.

The earth's atmosphere is primarily composed of nitrogen (N_2), oxygen (O_2), and argon (Ar) [***Refer table***]. The concentration of water vapor (H_2O) is highly variable, particularly near the tropical surface, where in terms of volume it can vary from nearly 0.1 percent to as high as 4 percent. There are many minor constituents or trace gases, like neon (Ne), helium (He), krypton (Kr), and xenon (Xe), that are inert; and some active such as carbon dioxide (CO_2), methane (CH_4), hydrogen (H_2), nitrous oxide (NO), carbon monoxide (CO), ozone (O_3), and sulfur dioxide (SO_2), that play important roles in radiative and biological processes.

Table- Principal composition of the atmosphere

Molecule	Fraction volume near surface	Vertical distribution
Major constituents		
N_2	7.8084×10^{-1}	Mixed in homosphere photochemical dissociation high in thermosphere
O_2	2.0946×10^{-1}	Mixed in homosphere; photochemically dissociated in thermosphere, with some dissociation in mesosphere and stratosphere
Ar	9.34×10^{-3}	Mixed in homosphere with diffusive separation increasing above
Important radiative constituents		
CO_2	3.5×10^{-4}	Mixed in homosphere; photochemical dissociation in thermosphere
H_2O	Highly variable	Forms clouds in troposphere; little in stratosphere; photochemical dissociation above mesosphere
O_3	Variable	Small amounts, 10^{-8}, in troposphere; important layer, 10^{-6} to 10^{-5}, in stratosphere; dissociated above
Other constituents		
Ne	1.82×10^{-5}	
He	5.24×10^{-6}	Mixed in homosphere with diffusive separation increasing above
Kr	1.14×10^{-6}	
CH_4	1.15×10^{-6}	Mixed in troposphere; dissociated in upper stratosphere and above
H_2	5×10^{-7}	Mixed in homosphere; product of H_2O photochemical reactions in lower thermosphere, and dissociated above
NO	$\square 10^{-8}$	Photochemically produced in stratosphere and mesosphere

Note: *Other gases, like CO, N_2O, NO_2, and many by-products of atmospheric pollution also exist in small amounts especially in the lower layers of the atmosphere.*

Air carries many kinds of dust of meteoric as well as terrestrial origin, and microorganisms, pollen, salt particles, and various gaseous and solid impurities resulting from human activity. These solid and liquid particles in suspension are called *aerosols* (diameter < 1 μm =

micrometre). These are created by gas-to-particle reactions or are lifted from the surface by the wind. Part of these aerosols can become centers of condensation or deposition in the growth of water and ice clouds, and are called *hygroscopic nuclei.*

One of the remarkable properties of the earth's atmosphere is the large amount of free molecular oxygen in the presence of gases such as nitrogen, methane, water vapor, hydrogen etc. that are capable of being oxidized. The atmosphere is in a highly oxidizing state that is far from chemical equilibrium, due to a continuous source of reactive gases derived from biological processes. Life- of both plants and animals plays a vital role in maintaining the present atmospheric composition.

■ 3.1.8 Change of atmospheric constituents through latitude, height and time

Some of the important atmospheric constituents like carbon dioxide, ozone, water vapour and aerosols (*although aerosols are particulate matters, these behave like a gas*) show changes through one or more of the following attributes, namely latitude, height and time. Carbon dioxide is balanced in the atmosphere through the process of photosynthesis; but owing to excessive burning of fossil fuels and deforestation the cycle has been disturbed since the Industrial Revolution. It is estimated that in 1750 the atmospheric concentration of carbon dioxide was 280 ppm, which increased to 380 ppm in the year 2000. Ozone is toxic for life near the earth's surface, but it protects life by absorbing ultra-violet rays in the stratosphere, where its concentration is maximum but very low. At standard temperature and pressure thickness [measured in Dobson Unit (DU), 1 DU= 1 part per billion (ppb)] of ozone is only 0.29 cm at the equator and 0.40 cm at the poles. But the concentration of ozone is also thinning (especially in spring time), called *ozone hole,* particularly found at the poles, e.g. in Antarctica it was about 300 DU in 1970, and was reduced to about 94 DU in 1994, and in 2001 it was about 90 DU due to emission of chlorofluorocarbons (CFCs) into the atmosphere. Water vapor is more in the lower latitudes especially in summer for high rate of evapo-transpirations. Its concentration in the atmosphere varies between 0.1 to 4 percent by volume. Concentration of aerosols largely depends on dust storms, volcanic eruptions, forest fires and various sprays related to anthropogenic activities.

■ 3.1.9 Vertical structure of the earth's atmosphere

The earth's atmosphere is composed of various distinct layers. The lowermost troposphere extends upward from the earth's surface to a height of about 8.1 km at the poles, to about 11.3 km in mid-latitudes, and to about 16.1 km at the equator. The air in the troposphere is in constant motion both horizontally and vertically, and most of the weather phenomena are observed in this layer, for which it is also called *turbo-sphere.* Throughout the troposphere temperature decreases with altitude at an average rate of about 6.5°C per km, called the *lapse rate*; reaching the minimum of about −57°C at the tropopause, a zone between the troposphere and the stratosphere. Concentration of ozone is the maximum in the lower part of the stratosphere, where temperature changes little with altitude, so it is called *isothermal layer.* This layer extends up to 50 km (at the mesopause), above which is the mesosphere extending to about 80 km above the earth's surface; the temperature sharply decreases from around 10°C at the base of the mesosphere to −110°C, before it begins to rise at the top of the mesosphere. The next layer is the thermosphere, which extends upward from the mesosphere to about 640 km; its temperature increases rapidly with altitude because of the absorption of short-wave radiation by ionization processes, although, because of the thinness of the air, little heat energy

is available. Here A*urora Borealis* (in the northern hemisphere) and *Aurora Australis* (in the southern hemisphere) are found. The final layer is the exosphere, which gradually gets thinner as it reaches into the vacuum of space at around 700 km above the earth's surface; the atmosphere is so attenuated at this altitude that the average distance air molecules travel without colliding is equal to the radius of the earth. Although some gas molecules and particles out to about 64,400 km are trapped by the earth's gravitational and magnetic fields, the density of the atmosphere at an altitude of about 9,700 km is comparable to that of interplanetary space. The ionosphere is in the range of 80 to 640 km that contains a high concentration of electrically charged particles (ions); these particles are responsible for reflecting radio signals important for telecommunications. However, in geography, we are more interested about the lower layers of the atmosphere, specifically about the troposphere where weather processes take place.

Below about 100 km in altitude, the atmosphere's composition of major constituents is mostly uniform. This region is known as the *homosphere* to distinguish it from the *heterophere* above 100 km, where the relative amounts of the major constituents change with height. In the homosphere there are sufficient atmospheric motions and an enough short molecular free path to maintain uniformity in composition. Above the boundary between the homosphere and the heterosphere, known as the homopause, the mean free path of the individual molecules becomes long enough that gravity is able to partially separate the lighter molecules from the heavier ones. The mean free path is the average distance that a particle will travel before encountering a collision. Hence the average molecular weight of the heterosphere decreases with height as the lighter atoms dominate the composition.

■ 3.1.10 The hydrostatic equation

The total mass of the earth's atmosphere is about 5.25×10^{15} metric tons of which nearly fifty percent lies within 5.5 km and ninety nine percent lie within 30 km from the earth's surface. The vertical distribution of gaseous mass is maintained by a balance between the downward force of gravity and the upward pressure gradient force. The balance is known as the ***hydrostatic balance*** or the ***barometric law***. Hence, the declining atmospheric pressure that is measured while ascending in the atmosphere is a result of gravity.

The principle of hydrostatic equilibrium is that the pressure at any point in a fluid at rest (therefore, 'hydrostatic') is just *due to the weight of the overlying fluid.* As pressure is just force per unit area, the pressure at the bottom of a fluid is the weight of a column of the fluid, one unit of area in cross-section. Hydrostatic equilibrium is a little more complicated to apply to air, because air is very compressible. However, the same principle still applies, but it needs consideration of density that varies with pressure and temperature. In fact, the mass of a unit-area column of height (**h**) and density (**ρ** > Greek word '*rho*') is just (**ρh**); and the weight of the column is its mass times the acceleration of gravity, **g**. But the weight of the unit-area column is the force it exerts per unit area at its base i.e. the pressure (**P**). So,$\mathbf{P = -g\,\rho\,h}$.

For example, the density of water is 1000 kilograms per cubic meter (in SI units), so the weight of a cubic meter of water is 1000 kg times **g**, the acceleration of gravity (9.8 m/ sec^2), or 9800 newton. This force is exerted over 1 m^2, so the pressure produced by a 1 meter depth of water is 9800 pascals (the Pa is the SI unit of pressure, equal to 1 newton per square meter).

The unit of pressure used in atmospheric work on earth is the hectopascal; 1 hPa = 100 Pa. So the pressure 1 m below the surface of water (ignoring the pressure exerted by the atmosphere on top of it) is 98 hPa. Standard atmospheric pressure (i.e the globally averaged pressure at mean sea level) is 1013.25 millibars or 101,325 pascals or 1013.25 hPa, so it takes 1013.25/98

= 10.33 meters (or 34 feet) of water to produce a pressure of 1 atmosphere. The negative sign is due to the fact that pressure decreases with height (usually when graphing, the values on the y-axis increase with height, this is the opposite with pressure in the atmosphere).

Density of air is a function of temperature and moisture content. Increasing water vapor content and/ or increasing the temperature causes the density to decrease. In very cold air, the air is very dense. Therefore, the *dP/dh* (the change in pressure with height) is large in cold air. In warm air this is the opposite case; warm air expands and takes up a larger volume. The thickness of warm air and the depth of the atmosphere are greater in a warm air mass. Since warm air has a low density, the change in pressure with height in warm air is smaller than in cold air. For example, the 500 hPa level is closer to the surface in arctic regions than tropical regions because the change in pressure with height is greater in the former than the latter.

Section-III: The Greenhouse Effect

■ 3.1.11 The science of the greenhouse effect

In order to maintain an energy balance, the earth must emit about the same amount of radiation as it absorbs from the sun. The terrestrial radiation occurs in the infrared part of the spectrum and hence it is strongly affected by water vapor, clouds, carbon dioxide, ozone and other trace gases. The ability of these gases to absorb and emit in the infrared allows them to effectively trap some of the outgoing radiation that is emitted by the surface, creating a situation called greenhouse effect.

It is important to note here that owing to the greenhouse effect of the earth's atmosphere, the mean annual temperature of the earth is about 15°C; otherwise it would have been around -18°C (estimated through application of the Thermo-dynamic Laws), which means the earth is warmer by about 33°C due to the presence of the atmosphere. Therefore, a distinction should be made between natural greenhouse effect of the atmosphere and the so-called greenhouse effect that is widely discussed in these days. The frequently discussed contemporary greenhouse effect is mostly a result of anthropogenic intervention in the form of increasing injection of carbon dioxide, methane, etc into the atmosphere. The present day greenhouse effect can be better termed as ***enhanced greenhouse effect*** that is responsible for rapid increase of earth's mean temperature, and has already resulted in so many debates throughout the world because of its far reaching adverse consequences.

■ 3.1.12 The greenhouse gases and their impact

The major greenhouse gases, their sources and characteristics can be summarized in the following table.

Greenhouse gases	Source of origin	Characteristics			
		1750 AD	2000 AD	Increase (in percent)	Atmospheric life-time (years)
Carbon dioxide (CO_2)	Deforestation, Change of land use, Burning of fossil fuels	280 ppm	368 ppm	31	50-200
Methane (CH_4)	Freshwater wetlands, Wet rice fields, Bio-mass burning, Enteric fermentation in cattle	700 ppb	1750 ppb	151	12
Nitrous oxide (N_2O)	Break down of nitrogen rich fertilizer in soil, Livestock waste, Bio-mass burning, Burning of nitrogen-rich fuel, Nitrate-rich ground water	270 ppb	316 ppb	17	114
Chlorofluoro -carbons (CFC-11)	Propellant in aerosol sprays, Solvent in air conditioning and Refrigeration units, Production of plastic foam for packing food, etc.	0	282 ppt		45-260

Note: m=million, b=billion, t=trillion, ppm= parts per million, so as ppb and ppt; 1750 AD more or less corresponds to pre-industrial period, and the year 2000 AD can be taken as contemporary.

Detailed scientific study under the leadership of Intergovernmental Panel of Climate Change (IPCC) has shown that the earth's mean temperature has increased by 0.5°C during the last one hundred years that can be attributed to anthropogenic influence on greenhouse effect. It is also believed that if the process goes on at the present rate the highest temperature may be recorded during the middle of the twenty first century in the last two thousand years.

■ 3.1.13 Consequences of greenhouse effect

The immediate impact of (enhanced) greenhouse effect is the rise of mean global temperature, popularly known as ***global warming.*** Some of the probable consequences of greenhouse effect are as follows: (i) *Climate change*- leading to change in the distribution pattern of global temperature and precipitation due to change in global atmospheric circulation; (ii) *Rise of sea*

level-due to heat related volume expansion of the ocean water and addition of ice-melt water in the oceans; (iii) *Submergence* of low-lying coastal plains, and its impact on water resources, habitats, bio-diversity, human settlements, health etc. and (iv) *International conflicts*, co-operations and politics over reduction and management of carbon dioxide emission, among the countries. Although there could be some beneficial effects of carbon dioxide and its resultant global warming through increase rate of plant growth; but this negligible positive effect may not be actually realized due to many negative effects of global warming.

3.1.14 Debates over greenhouse gases

It has been estimated that carbon dioxide alone is responsible for about fifty percent of the increase in greenhouse effect. The industrially developed countries of the world emit too much carbon dioxide as a result of burning of fossil fuels in generation of electricity, running motor vehicles etc. Although total amount of carbon dioxide emission in the developing countries, like India, is also considerably high, here per capita emission is very low compared to the developed nations of the world. The rice producing countries of South Asia are very often blamed for their high methane emission from wet paddy fields and livestocks. It is said that heat absorption capacity of methane is twenty times higher than carbon dioxide. But it is also true that the lifetime of methane is only ten years, which is 50-200 years in case of carbon dioxide. Moreover, the emissions of carbon dioxide in the countries of Europe and North America are related to huge energy consumption to ensure a high standard of living, whereas methane emission in the developing countries is due to their life sustaining traditional activities. However, both are detrimental for human civilization and suitable measures should be taken.

Rise in global temperature was one of the prime agenda in the Earth Summit of United Nations Conference on Environment and Development (UNCED) in Rio De Jeneiro city of Brazil in 1992. In 1997 a summit to reduce global warming was held in Kyoto city of Japan, where resolutions were taken by the countries to reduce emissions of carbon dioxide. December 1-15, 2007 witnessed the United Nations Climate Change Conference in Bali (Indonesia) where 190 participating nations attended to prepare a road map for reduction of human-induced global warming in view of expiry of Kyoto Protocol in 2012.

■ 3.1.15 Key words and study guides

The discussion as above has tried to incorporate the following key words with their meaningful understanding in climatological studies among the advanced learners in geography:

Atmosphere, Climate system, Climatology, Meteorology, Standard atmosphere, Atmospheric composition, Vertical structure of the atmosphere, Lapse rate, Hydrostatic equation, Ozone hole, Greenhouse effect and Global warming.

The points discussed here are only illustrative, but concise and to the point. Readers are advised to follow some of the basic literatures of climatology as given in the reference. Advanced readers may consult other books and journals available in various libraries and take note of the latest development in some of the current topics of the subject.

■ 3.1.16 Self-assessment questions

A. Descriptive/ long analytical type

1. **Classify and define each of the different branches of climatology.**
2. **Account for the constituents of the atmosphere and state their importance.**
3. **Discuss about the vertical layers of the atmosphere and their importance.**
4. **Describe the nature and scope of climatology.**
5. **Discuss the role of man in global warming.**

B. Short answer type

1. **What is climate system?**
2. **Differentiate between climatology and meteorology.**
3. **What is hydrostatic equation?**
4. **What is the importance of ozone layer?**
5. **What is enhanced greenhouse effect?**

■ 3.1.17 References

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PART – I
Paper-II : Module- III
Unit – 02

Module Structure

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- 3.2.4 RADIATION FROM THE SUN
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- 3.2.6 RADIATION LAWS
- 3.2.7 INSOLATION
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C. ATMOSPHERIC HUMIDITY AND ATMOSPHERIC STABILITY & INSTABILITY

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Paper-II : Module- III
Unit – 02

Content: 1. Nature of Radiation and Radiation Laws. Heat balance in Earth- Atmosphere System.
2. Factors influencing Vertical and horizontal distribution of temperature.
3. Various measures of atmospheric moisture content; Saturation, Unsaturation and Supersaturation; Vapour Pressure; Adiabatic temperature changes; Lapse Rates; Atmospheric Stability and Instability.

A. NATURE OF RADIATION AND RADIATION LAWS. HEAT BALANCE IN EARTH- ATMOSPHERE SYSTEM

■ 3.2.1 INTRODUCTION

All aspects of the climate system of the Earth — the winds, rain, clouds and temperature — are the result of energy transfers and transformations within the Earth/atmosphere system. The whole process starts when energy from the Sun arrives at the top of the atmosphere in the form of radiant energy, or radiation. It is transferred down through the atmosphere, interacting with it, so that some energy is reflected back to space, some is absorbed and transformed into heat and some is transmitted to the surface of the Earth. The radiation that penetrates to the surface and is absorbed and can heat the surface, evaporate water, melt snow and heat the underlying soil. This transformed energy is eventually transferred to the atmosphere and finally returned to space again in the form of radiation. Variations in the amount of radiant energy received from the Sun and variations in the interaction with the Earth and atmosphere create the temporal and spatial variations in energy exchanges which lead to our climate.

Thus the earth-atmosphere system is sustained by the supply of energy from the sun. Solar radiation is the ultimate source of energy that results in the varied atmospheric conditions experienced on Earth. It is fitting that a study of climatology is initiated by examining energy transferred and exchanged in the earth-atmosphere system.

Energy is the capacity for doing work. It can exist in a variety of forms and change from one to another. The transfer of energy from place to place is of major importance in climatology. There are basically three ways in which this transfer can take place: conduction, convection, and radiation. **Conduction** consists of energy transfer directly from molecule to molecule where the molecules are densely packed and contact one another. Energy always moves from an area of more energy to an area of less energy. In a sense, it is much as water flows from high places to lower places. **Convection** involves the transfer of energy by the movement of an energy-laden substance from one location to another. Both convection and conduction depend on the existence of a physical substance in which to operate. This substance may be a solid, liquid, or gas. **Radiation** is the only means of energy transfer through space without the aid of a material medium. The major source of energy on our planet is the sun. Between the sun and the earth, where a minimum of matter exists, radiation is the only important means of energy transfer. So important is this solar input that most climatological phenomena are related to it.

■ 3.2.2 OBJECTIVES :

The earth and the biospheric ecosystem receives energy three basic sources viz. (i) Solar **radiation,** (ii) **gravity** and (iii) endogenetic radiation is the most significant source of terrestrial heat energy. The endogenetic forces caused by varying thermal conditions deep within the earth create relief features of varying orders and dimensions on the earth's surface which in turn affect water flow, vegetation cover, development of soils, weather and climate etc. Gravity forces help in the down slope movement of water and ice and thus facilitate in transforming potential energy into kinetic energy.

Solar energy received through solar radiation heats the earth's surface and the atmosphere and thus is responsible for the movement of air and currents through changes in pressure gradients; drives the hydrological cycle through evaporation and precipitation which in turn helps in the cycling and recycling of nutrients and chemical elements in the biosphere through the broader cyclic pathways collectively known as biogeochemical cycles; helps the plants to prepare their food through the process of photosynthesis which in fact changes solar energy into chemical energy which is used by plants, animals and man through different trophic levels of food chains and food webs.

Radiation balance or heat balance is very important for biological communities in the biospheric ecosystem and hence a detailed discussion on global radiation and heat balance and the role of man in the alteration and maintenance of global and regional heat balances of the earth and its atmosphere is not only desirable but is also necessary for future environmental and ecological planning.

It may be pointed out that the solar energy is responsible for the functioning and maintenance of the 'earth-atmosphere system' and the solar energy is received through solar radiation. Different types of weather phenomena which occur on the earth's surface depend on the mode of transfer and exchange of solar energy between the earth's surface and the atmosphere. The energy transfer From place to place takes place through the processes of conduction, convection and radiation.

Solar radiation is becoming increasingly appreciated because of its influence on living matter and the feasibility of its application for useful purposes. It is a perpetual source of natural energy that, along with other forms of renewable energy, has a great potential for a wide variety of applications because it is abundant and accessible. Solar radiation is rapidly gaining ground as a supplement to the nonrenewable sources of energy, which have a finite supply.

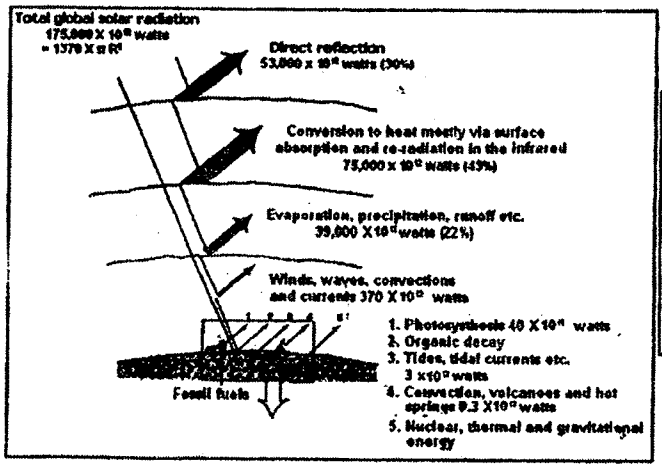
Recent developments in the areas of photochemistry and photobiology have also helped in bringing attention to solar radiation. The significant depletion of the stratospheric ozone layer, which shields the earth from much of the biologically injurious solar ultraviolet radiation (UVR), is apparently due to human activity and has now become a popular topic. Adverse biological effects of UVR on man include, among others, sunburn (erythema), conjunctivitis, and skin cancer (WHO 1979). In contrast, the vital phenomenon of photosynthesis is an example of the beneficial effects of sunlight in the natural environment. Other beneficial and harmful effects on a variety of living beings, especially microorganisms, are well documented (Jagger 1976; Chamberlin and Mitchell 1978; Harm 1980; Senger 1980). Solar radiation has, therefore, a prominent ecological role.

This module has been designed to give the students a better understanding of:

- Solar radiation
- Electromagnetic spectrum
- Mathematical concepts that apply to solar radiation
- Climate variation due to unequal distribution of solar radiation
- Seasonal weather changes
- Global energy balance
- Daily changes in solar radiation
- Changes in solar irradiance due to solar cycles
- Effects of solar irradiance variations on the earth system

3.2.3 ENERGY CASCADE :

The whole process of energy exchange in the Earth/atmosphere system can be summarized by the energy cascade. This indicates the many and various forms of energy that are possible, the tremendous variations in their amounts and the ability of the system to store energy. Energy exchanges are going on all the time on a variety of time scales. Some processes are rapid enough to be seen. Energy from the Sun is used to heat a water surface throughout the day. Some of this energy is used for evaporation, which is a form of energy transfer. This creates humid air which, again as the result of solar heating, ascends to condense and form clouds. Energy is stored in these clouds as potential energy. This will soon be released if conditions are appropriate for the development of rain. Thus there is short-term energy storage. On a much longer time scale, when we heat our homes using coal or oil, we are experiencing the final stages of an energy exchange process that has taken millions of years to complete. Solar radiant energy was used directly to build plant and animal tissue which was subsequently stored when buried and converted to coal or oil. We now use this fossilized radiant energy to create heat.



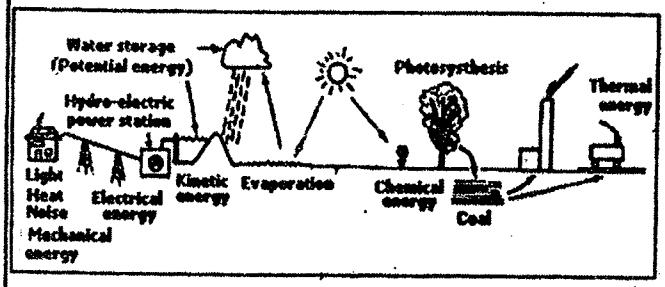


Fig- Energy

Table : Energy Forms

Radiation	The emission and propagation of energy in the form of waves
Kinetic energy	The energy due to motion: one half the product of the mass of a body and the square of its velocity
Potential energy	Energy that a body possesses by virtue of its position and that is potentially converted to another, usually kinetic energy
Chemical energy	Energy used or released in chemical reactions
Atomic energy	Energy released from an atomic nucleus at the expense of its mass
Electrical energy	Energy resulting from the force between two objects having the physical property of charge
Heat energy	A form of energy representing aggregate internal energy of motions of atoms and molecules in a body

Examples of Transformations

Atomic energy (Sun) → Radiation (Sunlight) → Heat (Earth surface) → Radiation (Terrestrial)

Radiation (Sunlight) → Chemical energy (Photosynthesis) → Food chain

Potential energy (Water vapor) → Kinetic energy (Raindrop) → Heat (Friction)

■ 3.2.4 RADIATION FROM THE SUN :

The source of all energy on the Earth is the Sun. The radiant solar energy received by the Earth arises from nuclear reactions taking place on the Sun. In the immensely high temperatures of the Sun (surface temperature of 6000°K), a part of the enormous energy is locked up in the nucleus of the hydrogen atom which is released by nuclear fusion. In this process of fusion, four hydrogen nuclei (four protons) fuse to form a helium nucleus (two protons and two neutrons).

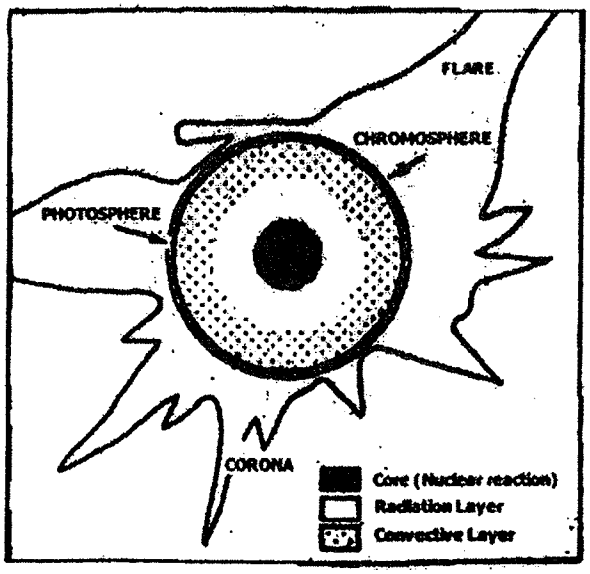
The mass of the helium nucleus is about 0.7 per cent less than the sum of the four hydrogen nuclei. This lost mass is converted to a quantum of energy in the form of gamma (γ) radiation. The excess mass (m) is converted into energy according to Einstein's equation, $e = mc^2$, whereby mass, m, is related to energy, e, and c, is the speed of light (3, 00,000 km per second). Because c is such an enormous number, a very small mass is converted into tremendous amount of energy. Some of the energy produced by nuclear fusion is used to bind the helium nucleus together. The rest of the energy is radiated and transported to the Sun's surface, from where this energy is radiated off to space.

In fact, the solar energy is radiated from the surface of the sun but the source of energy is the interior of the sun. The sun is a gaseous mass with a diameter 109 times that of Earth. The source of the sun's energy is nuclear fusion produced in the core of the sun, where a nuclear reaction takes place that changes hydrogen into helium. Because the sun is a gaseous mix, no sharp boundaries exist within it, and

different sections have different characteristics; it may be described using arbitrary divisions. Major parts are the core, photosphere (or visible surface), chromosphere, and corona (Fig).

•Photosphere

The photosphere is the bright outer layer of the sun that emits most of the radiation, particularly visible light. It consists of a zone of burning gases 300 kilometers thick. The photosphere is an extremely uneven surface. There are many small bright areas called *granules.* Their brightness is the result of bursts of extremely hot gases formed in the photosphere that well up to the surface. There are darker areas arcund each granule that are cooler gases, known as sunspots and hotspots, also known as faculae. The granules average 1000 kilo- meters in diameter. The hot gases spread out, cool on reaching the surface, and settle back below the surface. The net effect of all of these granules is convection of hot gases outward and cooler gases inward. It is much like the boiling of a large kettle. The elements in the photosphere are hydrogen (90 percent) and helium (10 percent). At the radiative surface, the effective temperature is on the order of 6000°K. The surface temperature determines both the amount of energy emitted and the wavelengths at which it occurs.



•Chromosphere

Just above the photosphere is the chromosphere. It is a relatively thin layer of burning gases. This region of gases is under little pressure and extends away from the sun as much as a million kilometers. It is here that the particles reach velocities high enough to leave the sun. The electrons and protons escape the sun in a stream called the *solar wind.* When they reach the earth environment, they meet the magnetic field that surrounds the earth. The magnetic field diverts most of these particles toward the two poles. One feature of solar activity that occasionally affects the earth are solar flares. They are sudden and explosive bursts of energy near sunspot clusters. They have a life span of only a matter of hours. They emit huge quantities of radiant energy and atomic particles. The atomic particles add to the solar wind. When these particles reach Earth, they disturb the ionosphere. This in turn interrupts radio and satellite communications and triggers the aurora.

•Sunspots

One of the most prominent visible features of the sun's surface are dark areas known as **sunspots.** Sunspots appear as dark areas because they are about 1500°C cooler than the surrounding chromosphere. Science credits Galileo with reasoning that they were a feature of the sun and not clouds between the earth and the sun. They start as small areas about 1600 kilometers in diameter. The individual sunspot has a lifetime ranging from a few days to a few months. Each spot has a black center, or umbra, and a lighter region, or penumbra, surrounding it. Because records of sunspots have existed for many years and sunspots are relatively easy to see, they are one indicator of solar activity. The number of

sunspots appears to follow an 11-year cycle. First, the sunspots increase to a maximum, with 100 or so visible at a given time. Over a period of years, the number diminishes until only a few or none occurs. Change from the maximum to the minimum number takes about 5.5 years, and thus the complete cycle is 11 years. We must stress that this is not an absolute periodicity as the interval between maxima cannot be forecast with certainty. The 11 years represent a mean interval.

Just how the sunspot cycle influences weather and climate is a matter of controversy. Some researchers claim to have found that weather patterns in a particular part of the earth follow the sunspot cycle closely, in other cases, no relationships exist. Even the physical processes by which sunspots affect weather are not clear. The wavelengths of these emissions correspond to the wavelength of X-rays and they have different effects on different parts of the atmosphere. A further complication is that sunspot activity coincides with solar wind intensity, and it is difficult to separate the effects of each.

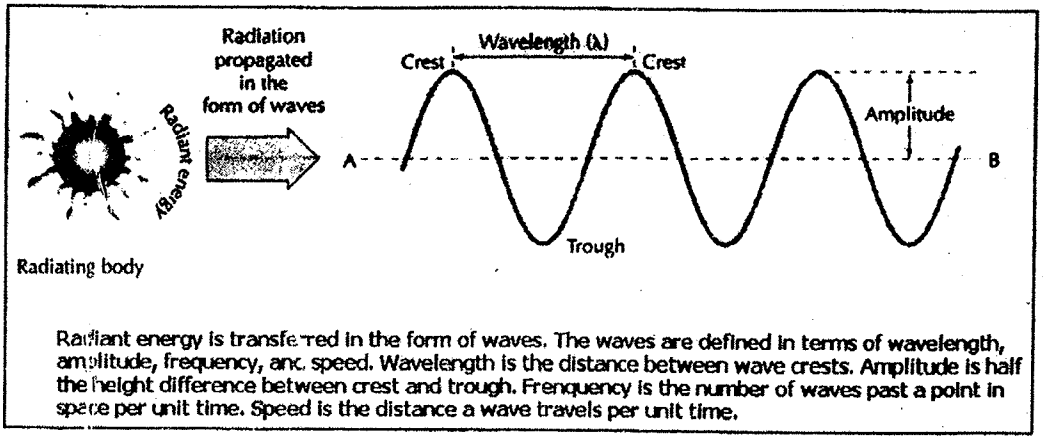
•Corona

Corona represents outermost zone of the sun's atmosphere and is characterized by very hot (having a temperature of one to two million° K = Kelvin) and rarefied gases.

The solar energy is radiated from the photosphere in the form of electromagnetic radiation waves of which the earth receives only 1/2 billionth part but even this energy (insolation) is equivalent to 23 trillion horse power which is capable for the sustenance of all life-forms in the biosphere and all weather phenomena.

■ 3.2.5 THE NATURE OF RADIATION

Every object above the temperature of absolute zero -273°C (- 459°F) radiates energy to its environment. It radiates energy in the form of electromagnetic waves that travel at the speed of light. Energy transferred in the form of waves has characteristics depending on **wavelength,** amplitude, and frequency.



Radiant energy is transferred in the form of waves. The waves are defined in terms of wavelength, amplitude, frequency, and speed. Wavelength is the distance between wave crests. Amplitude is half the height difference between crest and trough. Frequency is the number of waves past a point in space per unit time. Speed is the distance a wave travels per unit time.

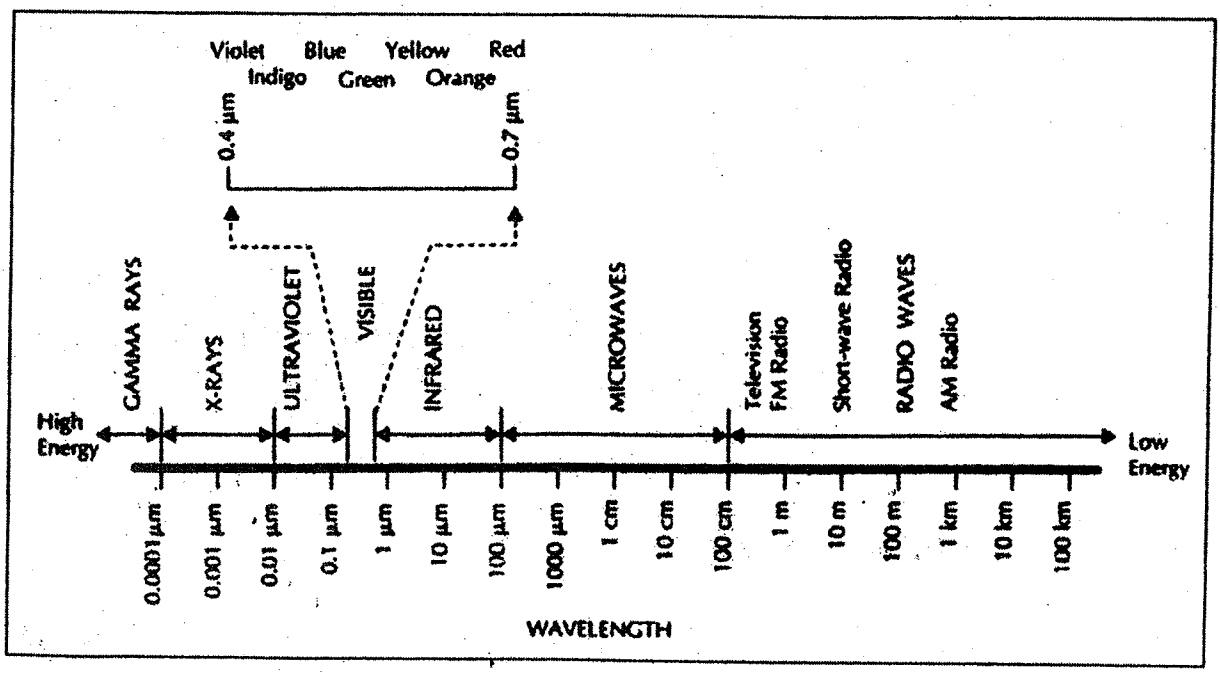
The energy from the sun is also emitted in the form of electromagnetic waves which travel outward in radial manner from the sun almost in straight line and take 8 minutes 20 seconds to reach the earth's surface after covering an average distance of 150 million km (93 million miles) between the sun and the earth. The electromagnetic radiation waves are expressed in terms of wavelengths (L). The straight distance between two successive crests or troughs is called wavelength (L) which is expressed in the length units of meters, centimeters, millimeters, microns etc. The number of radiation waves (one

radiation wave is equal to one wavelength) passing through a certain point per unit time (usually one second) is called wave frequency which varies according to the wavelengths of the radiation waves. There is inverse relationship between the wavelength, and wave frequency i.e. shorter the wavelength, higher the wave frequency and longer the wavelength, lower the wave frequency. In other words, high wave frequency is associated with short wavelength and low wave frequency is associated with long wavelength. Wave frequency is generally expressed as wave cycles per second. The wave cycles are usually expressed by the unit of measure of hertz. For example, one hertz per second represents one wave cycle meaning thereby only one wavelength passes per second from a fixed point. Hertz is further expressed in kilohertz (1,000 hertz) or megahertz (1,000,000 hertz).

The characteristics of the radiation emitted by an object mainly depend on its temperature. Hotter bodies emit more energy in shorter wavelengths at higher frequencies than cooler bodies. In other words, wavelength is inversely proportional to the temperature of the radiating surface. Thus, the Sun emits a range of radiation that is concentrated in the shorter wavelengths, while earth emits radiation in longer wavelengths. Radiation is the only form of energy that can travel through the vacuum of outer space. Thus energy receipt and disposal from the planet Earth must be in the form of radiation.

- ***Electromagnetic spectrum***

A fundamental characteristic of radiation is the wavelength of propagation. All bodies radiate at a large number of wavelengths. The complete set of possible wavelengths is called the *electromagnetic spectrum* (Fig.). Climatologically important radiation is within the wavelength range 0.1μm to100 μm.



This spectrum is often divided into two parts for simplification. Short wave radiation includes wavelengths of less than 4 micrometers (a thousandth of a millimeter) and is high in frequency and energy. Gamma rays, X-rays, ultraviolet rays, visible light rays and reflected (shorter wavelength or near) infrared rays are all short wave radiation. Long wave radiation (greater than 4 micrometers wavelength)

includes thermal (longer wavelength or far) infrared rays, microwaves and radio waves. All the waves travel at the speed of light (300,000 km or 186,000 miles, per second).

The electromagnetic radiation emitted from the outer surface of the sun consists of four spectra of radiation waves having different wavelengths and wave frequencies.

(1) The first spectrum of electromagnetic waves includes gamma rays, hard x-rays, soft x-rays and ultra violet rays. The wavelengths of this spectrum of the shortest wavelengths are expressed in the unit measure of angstrom wherein one angstrom is, equal to 0.000,000,01 cm or 10^8 cm. The wavelengths of the waves of the spectrum of the shortest waves are given in the following table.

Waves	Wavelength (in angstrom)	Frequency of wavelengths (in Megahertz)
1. Gamma Rays	less than 0.03	10^{14}
2. Hard X-Rays	0.03-0.6	10^{13}
3. Soft X-Rays	0.6-100	10^{12}- 10^{11}
4. Ultra-Violet Rays	100 - 4000	$10^{10} - 10^9$

(2) The second spectrum of the electromagnetic radiation waves is also called as the spectrum of visible light or rays which includes violet, blue, green, yellow, orange and red rays which carry 41 per cent of the total energy of the solar spectrum of all the electromagnetic radiation waves. The unit of the measure of wavelengths of this spectrum is Micron (one micron is equal to 0.0001 cm or 10,000 angstroms). The wave frequency of these different rays ranges between 10^{10} and 10^{11} megahertz per second. The wavelengths of these visible rays are as given below:

Visible Rays	**Wave lengths in microbes**
1. Violet rays	0.4-0.43
2. Blue rays	0.43-0.49
3. Green rays	0.49-0.53
4. Yellow rays	0.53-0.58
5. Red rays	0.58-0.70

(3) The third spectrum of the electromagnetic radiation waves is called as infrared spectrum which consists of infrared waves of the wavelengths ranging from 0.7 micron to 300 microns. The wave frequency ranges between 10^8 and 10^6 megahertz per second.

(4) The fourth spectrum of the electromagnetic radiation wave consists of long waves including microwaves, radar waves and radio waves. The unit measure of these wavelengths of long waves is usually centimetre to metre. The wavelengths of microwaves range between 0.03 cm and 1.0 cm. These waves are used to send messages from one place to other distant places. The wavelengths of radar waves vary from 10 cm to 100cm (1 m).The radar system is divided into two sub-systems the basis of frequency viz. (i) radio system, and (ii) television system. The radar, television and radio waves are divided into 6 categories on the basis of wave frequency and wavelengths.

	Frequency	Wavelengths
1.	Extremely High Frequency (EHF)	0.1 - 1.0cm
2.	Super High Frequency (SHF)	1.0 cm - 10.0 cm
3.	Ultra-High Frequency (UHF)	10.0- 100.0cm
4.	Very High Frequency (VHF)	1.0 m - 10.0m
5.	High Frequency (HF)	10m- 100m
6.	Low Frequency (LF)	more than 100m

3.2.6 RADIATION LAWS

If a body emits the maximum amount of radiation at a particular temperature and wavelength, or equivalently absorbs all of the incident radiation, it is called a black body. Several physical laws describe the properties of electromagnetic radiation that is emitted by a black body. By definition, at a given temperature, a black body absorbs all radiation incident on it at every wavelength and emits all radiation at every wavelength at the maximum rate possible for a given temperature; No radiation is reflected. A blackbody is therefore a perfect absorber and a perfect emitter. The term black body can be misleading because the concept does not refer to color. Objects that do not appear black may none the less be blackbodies, perfect radiators. Most gases are not blackbodies. Both the Sun and the Earth closely approximate perfect radiators, so that we can apply blackbody radiation laws to them. Black body radiation is characterized by the following properties:

- The radiant energy is determined uniquely by the temperature of the emitting body.
- The radiant energy emitted is the maximum possible at all wavelengths for a given temperature.
- The radiant energy emitted is isotropic.

1. WAVELENGTH- FREQUENCY RELATION

Radiant energy is characterized by wavelength (λ) . The product of wavelength and frequency of the wave is a constant, the speed of light (c).

$$c = \lambda f$$

Where λ is wavelength, f is frequency, and c the speed of light (3×10^{10} cm/s). The direct relationship indicates that as λ increases, f will decrease. *Short waves are characterized by high frequencies, long waves by low frequencies.*

2. PLANCK'S RADIATION LAW

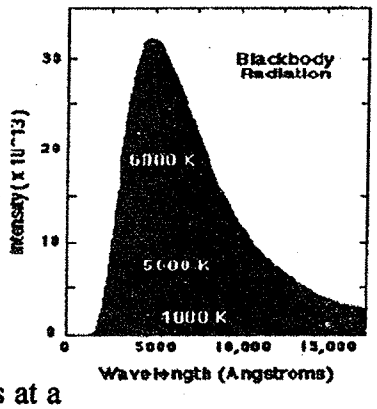
The primary law governing blackbody radiation is the Planck's Radiation Law (1900), which governs the intensity of radiation emitted by unit surface area into a fixed direction (solid angle) from the blackbody as a function of wavelength for a fixed temperature. The Planck's Law can be expressed through the following equation.

$$E(\lambda, T) = \frac{2hc^2}{\lambda^5} \frac{1}{e^{hc/\lambda kT} - 1}$$

$h = 6.625 \times 10^{-27}$ erg-sec (Planck Constant)

$k = 1.38 \times 10^{-16}$ erg/K (Boltzmann Constant)

$c = 3 \times 10^{10}$ cm/sec (Speed of Light)



The behavior is illustrated in the figure shown above. The Planck's Law gives a distribution that peaks at a certain wavelength, the peak shifts to shorter wavelengths for higher temperatures, and the area under the curve grows rapidly with increasing temperature.

• **Temperatures and Characteristic Wavelengths**

By the Planck Law, all heated objects emit a characteristic spectrum of electromagnetic radiation, and this spectrum is concentrated in higher wavelengths for cooler bodies. The following table summarizes the blackbody temperatures necessary to give a peak for emitted radiation in various regions of the spectrum.

Some Blackbody Temperatures

Region	Wavelength (centimeters)	Energy (eV)	Blackbody Temperature (K)
Radio	> 10	$< 10^{-5}$	< 0.03
Microwave	10 - 0.01	10^{-5} - 0.01	0.03 - 30
Infrared	0.01 - 7×10^{-5}	0.01 - 2	30 - 4100
Visible	7×10^{-5} - 4×10^{-5}	2 - 3	4100 - 7300
Ultraviolet	4×10^{-5} - 10^{-7}	3 - 10^3	7300 - 3×10^6
X-Rays	10^{-7} - 10^{-9}	10^3 - 10^5	3×10^6 - 3×10^8
Gamma Rays	$< 10^{-9}$	$> 10^5$	$> 3 \times 10^8$

The behavior of blackbody radiation is described by the Planck Law, but we can derive from the Planck's Law two other radiation laws that are very useful- the Wien Displacement Law and the Stefan-Boltzmann Law. The Wien Law gives the wavelength of the peak of the radiation distribution, while the Stefan-Boltzmann Law gives the total energy being emitted at all wavelengths by the blackbody

(which is the area under the Planck Law curve). Thus, the Wien Law explains the shift of the peak to shorter wavelengths as the temperature increases, while the Stefan-Boltzmann Law explains the growth in the height of the curve as the temperature increases. This growth is very abrupt, since it varies as the fourth power of the temperature.

3. WIEN'S DISPLACEMENT LAW

It states that "*the wavelength at which a black body **emits maximum** radiation is **inversely proportional** to the **absolute temperature**, T, of the black body*".

The equation for blackbody radiation (the Planck equation) is:

$$F_\lambda = 2\pi h c^2 \lambda^{-5} / (\exp(hc/k\lambda T) - 1)$$

or, combining the constants:

$$F_\lambda = c_1 \lambda^{-5} / \exp(c_2/\lambda T) - 1),$$

Where $c_1 = 2\pi hc^2 = 3.7419 \times 10^{-5}$ erg cm^2 s^{-1} [λ in cm] and $c_2 = hc/k = 1.4288$ cm °K.

In order to find the wavelength for which the emission is a maximum (at each temperature), we must take the derivative of this function and set it equal to 0, that is, to find the inflection point of the curve, the point at which a line *tangent* to the curve has a slope of 0. To do this, the first rule we will use is:

$$d(uv) = u\,dv + v\,du$$

Where:

$$u = c_1 \lambda^{-5};$$

Hence, $du = -5\, c_1 \lambda^{-6}$

and $v = [\exp(c_2/\lambda T) - 1)]^{-1}$

Hence, $dv = [c_2/(\lambda^2 T)]\,[\exp(c_2/\lambda T)/(\exp(c_2/\lambda T) - 1)^2]$.

Combining these terms, we obtain:

$$0 = u\,dv + v\,du =$$
$$c_1 \lambda^{-5}\,[c_2/(\lambda^2 T)]\,[\exp(c_2/\lambda T)/(\exp(c_2/\lambda T) - 1)] + [\exp(c_2/\lambda T) - 1)](-5\, c_1 \lambda^{-6})]$$

Combining terms:

$$5c_1/[\lambda^6(\exp(c_2/\lambda T) - 1)] = c_1 c_2 \exp(c_2/\lambda T)/[\lambda^7 T\,(\exp(c_2/\lambda T) - 1)]^2$$

This reduces to:

$$5 = c_2 \exp(c_2/\lambda T) / [\lambda T\,(\exp(c_2/\lambda T) - 1)]$$

or $\lambda T = [c_2/5][\exp(c_2/\lambda T)/(\exp(c_2/\lambda T) - 1)]$

We are almost there $c_2/5$ is easy to evaluate but the terms containing the exponentials are a bit more difficult because they still contain the wavelength variable. However, it is easy to see that the term containing the ratio of the 2 exponentials should be very nearly equal to 1 when we are near the peak of emission;

$$\exp(c_2/\lambda T) \backsimeq \exp(c_2/\lambda T) - 1$$

So let us iterate to obtain the final value for the right hand side of the equation. As a first guess, let us take $c_2/5$, or 0.28777 as the value of λT. Using this value to evaluate the exponentials, we find a "correction factor" of 1.00681, yielding a new guess of 0.28973 for λT. With this value for λT, the ratio of the exponentials is 1.00703. Correcting the guess again, we obtain 0.28979. With this value the ratio of the exponential terms is now 1.00705, yielding a corrected value of 0.28979. We have apparently converged in only 3 iterations. Therefore the final equation is:

$$\lambda T = 0.28979$$

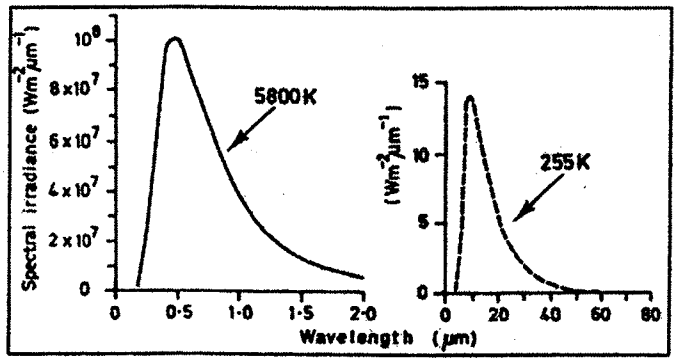
$$\lambda = \frac{0.28979}{T}$$

When wavelength is expressed in μm

$$\lambda = \frac{2897}{T}$$

This equation is known as the Wien's Displacement Law.

The figures show the Plank's curves of irradiance for perfectly radiating bodies that have temperatures that correspond approximately to those of the Sun (5,800 K) and the Earth (255 K). For a given temperature, T, these Planck curves are uniquely defined and have a characteristic shape. The radiating or black body temperature of the Earth is about 33 K less than the mean surface temperature.



Thus, the hotter the radiating body, the shorter is the wavelength of maximum radiation. This law can be visualized from the heating of a metal. As the metal is heated, it starts emitting radiation. Initially, the longer infrared radiation is detectable as heat. As it is heated more, it emits more of its energy in longer wavelengths and glows red, as it is heated even more, it will turn yellow, then white and at very high temperature blue, i.e., the wavelength goes on becoming shorter and shorter. The Sun, which has a surface temperature of 5800 °K, radiates maximum energy at 0.5 micrometers, which is in the visible range. The maximum radiation for the earth occurs at a wavelength of 10 micrometers, well within the infrared range. Because the maximum earth radiation is roughly 20 times longer than the maximum solar radiation, terrestrial radiation is often referred to as **longwave radiation** a:.d solar radiation is called **shortwave radiation.**

4. STEFAN-BOLTZMANN LAW

The equation for blackbody radiation (the Planck equation) is:

$$F_\lambda = 2\,\pi h\, c^2\, \lambda^{-5} / (\exp(hc/k\lambda T) - 1)$$

or, combining the constants:

$$F_\lambda = c_1\, \lambda^{-5} / \exp(c_2 /\lambda T) - 1)$$

where $c_1 = 2\,\pi hc^2 = 3.7419 \times 10^{-5}$ erg cm^2 s^{-1} [λ in cm] and $c_2 = hc/k = 1.4288$ cm °K.

In order to find the total energy emitted by a body at a given temperature, it is necessary to make a transformation of variables, from λ to y, where $y = h\,c/\lambda\,kT$. It will be difficult to make attempt to derive the correct value of the Stefan-Boltzmann constant as that requires knowledge of complex variable theory. Therefore, it is ignored that we should be integrating the specific intensity, which differs by a factor of $4\pi/c$ from our equation above. Here simply the constants are collected, and attention has been paid on demonstrating that the total energy radiated varies as a power of the temperature.

Therefore, we wish to find:

$$f = \int_0^\infty F_\lambda d\lambda$$

Substituting $y = h\,c/\lambda\,kT$ into this equation, and finding that:

$$d\lambda = -[hc/kT]\, y^{-2}\, dy$$

We obtain

$$f = [2\pi\, k^5T^5/h^4\, c^3] \int [y^5/(e^y - 1)]\, [-[hc/kT]\, y^{-2}\, dy]$$

or, combining terms:

$$f = [2\pi\, k^4T^4/\, h^3c^2] \int y^3/(e^y - 1)]\, dy$$

or,

$$f = \sigma\, T^4 \int y^3/(e^y - 1)]\, dy$$

Integrated over all wavelengths. It can be shown that the remaining integral evaluates to a constant ($\pi^4/15$), which can then be combined with the constant already removed from the integral, leaving us with:

$$f = \sigma\, T^4$$

When the constant is properly evaluated, it is found to be $\sigma = 5.67 \times 10^{-5}$ erg cm^{-2} s^{-1}K^{-4}, which is known as the Stefan-Boltzmann constant.
This equation is known as the Stefan-Boltzmann Law.

Hence, **Stefan-Boltzmann Law** states that "*the rate at which a black body radiates energy across all wavelength (called **emittance**), that is directly proportional to the fourth power of the **absolute temperature**, T, of the radiating body*".

5. KIRCHOFF'S LAW

Gustav Robert Kirchhoff's contribution to our understanding of how light and matter interact is his set of three laws of radiation. They predict what sort of spectrum an object will emit based upon the physical properties of the object. Kirchhoff devised these laws in the latter half of the nineteenth century, prior to our understanding of atomic physics and quantum mechanics, but on a macroscopic level they describe the interaction of matter and radiation quite well. The laws are as follows:

1. Any hot, dense object will emit a continuous spectrum - a black body spectrum.
2. A hot, thin gas will emit light only at specific wavelengths according to the electron configuration of the atoms in the gas - an emission line spectrum.
3. A continuous spectrum passed through a cool, thin gas will result in a continuum spectrum with breaks at the same wavelengths as the emission lines described in the Second Law -- an absorption line spectrum.

These three laws embody much of the fundamental physics of radiation and radiative transfer. The first is a simplified explanation of black body radiation, namely that any dense object will emit a characteristic, continuous spectrum. It was later determined that the shape and intensity of this spectrum is *only* a function of the object's temperature, and nothing else, but from a purely phenomenological standpoint, the first law is a good descriptor of black bodies. In particular, it makes no qualifications as to the properties of the object - it could be a metal rod in a fire, it could be a jar full of mercury, or an incredibly dense sphere of gas. All that matters is that it is dense. More accurately, we now say it is "optically thick" rather than dense, but Kirchhoff's description is good enough.

The second law says that a thin ("optically thin"), hot gas will have an emission line spectrum; the third law states that a cool gas will behave the opposite way, and exhibit absorption lines. As the theory behind atomic structure and quantum mechanics grew during the late nineteenth century, Kirchhoff and others (notably Robert Bunsen) realized that each element has its own unique signature of emission and absorption lines, governed by its electron configuration. The lines are generated by electrons emitting and absorbing energy by shifting their position within the electronic structure of a given atom.

In nut shell, these three laws of Kirchhoff relate emissivity to absorption (or absorptivity) of radiation at a particular wavelength.

$$\alpha_\lambda = \varepsilon_\lambda$$

α_λ is the fractional amount of energy that is absorbed (compared with that of a black body) at a given wavelength while ε_λ is emissivity at that wavelength.
This law shows that strong absorbers of radiation are also strong emitters.

The degree to which a real body approaches a black body is given by the emissivity of the body

$$\varepsilon_\lambda = E_\lambda / E^*_\lambda$$

Where, for the wavelength λ, ε_λ is the emissivity and E_λ and E^*_λ are the emissions of the real and black bodies respectively. The value of the emissivity is dependent on wavelength. In general, solids and liquids radiate across a continuous spectral interval with a more or less constant emissivity, usually between 0.9 and 1.0. Gases, on the other hand, radiate only at specific wavelengths, and so have variable emissivities

All atoms of a given element exhibit the same set of lines. This is important, because it means that hydrogen atoms (and all other elements) behave the same way on the Sun as they do here on Earth. In this way, we can apply our knowledge of gases here on Earth to what we see elsewhere in the universe, and use light as a way to study the physical properties of distant objects. This is precisely what Kirchhoff and others did in their studies of the Sun -- by comparing the absorption lines in the solar spectrum to those of gases here on Earth, they found the Sun's photosphere is composed of elements like hydrogen, helium, calcium, iron, and nearly every other element we see here on Earth.

■ 3.2.7 INSOLATION

The radiation coming from the Sun is called as insolation (INcoming SOLar radi **ATION).** The top of the Earth's atmosphere receives a fraction approximately equal to 4.5 X 10^{-10} of the energy output of the photosphere. This represents the energy available to drive the climate system. The amount is usually expressed in terms of the *solar constant.*

• Solar Constant:

The solar constant is the amount of incoming solar electromagnetic radiation per unit area, measured on the outer surface of Earth's atmosphere, in a plane perpendicular to the rays. The solar constant includes all types of solar radiation, not just the visible light. It is measured by satellite to be roughly 1366 watts per square meter, though it fluctuates by about 6.9% during a year - from 1412 W/m^2 in early January to 1321 W/m^2 in early July, due to the earth's varying distance from the sun, and by a few parts per thousand from day to day. Thus, for the whole Earth, with a cross section of 127,400,000 km^2, the power is 1.740×10^{17} W, plus or minus 3.5%. The solar constant is not quite constant over long time periods either; see solar variation. The value 1366 W/m^2 is equivalent to 1.96 calories per minute per square centimeter, which can also be expressed as 1.96 langleys (or Ly) per minute.

The Earth receives a total amount of radiation determined by its cross section (π R^2), but as the planet rotates this energy is distributed across the entire surface area (4 π R^2). Hence, the average incoming solar radiation (called sometimes the solar irradiance), taking into account the half of the planet not receiving any solar radiation at all, is one fourth the solar constant or ~342 W/m^2. At any given location and time, the amount received at the surface depends on the state of the atmosphere and the latitude.

Factors Governing Insolation

The amount of insolation received by the Earth is governed by many factors. They are as follows.

a) SOLAR ACTIVITY

• Sunspots

Sunspots are relatively dark areas on the surface of the Sun where intense magnetic activity inhibits convection and so cools the surface. The number of sunspots correlates with the intensity of solar radiation. Based on work by Abbot, Foukal et al. (1977) realized that higher values of radiation are

associated with more sunspots. It has been detected that because the areas surrounding sunspots are brighter, the overall effect is that more sunspots means a brighter sun.

Sunspot numbers over the past 11,400 years have been reconstructed using dendrochronologically dated radiocarbon concentrations. The level of solar activity during the past 70 years is exceptional - the last period of similar magnitude occurred over 8,000 years ago. The Sun was at a similarly high level of magnetic activity for only ~10% of the past 11,400 years and almost all of the earlier high-activity periods were shorter than the present episode.

Solar activity events recorded in radiocarbon.

Solar activity events and approximate dates

Event	Start	End
Oort minimum	1040	1080
Medieval maximum	1100	1250
Wolf minimum	1280	1350
Spörer Minimum	1450	1550
Maunder Minimum	1645	1715
Dalton Minimum	1790	1820
Modern Maximum	1950	ongoing

• Solar cycles

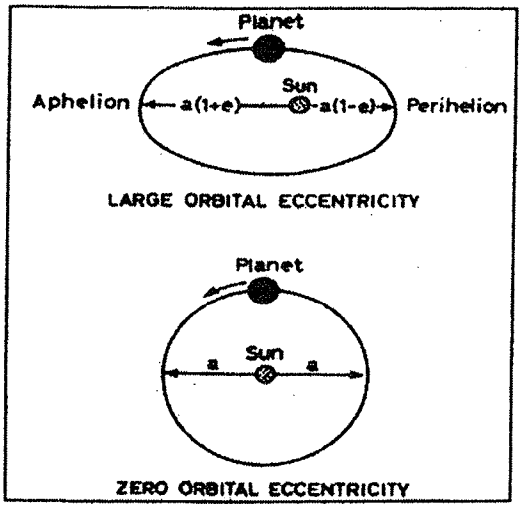
Solar cycles are cyclic changes in behavior of the Sun. Many possible patterns have been suggested; only the 11 and 22 year cycles are clear in the observations.

- 11 years: Most obvious is a gradual increase and decrease of the number of sunspots over a period of about 11 years, called the Schwabe cycle and named after Heinrich Schwabe. The Babcock Model explains this as being due to a shedding of entangled magnetic fields. The Sun's surface is also the most active when there are more sunspots, although the luminosity does not change much due to an increase in bright spots (faculae).
- 22 years: Hale cycle, named after George Ellery Hale. The magnetic field of the Sun reverses during each Schwabe cycle, so the magnetic poles return to the same state after two reversals.
- 87 years (70-100 years): Gleissberg cycle, named after Wolfgang Gleißberg, is thought to be an amplitude modulation of the 11-year Schwabe Cycle (Sonnett and Finney, 1990).Braun, et al, (2005)

(b) EARTH'S ORBIT AROUND THE SUN

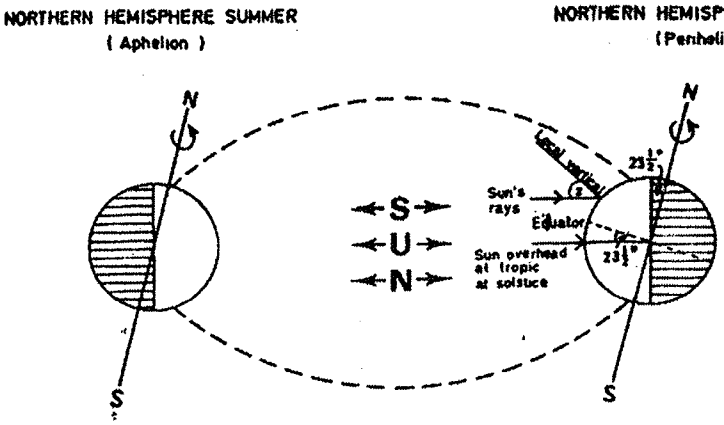
The Earth revolves around the Sun in an elliptical orbit with a period of one year. The *eccentricity* of the orbit, a measure of the variation in the Earth—Sun distance, is such that at present the Earth is closest to the Sun (perihelion) in the Northern Hemisphere winter. The eccentricity of the Earth's orbit is very small. Although the eccentricity changes very slowly with time, the present eccentricity has a relatively minor influence on the variation in radiation receipt. Much more significant for seasonal variations is the inclination of the Earth's axis. The axis, the line through the centre of the Earth joining the two poles, is tilted by 23.5° from the perpendicular to the plane of the ecliptic, the plane of the Earth's orbit around the Sun. Since the axis retains the same orientation with respect to the galaxy, the effect is to

create seasonal variations in the amount and intensity of radiation received at a given spot at the top of the atmosphere and, eventually, at the surface of the Earth.



(c) DAILY AND SEASONAL VARIATIONS IN SOLAR RADIATION

The consequences of the *axial tilt* can be seen by considering Fig. Both the duration of daylight and the height of the Sun in the sky vary with time. To a good approximation we can say that the length of daylight is proportional to the fraction of the latitude circle that is unshaded. At the extreme positions the noontime Sun is overhead at either the Tropic of Cancer, giving the summer solstice, or Tropic of Capricorn, creating the winter solstice. At the latter, in areas north of the Arctic Circle there is 24-hour night whilst south of the Antarctic Circle there is 24-hour daylight. The equinoxes, at which there is 12 hours daylight everywhere on the Earth, occur when the Sun is overhead at the equator on 22 March and 22 September.



The height of the Sun in the sky is usually given in terms of the solar *zenith angle*. This is the angular distance between the Sun's rays and the local vertical, and is given by

$$\cos Z = \sin\theta \sin\delta + \cos\theta \cos\delta \cos h$$

Where θ is the latitude of the place, δ is the solar declination and h is the hour angle, which is zero at local noon and increases in magnitude by $\pi/12$, (15°), for every hour before or after noon. The 'half day length', H, can be calculated from the above equation by noting that at sunrise and sunset cos Z = 0 (Z = π /2, (90°)). Thus

$$\cos H = - \tan\theta \tan\delta$$

The amount of incoming energy on a horizontal surface at the top of the atmosphere I_0 is related to Z by

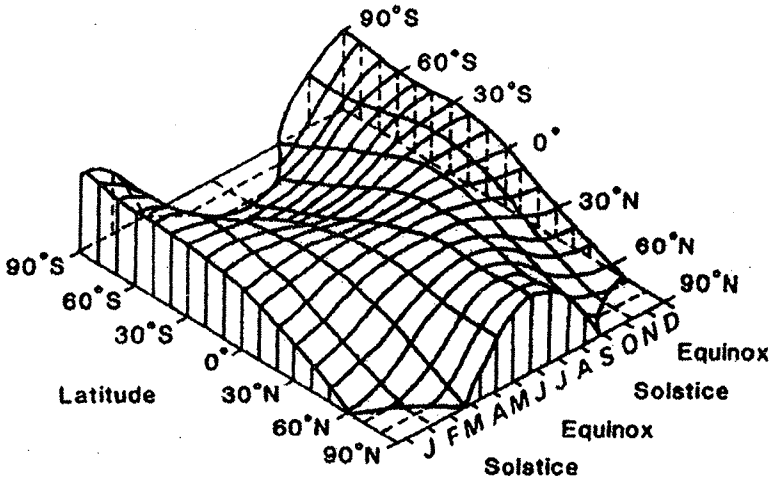
$$I_0 = S_F (d/d')^2 \cos Z \qquad [2]$$

where S_F is the solar constant and d/d' is the correction factor for the variable Earth-Sun distance, d being the mean Earth-Sun distance and d' its instantaneous value. Combining equations [2.6] and [2.8] and integrating from $-H$ to $+H$, the daily total radiation at the top of the atmosphere is

$$I_{DT} = \frac{86400}{\pi} S_F (d/d')^2 (H \sin\theta \sin\delta + \cos\theta \cos\delta \sin H')$$

Where H is expressed in radians.

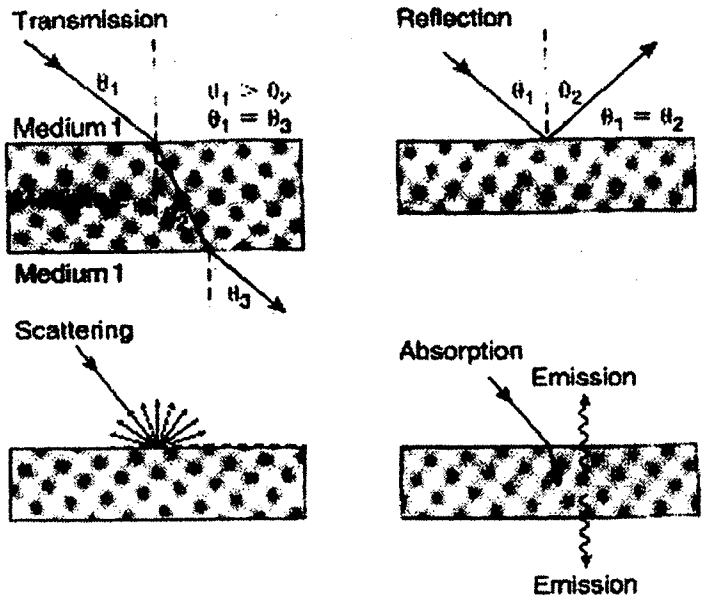
The resultant variation in the incident solar energy, or insolation, at the top of the atmosphere as a function of latitude and month is shown in Fig. 2.8. It can be seen that while the insolation near the equator is never as great as the maxima achieved at the poles, it is consistently high throughout the year. Polar insolation, on the other hand, is zero during the polar night but peaks during the polar day when the Sun is permanently above the horizon. This spatial and temporal variation in radiation that enters the atmosphere is vital for driving the climate system.



The variation of insolation (at the atmosphere) as a function of latitude and month for the whole globe. The very large amount of radiation received at the poles in summer are the result of the 24 hours of daylight at that time.

■ 3.2.8 ATMOSPHERIC INTERVENTIONS

Solar radiation is partially depleted and attenuated as it traverses the atmospheric layers, preventing a substantial portion of it from reaching the earth's surface. This phenomenon is due to transmission, absorption, scattering, and reflection in the upper atmosphere (stratosphere), with its thin layer of ozone, and the lower atmosphere (troposphere), within which cloud formations occur and weather conditions manifest themselves.



The intensity of radiation reaching a planet is in proportion to a basic physical law known as *square law*. This law states that the *inverse* the area illuminated, and hence the intensity, varies with the squared distance from the light or energy source. Thus, if the intensity of radiation at a given distance X is one unit, at a distance of 2X the intensity of the light will be one fourth that X. This law controls the intensity of solar energy intercepted by planets in the solar system. Earth only receives about 1/2,000,000,000 of the sun's energy output.

Proportion of energy that is transmitted, reflected or absorbed depends upon:

- composition and physical properties of medium
- wavelength or frequency of incident radiation
- angle at which incident radiation strikes a surface

• ***Transmission*** – This is the process by which incident radiation passes through matter w/o measurable attenuation (transparent to radiation); cause change in velocity and wavelength but not frequency. Reflection, scattering, and absorption deplete the solar beam as it passes through the atmosphere. **Transmissivity** is the proportion of the solar radiation ultimately passing through the atmosphere. Transmissivity depends on both the state of the atmosphere and the distance the solar beam must travel through it. The relative distance the solar beam travels through the atmosphere is the path length or optical air mass. The path length has a value of 1 when the sun is directly overhead or 90° above the horizon. The path length increases as the angle of the sun above the horizon decreases, and it can be calculated for any sun angle. For example, if the sun is 30° above the horizon, the path length has a value of two since the solar beam has twice the distance to travel through the atmosphere.

• ***Absorption*** – Absorption is the process by which incident radiation is taken in by the medium (e.g., surface, atmospheric particulates, atmospheric layer) and the medium is opaque to incident radiation. *Absorption* of shortwave radiation by atmospheric gases is relatively small and is usually considerably less important than scattering. The atmosphere is almost completely transparent near the peak of the solar Planck curve.

The stratospheric ozone layer has a strong absorption affinity for solar UVR, depending on wavelength. Absorption, being more effective for the shorter wavelengths, tends to reach its peak at 250 nm and drops rapidly with an increase in wavelength, even beyond 350 nm. Thus, the biological harmful radiations below 280 nm (vacuum UV and UV-C) are completely shielded by the ozone layer. This is also responsible for the temperature inversion at the tropopause. Only a fraction of the UV-B and UV-A wavelength bands reach ground level. Depletion of the protective ozone layer beyond the critical level by certain atmospheric pollutants (fluorocarbons and nitrogen oxides) that interact photochemically with ozone will promote the transmission of highly injurious UVR (El-Hinnawi and Hashmi 1982).

There are a few narrow regions of the spectrum, called 'bands', where absorption by oxygen, ozone and water vapour occurs. In total, this gaseous absorption removes only about 18% of the energy arriving at the top of the atmosphere from the beam with absorption by clouds removing another 2%. This is much less than the amount of energy that is absorbed at the surface (~50%). Since absorption leads directly to heating, this fact has a great consequence for the energetics of the atmosphere.

Absorption of radiation by even thick cloud formations is less than 10%. Whereas gases, water vapour, and particulate matter cause depletion mainly in the short-wave region of the spectrum, atmospheric gases and clouds deplete absorption at specific wavelength intervals called absorption bands. These occur largely in the longer-wave region and are in contrast to the intervening regions characterized by their transmission bands, or atmospheric windows. The gases involved in the absorption phenomenon in the red and infrared regions are ozone and carbon dioxide.

• ***Specular reflection*** – Reflection is a process whereby incident radiation "bounces off" the surface of substance in a single, predictable direction; caused by surfaces smooth relative to wavelengths of incident radiation; no change in velocity or wavelength. A very small proportion of incident radiation is reflected back by the atmosphere. Clouds are the most important reflector having reflectivity ranging between 40 – 90%.

• *Scattering (diffuse reflection)* - Scattering occurs when incident radiation is dispersed or spread out unpredictably in many different directions. This occurs when surfaces are rough relative to wavelengths of incident radiation. There is no change in velocity or wavelength of the incident radiation. The radiation bounces in all directions-upward, sideways and downward. The result of scattering by the gases and particles in the atmosphere is that insolation reaches the ground from all parts of the sky, not just in rays directly from the Sun. In this it illuminates a shaded area or a room where direct sunlight is absent; it produces the so-called **diffused light** that accounts for brightness of the daytime sky. In contrast, bodies like the Moon and Mercury, which are without atmospheres, have dark skies and 'pitch black' shadows, even during daylight hours.

The two major processes involved in tropospheric scattering are determined by the size of the molecules and particles and are known as **selective scattering** and **nonselective scattering**.

Selective scattering is caused by smoke, fumes, haze, and gas molecules that are the same size, or smaller, than the incident radiation wavelength. Scattering in these cases is inversely proportional to wavelength and is most effective for the shortest wavelengths. The degree of scattering decreases in the following order: UV-B > UV-A > violet > blue > green > yellow > orange > red > infrared. When the atmosphere is clear and relatively transparent, selective scattering is less severe than when it is extensively polluted.

Scattering particles such as atmospheric gas molecules which are small compared to the wavelength of the incident radiation produce *Rayleigh scattering*. The amount of scattering can be shown to be inversely proportional to the fourth power of the wavelength. Thus for visible radiation the scattering of blue light (wavelength —0.4 μm) is 10 times greater than for red light (wavelength — 0.7μm). Selective scattering of sunlight in the blue region of the spectrum under clear-sky conditions accounts for the blue sky when the degree of scattering is sufficiently high. This is determined by the length of the atmospheric path traversed by sunlight. With the sun overhead at noon, the sky appears white because little scattering occurs at the minimum atmospheric path length. At sunrise and sunset, however, the solar disc appears red because of the increased atmospheric path associated with blue light scattering and relatively little scattering of the red component. Selective scattering may range from 10% in the early morning to 20% in the late afternoon (McVeigh 1977). The very long path length of the radiation through the atmosphere at that time causes most of the shorter visible wavelengths to be scattered many times and hence dispersed from the direct solar beam, leaving only the red component unaffected, creating a much redder Sun than during the rest of the day. The reddish sky often associated with this is a result of scattering of red wavelengths slightly out of the direct beam.

Whenever clouds, pollution particles, or water droplets are present in the atmosphere *Mie scattering* occurs. This is effective whenever the scattering particles are of a similar size to the wavelength of the incident radiation. In this case scattering is almost entirely in the forward direction. The amount and direction of scattering is a function of both the particle size and the wavelength of the radiation. However, there is a tendency to scatter light of all waves lengths, the effect of which is most readily seen when the atmosphere is turbid (i.e. laden with pollution) and creates a light blue/grey sky, since no wavelengths are preferentially scattered. As most cloud droplets absorb radiation as well as scattering it, the effect is less obvious in cloudy conditions.

Nonselective scattering is caused by dust, fog, and clouds with particle sizes more than 10 times the wavelength of the incident radiation. As scattering in this case is not wavelength-dependent, it is equal for all wavelengths. Because of this, clouds appear white. Clouds also reflect incident solar radiation back

into space; this varies with their thickness and albedo (ratio of reflected to incident light). Thin clouds may reflect less than 20% of the incident solar radiation, whereas a thick and dense cloud may reflect over 80%.

Although some photons are only scattered once as they pass through the atmosphere, *multiple scattering* is more common. Scattering within clouds is always multiple scattering. The effect can also be seen in conditions of a *whiteout* occurring in high latitudes. Here multiple scattering between a bright snow surface and the base of a low cloud layer makes it extremely difficult to see which is which, or where the horizon is located, and to distinguish features of the surface.

The total solar radiation received at ground level consists of direct and indirect radiation (scattered, diffused, or reflected). The UVR component does not exceed 5% of the total incident radiation at sea level under cloudless atmospheric conditions. The intensity of sunlight at ground level varies with latitude, geographic location, season, cloud coverage, atmospheric pollution, elevation above sea level, and solar altitude. The 23.5° tilt of the earth's axis affects the angle of incidence of solar radiation on the earth's surface and causes seasonal and latitudinal variations in day length. At high altitudes, the intensity of UVR is significantly higher than at sea level. The spectral distribution of solar energy at sea level is roughly 3%, 44%, and 53% in the UV, visible, and infrared regions, respectively. In practice, therefore, these variables need to be considered for the use of solar energy, including its UVR component.

■ 3.2.9 SOLAR RADIATION AT THE EARTH'S SURFACE

The final interaction as the solar radiation passes through the atmosphere is with the surface of the Earth itself. Radiation incident on an opaque surface is either absorbed or reflected. The proportion of the incident energy that is reflected, the *surface albedo,* is not highly wavelength dependent and can be treated as a single value for a given surface type. Most natural land surfaces have albedos between 0.10 and 0.25, with Man-made surfaces having albedos slightly higher. Snow, with a high albedo, is a notable exception. Water is also an exception both in its generally low value and in that the value varies strongly with the zenith angle.

- ***Surface albedo***

A high albedo indicates that much of the incident energy is reflected rather than absorbed. For example, the high albedo of snow means that it reflects much of the incident energy, instead of absorbing it and being warmed. Thus a clean snow surface can survive on a sunny day. Dirty snow includes material of a lower albedo within it and will absorb more energy and melt much faster. Similarly, albedo differences between vegetation and nearby Man-made surfaces are one of the causes of the temperature differences between them. Although more than albedo must be considered in analyzing these temperature differences, the surface albedo is

Material	Percent Reflected
Fresh snow	80–95
Old snow	50–60
Thick cloud	70–80
Thin cloud	20–30
Water (sun near horizon)	50–80
Water (sun near zenith)	3–5
Asphalt	5–10
Light soil	25–45
Dark soil	5–15
Dry soil	20–25
Wet soil	15–25
Deciduous forest	15–20
Coniferous forest	10–15
Crops	10–25
Earth system	35

of prime consideration in the establishment of local climates. In general, the albedo of the Earth's surface is around 0.15, mainly because of the predominance of water as a surface type. Consequently the majority of the energy reaching the surface is absorbed. Indeed, approximately 50% of the solar energy reaching the planet is absorbed at the surface, compared to only 20% absorbed by the atmosphere. The planetary albedo is seen to be 0.3, i.e. 30% of the incident radiation is reflected. The predominance of absorption and heating at the surface indicates that the major source of heating for the lower part of the atmosphere is the surface.

• **Terrestrial Radiation**

Approximately 51 per cent of the solar energy that strikes the top of the atmosphere reaches the Earth's surface is directly or indirectly (scattered) and absorbed. The absorbed energy causes the surface temperature to rise and in turn the surface becomes an energy radiator. Whereas the Sun emits short - wave radiation to space, the Earth radiates long - wave or infrared radiation to space, having a wavelength between 1 and 30 μm. This is known as **terrestrial radiation.** The infrared radiation or the long wave radiation is different from reflection. In reflection, rays are turned directly back without being absorbed, whereas in infrared radiation, the objects gets heated first and this heat is radiated in the form of infrared radiation (Wein's Displacement Law). Thus, the Earth's temperature controls both the amounts of radiation, which is emitted, and its energy spectrum. This infrared emission is particularly in 5 - 80 μm wavelengths with a peak emission at 10 μm. The atmosphere as a whole is rather an efficient absorber of radiation between 1 and 30 μm. While the atmosphere is transparent to the solar radiation, it is only partially transparent to the long wave radiation from the Earth's surface. It absorbs 94 per cent of the long wave emission, allowing only 6 per cent to escape directly to space. Water vapour and carbon dioxide are the main constituents of the atmosphere that absorb the outgoing radiation, water vapour in 5.5 - 8.0 μm and 20 μm wavelength and carbon dioxide in 4.5 μm and 14-16 μm. Because the atmosphere is largely transparent to solar (shortwave) radiation and more absorptive to terrestrial (longwave) radiation, the atmosphere is heated from the ground up. When gases in the atmosphere absorb terrestrial radiation, they get warmed, but eventually they radiate this energy away. Some travels upward where it may be reabsorbed by other gas molecules, a possibility that becomes much less likely with increasing height because the concentration of water vapour decreases with altitude. The remainder travels downward and is again absorbed by the Earth. Thus, the Earth's surface is being continually supplied with heat from the atmosphere, as well as, from the Sun. This energy will again be emitted by the Earth's surface and some will be returned to the atmosphere, which will, in turn, radiate some earthward and so forth. This game of radiation and re-radiation keeps the Earth's average temperature 35° C warmer than it would otherwise be.

The atmosphere as a whole is much more transparent to shortwave solar radiation than longwave terrestrial radiation. However, the band between 8 and 13 μm is almost transparent to long wave infrared radiation and is called **radiation window or atmospheric window.** Through this window, radiation passes unimpeded to the space. This fact is used by infrared sensors on board meteorological satellites to detect surface and cloud top temperatures from space.

3.2.10 WORLD DISTRIBUTION OF SOLAR RADIATION

Solar radiation is unevenly distributed throughout the world because of such variables as solar altitude, which is associated with latitude and season, and atmospheric conditions, which are determined by cloud coverage and degree of pollution. The following guidelines are useful for the broad identification of the geographic areas with favourable solar energy conditions in the Northern Hemisphere based on the collection of the direct component of sunlight. Similar conditions apply for the Southern Hemisphere (Acra et al. 1984).

The most favourable belt (15-35° N) encompasses many of the developing nations in northern Africa and southern parts of Asia. It has over 3 000 h/year of sunshine and limited cloud coverage. More than 90% of the incident solar radiation comes as direct radiation.

The moderately favourable belt (0-15° N), or equatorial belt, has high atmospheric humidity and cloudiness that tend to increase the proportion of the scattered radiation. The global solar intensity is almost uniform throughout the year as the seasonal variations are only slight. Sunshine is estimated at 2 500 h/year.

In the less favourable belt (35-45° N), the scattering of the solar radiation is significantly increased because of the higher latitudes and lower solar altitude. In addition, cloudiness and atmospheric pollution are important factors that tend to reduce sharply the solar radiation intensity. However, regions beyond 45° N have less favourable conditions for the use of direct solar radiation. This is because almost half of it is in the form of scattered radiation, which is more difficult to collect for use. This limitation, however, does not strictly apply to the potentials for solar UVR applications.

■ 3.2.11 RADIATION BALANCE

For the system as a whole - that is the entire planet and its atmospheric envelope - there is a long-term balance between incoming and outgoing radiation. If this were not the case the total energy content of the system would increase or decrease through time and the Earth would experience a progressive warming or cooling. This balance can be represented as-

Net radiation = incoming solar radiation (mainly shortwave) minus outgoing radiation (mainly long wave) = 0

Here we need to consider not only inputs and outputs, but also the throughput of energy. This is the energy which, at any point in time, is being transferred or stored within the earth or its atmosphere. This is because within any closed system the balance of energy exchange is not only a function of relative surface temperatures and absorbance and emittance characteristics of all parts of the system, but it also depends on modes of energy transfer other than radiation. These are conduction and convection as well as energy-dependent changes of state, such as the evaporation of water, involving latent heat exchange. So, although a long-term energy balance may exist for the whole system, there will still be energy im-balances, transfers and changes in energy storage within the system.

• The Atmospheric System

Exchange and throughput of shortwave solar radiation: On entering the atmosphere the short wave solar radiation encounters molecules of gases, liquids and solids, all of which are able partly to absorb or reflect it. The gases of the atmosphere and suspended liquid and solid matter **absorb** selectively from the solar beam. Ozone (O_3) and water vapour (H_2O), for example, are major absorbers of radiation but affect different parts of the solar spectrum (Ozone absorbs large proportion of ultraviolet radiation in the waveband 0.23-0.32 μm; water vapour 5 μm -8 μm and 11 μm -80 μm i.e. infrared). Between these, are the bands of low absorption, referred to as **radiation windows**. In addition to ozone and water vapour, both oxygen and carbon dioxide absorb radiation. Carbon dioxide absorbs mainly in the infrared range

between wavelengths 12 μm and 18 μm. Further absorption also takes place due to the presence of suspended liquid and solid particles. Ice crystals and water droplets suspended in clouds also absorb in the infrared range at wavelengths 3, 6 and 12 μm. There is considerable loss by absorption in the short- and long wave parts of the solar spectrum, with relatively little absorption of visible radiation.
In the atmosphere, gases and suspended matter can both disperse incident solar radiation. A unidirectional solar beam is partially transformed into a multidirectional **scatter** of radiation (**diffuse reflection**), some of which ultimately passes back out of the atmosphere into space. In the visible part of the solar spectrum, blue light is scattered to a greater extent than other wave lengths, resulting in the predominantly blue colour of the sky.

The intervention of a band of cloud across the solar beam effectively reduces the amount of radiation reaching the Earth's surface. The upper surfaces of clouds are good reflectors of radiation, the amount reflected being dependent upon cloud type, cover and thickness. A light cover of cirrus cloud is a relatively ineffective reflector, whereas dense stratiform and cumuliform cloud may reflect more than 50% of the solar radiation incident upon them. Reflection from heavy storm clouds may be as high as 90%.

The atmosphere directly absorbs a small proportion, some 17 units on average (K_A), of the solar radiation input (100 units), mainly in the short and long wavelengths. The proportion is small because its major constituents are not efficient absorbers in the wavelengths covered by the solar spectrum. However, this absorption of solar radiation contributes to an increase in the internal energy store of the atmosphere. Of the remaining solar radiation, 29 units are lost as output to space by reflection. This is made up of 6 units lost by scattering ($K_{Aa}\uparrow$) and 23 units lost through cloud reflection ($K_{Ac}\uparrow$). A further 54 units of radiant energy are output to Earth surface systems and can be divided into 36 units ($K_D\downarrow$) of direct radiation and 18 units ($K_d\downarrow$) of diffuse radiation, again as a result of scattering. This throughput of solar radiation forms part of what is known as the **solar energy cascade**.

Exchange and throughput of longwave radiation: Gases such as carbon dioxide and water vapour, together with suspended water droplets and ice crystals in clouds, are more effective absorbers in the infrared part of the electromagnetic spectrum particularly for wavelengths greater than 8 μm. As the spectrum of longwave terrestrial radiation from the Earth's surface extends over wavelengths 3 μm to 30 μm. with a maximum emission at 10 μm. a significant proportion will therefore be absorbed in the atmosphere. In fact only about 7% of terrestrial radiation passes directly into space, the remainder being absorbed. This is commonly referred to as the **greenhouse effect**. The absorbed radiation is re-emitted, as the atmosphere acts as a radiator. Approximately 60% returns to the Earth's surface systems as counter-radiation. As most of the carbon dioxide, water vapour and clouds are in the lowest 10 km of the atmosphere, it is at this level that the greatest absorption and emission take place.

The radiation balance of the atmosphere: The atmosphere receives shortwave radiation from the Sun and by reflection from the Earth's surface. Of this it absorbs only a small proportion (K_A). It also receives longwave terrestrial radiation, a large proportion of which it absorbs ($L_{EA}\uparrow$) remainder passing directly to space. The atmosphere radiates at long wavelengths to space ($L_A\uparrow$) and the ground surface ($L\downarrow$). Thus the radiation balance in the atmosphere (Q^*_A) can be written as- $Q^*_A = K_A + L_{EA}\uparrow - L_A\uparrow - L\downarrow$. For the whole atmosphere, assuming a solar constant of 100 units, 17 units are absorbed from the solar beam and 91 from terrestrial radiation. 57 units are radiated into space and 78 units back to the ground surface. The atmosphere thus receives 108 units while losing 135, which represents a net radiation balance of -27 units. In reality this energy loss does not take place because other heat transfer processes are at work

maintaining an energy balance.

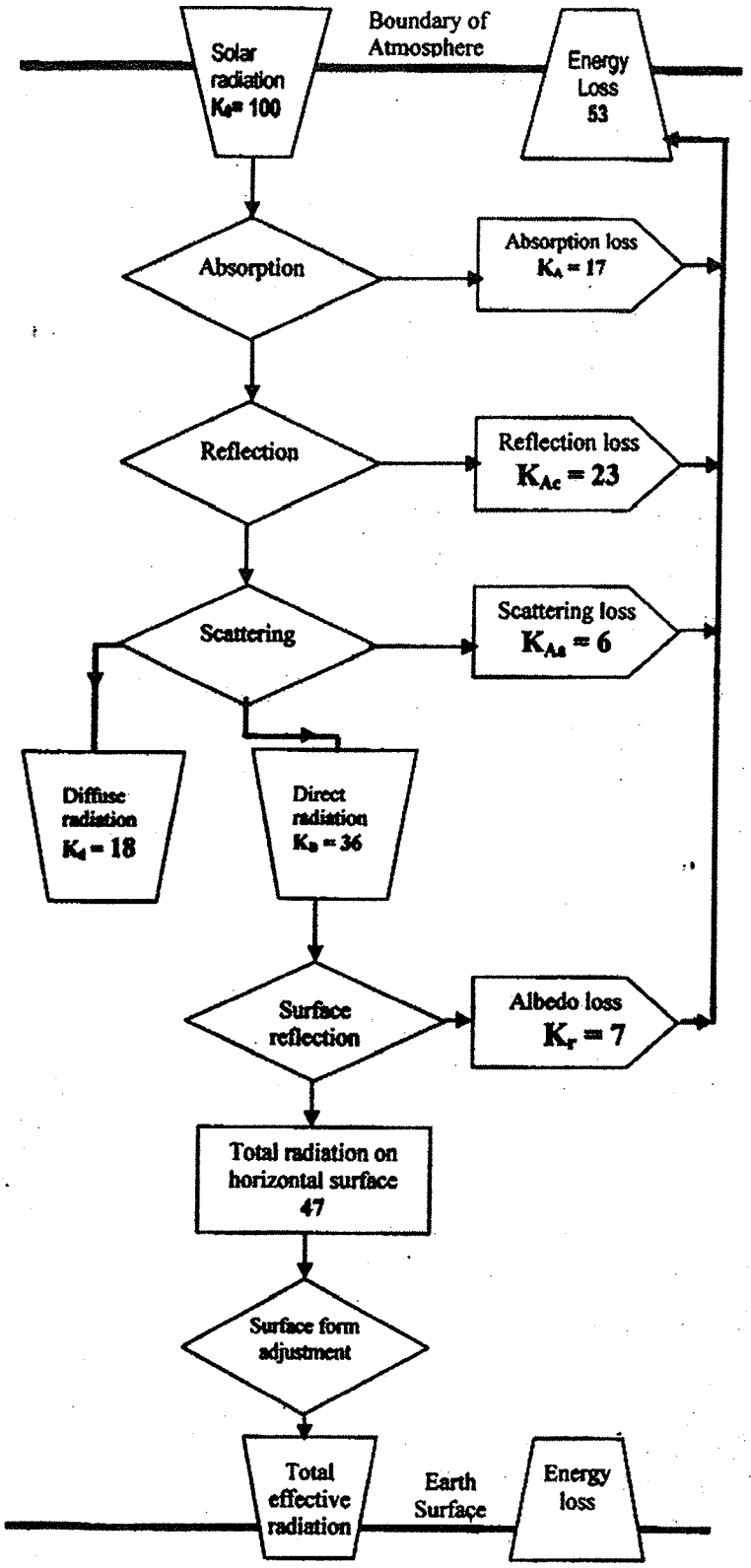


Fig: The solar energy cascade.

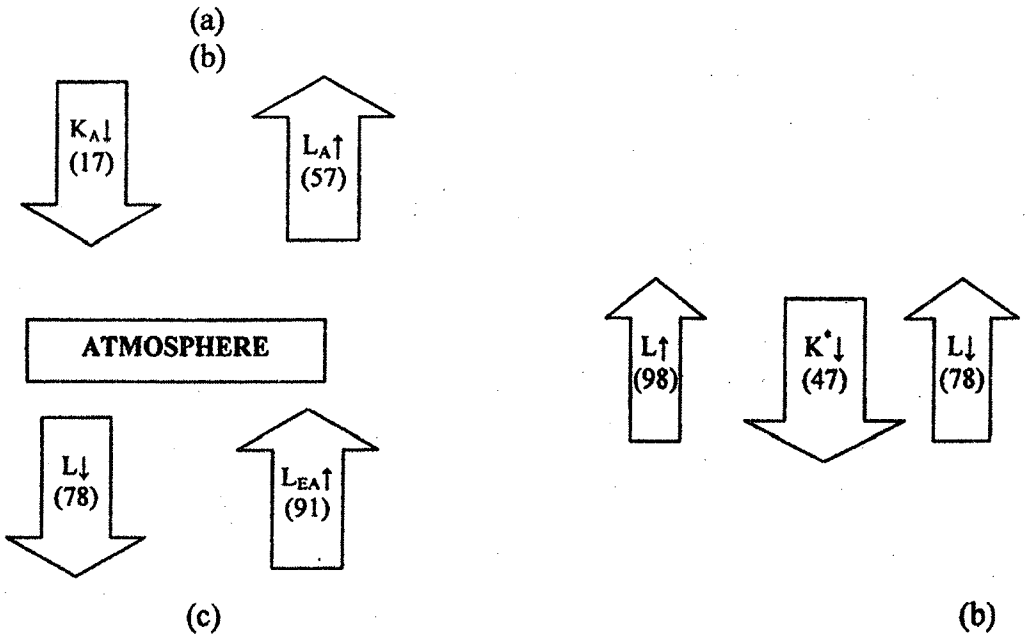


Fig. - Balance of radiation- (a) in the atmosphere and (b) at the earth's surface

• **Earth-surface systems**

• *Radiation exchange and throughput:* The input of shortwave solar radiation transferred from the atmosphere to Earth surface systems consists of both direct and diffuse radiation ($K_D\downarrow + K_d\downarrow$) where,

$$K_D\downarrow + K_d\downarrow = K\downarrow = K_0\downarrow - K_A - K_{Aa}\uparrow - K_{Ac}\uparrow$$

A part of the solar beam which experiences scattering subsequently retains a generally earthward direction of motion and reaches the Earth's surface as diffuse radiation. The proportion of diffuse radiation varies considerably, but for the whole Earth surface it constitutes some 33% of total radiation reaching horizontal surfaces. The Earth's surface returns some of the solar radiation incident upon it by reflection back through the atmosphere, which represents 7 units of radiation lost from the surface. Effective solar radiation input on a horizontal surface is, therefore, reduced to 47 units. Then available net shortwave radiation at the earth's surface can be written as-

$$K^* = K\downarrow - K_r\uparrow$$

The amount of longwave counter radiation reaching the Earth's surface depends ultimately upon the absorptive properties of the lower atmosphere. Thus areas of the Earth's surface above which the atmosphere is usually humid and cloudy, such as equatorial regions, receive considerable amounts of counter-radiation. Over the whole of the Earth's surface, counter-radiation constitutes, on average, about 62% of total radiant energy received. The net balance of longwave radiation from the ground surface may be expressed in simple terms in the equation

$L^* = L\uparrow - L\downarrow$

Where $L\uparrow$ represents the longwave terrestrial radiation emitted from the ground surface, and $L\downarrow$ that returned by counter-radiation.

• *The radiation balance of the Earth's surface*: The Earth's surface receives shortwave radiation from the Sun (some of which is lost through reflection) and longwave counter-radiation from the atmosphere, while itself emitting longwave radiation. These flows are represented in Fig. 9 (b). The equation for the net radiation balance ((Q*) may be derived from the short- and longwave balances:

$Q^* = K^* + L^*$

For the whole of the Earth, the surface receives 125 units of radiation, while losing only 98. The balance of +27 units implies that the surface is gaining in energy. In reality, this does not take place so by inference; there must be a mechanism for dissipating this excess energy. The equality of atmospheric deficit and Earth-surface surplus of radiant energy suggests that the mechanism is one which transfers energy from the surface into the atmosphere above it.

The radiation balance of the Earth's surface varies considerably. There is a general trend towards a positive balance or surplus in low latitudes, and a negative balance or deficit in high latitudes. Factors such as cloudiness and atmospheric humidity, which affect the transmission of both solar and terrestrial radiation, and the radiative properties of the surface, create the spatial variation in radiation balance over the Earth's surface. The radiation balance of the Earth's surface is an important factor in determining the distribution of surface temperature. **The radiation arriving at the top of the atmosphere, from the Sun and from the solids and fluids of the Earth and its atmosphere exhibit the following balance-**

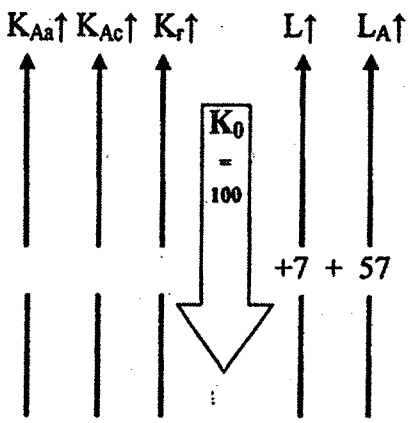


Fig. No. 10: Radiation balance at the outer boundary of the atmosphere

$$Q^* = K_0\downarrow - (K_r\uparrow + K_{Ac}\uparrow + K_{Aa}\uparrow + L\uparrow + L_A\uparrow)$$

Energy balance of the Earth-atmosphere system:

Some of solar and atmospheric radiation absorbed into the earth's surface is then reradiated and thus transferred into the atmosphere by **conduction** (Q_G) and **convection** (Q_H). In a moist environment a large proportion of energy is consumed in evaporation at the expense of heating the atmosphere. Thus a considerable amount of heat energy is transferred to the atmosphere as **latent heat** (Q_E). Furthermore, **lateral heat transfers** (Q_F) within the oceans and within the atmosphere through the corresponding circulations and along temperature gradients over or beneath the earth's surface- constitute a significant component of the heat balance. Hence the Equation of heat balance for the earth-atmosphere system becomes-

$$Q^* = Q_H + Q_G + Q_E + Q_F$$

■ 3.2.12 SUMMARY

The cascade of energy into, through, and out of the environment is dynamic and complex. The source for the energy that drives the atmosphere is solar radiation. Any kind of energy radiation obeys some laws. The supply of solar radiation is steady but not constant, amount being determined by many

factors. Changes occur in the amount of radiant energy ejected from the sun. It is steady enough to be called the solar constant. Energy reaching the atmosphere is disposed of in several ways. Some is reflected and scattered back to space, some is absorbed, and some is scattered and transmitted through to the surface. It is this latter energy that becomes the major heat source for the atmosphere. There is a built-in storage mechanism known as the greenhouse effect that raises the temperature such that life can exist. The energy balance of the planet is a steady-state system that maintains a mean temperature at the surface of about 15°C (59°F). But recently human activities have driven the atmosphere to lose its energy balance making it warmer, which has become a major concern in the present context.

B. FACTORS INFLUENCING VERTICAL AND HORIZONTAL DISTRIBUTION OF TEMPERATURE

■ 3.2.13 INTRODUCTION

The average temperature of the atmosphere near sea level is roughly 15°C. There are, however, wide fluctuations from day to day and from place to place. The lowest temperature ever recorded on the Earth's surface is -88°C which occurred at Vostok, Antarctica on August 24, 1960, while the highest temperature ever recorded is 58°C and it occurred in Azizia, Libya on September 13, 1922. This temperature not only varies spatially, i.e., from place to place but also vertically in the troposphere. Besides, it has been observed throughout the history too, that average temperatures have not remained stable. It is assumed that the average temperature today is below 15°C while it is expected that the average temperature would be more than 15°C after a century because of the greenhouse effect.

Thus, there are two aspects of temperature distribution—Spatial or Horizontal and Vertical.

■ 3.2.14 OBJECTIVES :

Major objective of this portion of this module is to make the students understand the factors which are responsible to cause spatial variation in the distribution of temperature over the surface of the earth. This will help them to explain the spatial pattern of climatic characteristics. Virtually, the difference in receipt of insolation is the most important determinant that causes latitudinal variation in temperature over he earth's surface and isotherms to be oriented latitudinally. But in reality, such an expected pattern of temperature distribution has often been distorted by the other factors operative. Therefore, students are required to have a clear idea about those factors and principles of their functioning. Furthermore, the vertical distribution of temperature across the atmospheric layers or the thermal structure of the atmosphere is also a function of many factors. The theoretical distribution of temperature along the vertical is also disturbed due to many reasons. They have also been taken into account.

■ 3.2.15 FACTORS OF HORIZONTAL TEMPERATURE DISTRIBUTION

The spatial aspect of temperature distribution is determined by a number of factors, such as latitude, altitude, differential behaviour of the Earth with respect to incoming solar radiation, distance from the sea, ocean currents, aspect and elevation, etc.

1. Latitude

Insolation is the prime factor affecting temperature. Insolation varies from place to place and this variation is a function of latitude. The amount of insolation is most intense in Low than in high latitudes. This means that away from the Equator, amount of insolation received goes on decreasing. The total amount of radiant solar energy received at any point on the Earth is basically governed by duration and intensity of insolation. These things get manifested in latitude, where the isotherms generally trend east-west with values decreasing towards the Pole, indicating a temperature decrease towards the Pole.

2. Altitude

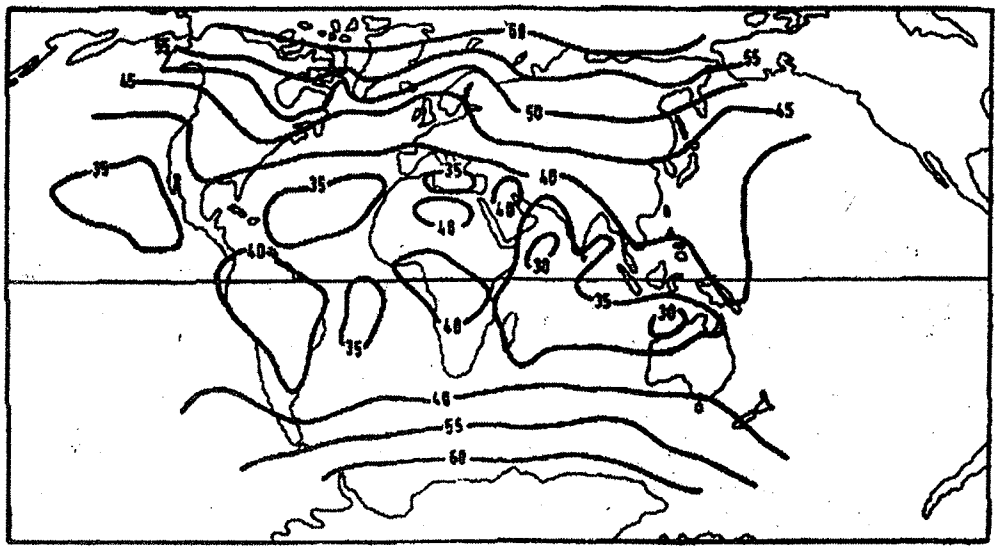
Throughout the troposphere, the temperature drops at a rate of 6.5° C/km. This lapse rate is known as **environmental lapse rate or normal lapse rate.**

This drop in temperature is because of two factors—

(a) The atmospheric heat source lies at the surface of the Earth, therefore, the higher the altitude, lower is the temperature.

(b) The lower part of the atmosphere contains water vapour and dust particles that absorbs large amount of terrestrial radiation than the upper atmosphere, which is deficient in water vapour and dust particles.

Although the actual insolation increases with altitude, the temperature is lower because of increased radiation loss through the thin atmosphere. Irrespective of the latitude, a temperature drop will be observed with altitude, for example, two cities in Ecuador, Quito and Guyaquil are near the Equator and relatively close to each other but the annual mean temperature at Guyaquil is 25.1°C as compared to Quito's mean of 13.31°C. Guyaquil is 12m above sea level while Quito is high enough in the Andes at 2800 metres. Delhi, in the Indo-Gangetic plain at a height of 219 m. has a mean June temperature of 33°C but Shimla lying very close to it, at 2204 m has the corresponding temperature of only 19°C. Altitude affects the daily temperature range also. Because of the reduced air density with height, the atmosphere absorbs little radiation, consequently, the intensity of insolation increases resulting in intense day time heating. At night, the rarity of the atmosphere causes the terrestrial radiation to be unimpeded causing rapid cooling.



Mean annual values of albedo of the Earth's surface

3. Distribution of Land and Sea

The factors which account for the differential heating of land and water are—

(a) Disparity in Albedo

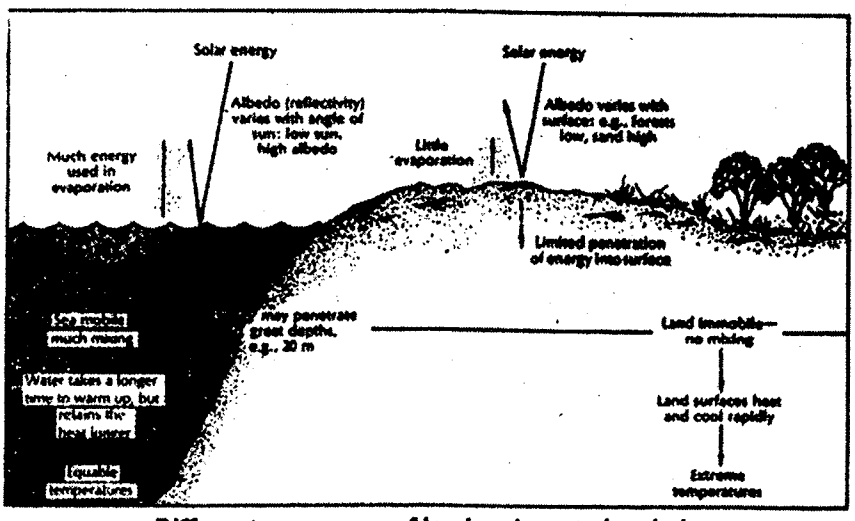
Albedo or **reflectivity** varies between different surfaces. Since there are also differences in cloudiness, with the different climates of continents and oceans, the pattern gets complicated. Greater albedos at the surface, such as the snow covered surface having 90 per cent albedo, mean that the amount of energy available for warming the atmosphere is reduced. This explains why Polar areas, in spite of having a very high receipt of insolation, have low temperatures.

(b) Variation in Specific Heat

The heat capacity or specific heat of a substance is the amount of heat (number of calories) required to raise the temperature of 1 gm of a substance by 1°C. The specific heat of water is five times as large as that of the land surface. This means that the same amount of heat applied to the same mass of water and land results in temperature increase that is five times greater for the land than for water. If the heat is withdrawn from the land or water, the temperature decrease is five times greater for the land than for water. In other words, there is smaller change of temperature in water body per unit than for land mass. These differences are further heightened by differences in thermal conductivity.

(c) Inequality in thermal conductivity

Loose dry soil is a very poor conductor of heat and only a superficial layer will experience a rise in temperature following energy input. This is because the only means of transfer of heat is by slow process of molecule by molecule conduction. As a result, the diurnal and annual changes of temperature are very large because they are confined to a very, shallow layer of ground. Water has only a fair conductivity, but its general mobility and transparency permit heat to circulate below surface layer. In the sea, for example, heat is transferred downwards not only by radiation and conduction but also by mixing of water to various depths. Since the temperature changes are spread over a large volume of water, the diurnal and annual changes are small.



Different responses of land and sea to insolation

(e) Differences in evaporation

It is obvious that evaporation occurs from ocean surface. Use of energy for evaporation reduces the amount of heat transferred to in the atmosphere, hence, the air temperature over oceans are lowered, particularly in winter where evaporation is greater than in summer. Higher evaporation basically results from the fact that the ocean temperature is higher than the air above it. In summer the air is warmer than the sea. It is notable that in wet tropics evaporation, rather evapotranspiration is greater from continents than over oceans.

(d) Differences in transparency

Land surfaces are practically opaque to solar radiation so that all the incoming heat is concentrated in the top fraction of an inch of the ground while in the sea one-third of radiation penetrates 30 ft. Thus, there will be smaller rise of temperature in water per unit input of heat since the heat is distributed through a larger volume of water than land.

The effect of differences in albedo, transparency, specific heat, and evaporation makes the water more conservative than the land with respect to temperature (Fig 5.2). The summers are cooler over oceans than over continents in the same latitude while the winters are warmer (the larger the landmass the greater is the contrast), giving rise to elements of continentality and oceanicity. Coastal location will, thus, have a smaller annual temperature range than on inland location, for example, Mumbai; has a very small annual range than Delhi.

From the climatic point of view, the effect of oceans is that of a gigantic cooling system in summer and a heating mechanism in winter. Sometimes, the heat trapped in the oceans is so much that it contributes more energy to the air above it than the Sun, The cold air (-30°C) which blows from the interior of the USA in winter, crosses the Gulf stream current (10°C) which transfers up to 1200 Ib/day to the air. Even inland lakes such as Lake Baikal in Siberia have a similar effect. This lake releases more heat in the winter months than the Sun provides to the area in summer! Great Lakes, similarly, have more or less the same kind of effect.

The effect of land and sea surface is that the oceans are warmer in winter than the continents in the same latitude while continents are relatively warmer in summer. This causes the isotherms to bend poleward over oceans in winter, poleward over the continents in summer, equatorward over oceans in summer and equatorward over continents in winter.

4. Winds

At most places, climate is basically 'imported', i.e., it is the result of conditions prevailing at some distance and which has been brought there by winds. A place may be continental with respect to its physical location but if the winds and air masses moving over it largely come from ocean, it may have a maritime climate. By the same analogy, a coastal location where air mass comes from the interior of the continent will have a continental climate despite having a coastal location

Onshore winds in the Tropics blowing over the cooler ocean tend to modify temperatures on the coastal margins. On the other hand, onshore winds, such as the Westerlies may carry mild temperatures from the oceans to the continental margins in winter and raise the temperature.

5. Ocean Currents

The fluid media of atmospheric gases and ocean waters are constantly in turbulent motion and transfer sensible and latent heat from Tropical regions towards Polar Regions and exchanges occur

between oceans and continents. The ocean water movement has prevented the excessive heat build up in the Tropical regions by transporting it poleward. Ocean currents while moving from one place to another tend to equalize the temperature. Thus, their effect on temperature is considerable, but variable. Besides, the currents have a moderating effect on the temperature of the place. The North Atlantic Drift keeps the winter time temperatures of whole of Western Europe much warmer than would be expected for such latitude. These moderating effects are carried far inland by the westerlies raising the temperatures. This current is responsible for preventing the freezing of the Baltic Sea. Many cities are habitable for the sake of this current. Berlin at 52°N and London at 51° N have a mean January temperature of 4-5°C.

The effect of cold currents is more pronounced in the tropics or during the summer months in middle latitude. Cool currents such as Californian, Humboldt, Canary, Benguela and Western Australian Current have substantial moderating effect on nearby places. Because of the cold Californian current coastal South California is 6°C colder compared to east coast locations of USA. Benguela current, lowers the temperature of Walvis Bay by 6°C compared to Durban which is on the eastern side and even farther poleward.

6. Cloudiness

Basically, the effect of insolation is part of the effect of different amounts of insolation. But cloudiness not only affects incoming solar radiation but terrestrial radiation as well. The recognition of the fact that clear nights are cold nights and cloudy nights are warm nights reflects the effect of clouds on outward radiation. A cloud cover traps most of the outgoing radiation. This means that atmosphere has more energy available for re-radiation to the ground and therefore surface temperatures are higher on cloudy than on clear nights. Ocean areas are cloudier than the continents because the evaporation takes place from the surface and then condenses over it and this affects surface temperatures.

The effect of cloud cover is different during the day and the night. During day time, it intercepts insolation and lowers the temperature while during night time; it intercepts outgoing radiation and raises the temperature. Cloudy regions, therefore, have smaller daily and annual ranges of temperatures than regions where neither insolation nor radiation are interrupted. Equatorial regions, Polar zones, mid latitude oceans and coasts are particularly cloudy, hence, have low range of temperature.

7. Geographic location

The geographical setting, such as, windward or leeward location of a place on the mountains and their orientation etc. greatly influence temperature at a given location. A windward coastal location subject to prevailing onshore winds will experience the full moderating influence of the ocean-cool summers and mild winters, as compared to inland situation, while a leeward coastal situation will have a more continental temperature regime because the winds do not carry the ocean's influence onshore.

It is because of the orientation of Himalayan ranges that whole of India is tropical in character despite having only half of its portion in the Tropics. The same mountain ranges are responsible for making southern China's temperature abnormally low in winter because it is exposed to cold out blowing winds from Siberia from which India is so effectively protected. The lack of any extensive east-west barrier in the United States permits Polar and tropical air to penetrate great distances into the continent, so that New Orleans may experience cold spells brought by air stream from the Arctic while very warm humid air streams from Gulf of Mexico brings heat waves to the northern States and even into Canada.

Thus, it is not only the latitude, which controls the temperature. There are many factors working together to produce the temperature pattern on the Earth.

■ 3.2.16 FACTORS OF VERTICAL TEMPERATURE DISTRIBUTION

The average rate of decrease of temperature upward in the atmosphere is 6.5°C/ km. This vertical gradient of temperature is commonly referred to as normal lapse rate. Sometimes, observations show no change with altitude and this is known as **isothermal** condition. This type of condition, however, rarely occurs over a long period of time.

The vertical distribution of temperature is influenced by the nature of the underlying surface, for example, temperature decreases most rapidly with altitude over continental areas in summer.

Certain special conditions in the lower troposphere may produce a reversal of the normal lapse rate so that the temperature actually increases with altitude. This is known as **temperature inversion** and the lapse rate is said to be inverted. Inversions that occur at ground levels are known as **surface inversion** while the one that occurs above is known as upper **air inversion.**

1. SURFACE AIR INVERSION

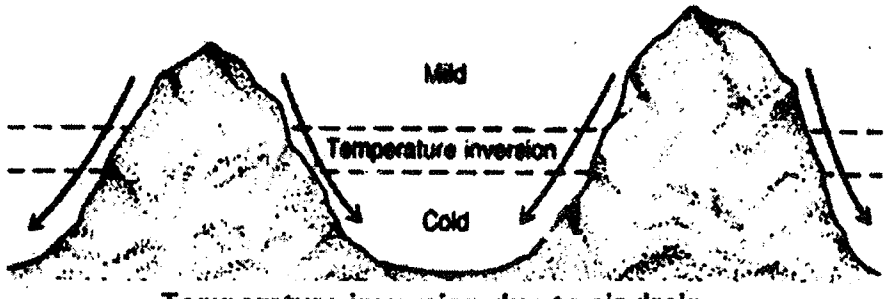
(a) Radiation Inversion

Land surface radiates heat more rapidly than air; ground is cooled more rapidly during night than the air. Thus, the coldest air lies at the ground and is overlaid by warmer air, while the layers in close contact with the ground are cooled by the process of radiation. The upper layers remain warmer than the lower layers. Thus, at a certain height, the temperature increases with altitude bringing about the inversion.

The ideal conditions for these night time inversions are,

(i) long nights allowing the outgoing Earth radiation to exceed incoming radiation,
(ii) clear sky so that loss of heat by terrestrial radiation is rapid,
(iii) cold dry air that absorbs very little Earth radiation,
(iv) calm air which allows very little mixing, and
(v) snow covered surface which owing to high reflectivity heats very little during the day time.

(b) Air Drainage Type of Inversion



Temperature inversion due to air drainage

Air drainage type of inversion is produced in the mountainous zones where the mountain slopes and mountain tops experience rapid night time drop in temperature. This leads to considerable cooling of that surface and its overlying air. Cooling of the valley sides and floor will be much less because of the radiation exchanges between the two valley walls and the floor. As a result, the cooler denser air of the top will start sinking to the floor following the mountain slope. The warmer air, thus, rests over the cooler air, producing temperature inversion.

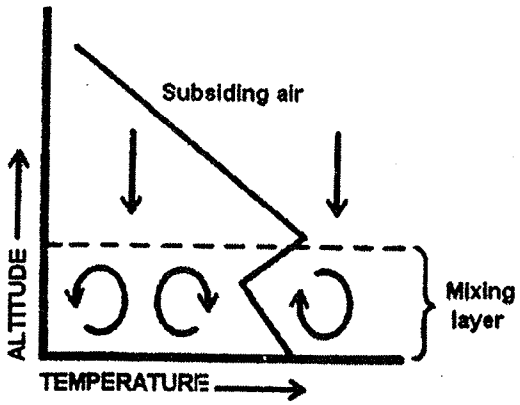
(c) Advection Inversion

Advection inversion is produced when a thick layer of warm air passes over the cold layer. Thus, temperature inversion would occur when warm air passes over *a* cool water surface, land surface or snow covered ground. These persistent inversions may be accompanied by thick fog if the air is moist.

2. UPPER - AIR INVERSION

(a) Subsidence Inversion

Subsidence inversion develops in the subtropics because of descent and adiabatic heating of air from the troposphere to the east of warm anticyclones. As a thick mass of air subsides, it warms at a rate of 10° C/km and at a particular level, produce inversion. These are common in semi-permanent high-pressure cells, such as, Azores High and Pacific High. Subsidence inversion is responsible for trapping pollutants and concentrating it in lower layers of the troposphere.



Temperature Inversion due to subsidence

(b) Convection Inversion

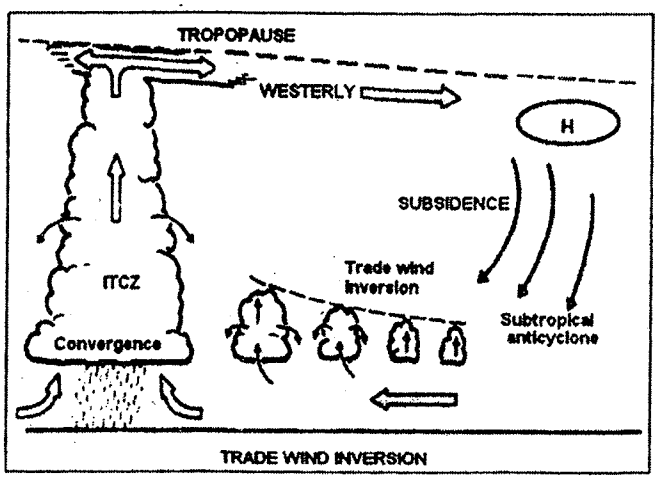
Convection currents are normally set up in the troposphere because of irregular heating of the surface. In convection some of the air is moved upwards, i.e., it ascends while some descends. The air, which goes upward, is cooled while that brought downward is heated. After prolonged mixing, the air at maximum height of turbulent penetration becomes colder than what it was before. At the bottom of the turbulence layer, the air will be warmer than what it originally was. The upper part of the turbulence zone which is cooler and the air above this zone, whose temperature has remain unaffected, comprise a temperature inversion zone.

(c) Frontal inversion

Frontal inversion occurs due to frontal convergence, when a warm air mass is forced from the ground surface by undercutting of a cold air mass at a cold front. Thus, the warmer air being relatively lighter overlies the colder and denser air. Alternatively, a similar inversion can be created when a warm air mass overrides a colder one at warm front. In these cases, the frontal zone itself is converted into inverted layer and moving upwards through the inversion layer, there is an increase in temperature with increasing altitudes. Frontal inversion is fairly common in mid latitudes.

(d) Trade Wind inversion

Trade wind inversion is present over the eastern part of the oceans and the adjoining coasts of subtropical latitudes. It is produced by the sinking of air as it moves equatorward around the eastern end of the high pressure areas over subtropical oceans. The heated air from the Equator rises and takes a westerly course towards north. Around subtropics it



sinks and moves equatorward in the form of NE Trades producing an inversion layer between them. In these cases, the frontal zone itself is converted into inversion layer and moving upon and through the inversion layer there is an increase in temperature with increasing altitude.

■ 3.2.17 SUMMARY

The theoretical distribution of the earth-surface temperature has been much distorted by several factors like altitude, ocean currents, winds, topography, forest cover etc. The distribution of temperature exhibits a general pattern of increasing trend towards the poles from the equator. This difference of energy receipt is the major cause for general wind circulation in the atmosphere by which the excess energy in the equatorial region is transported from equator to the Polar Regions. Vertical distribution of temperature in the atmosphere causes the air to lift which in turn causes condensation and rain making processes to operate.

C. ATMOSPHERIC HUMIDITY AND ATMOSPHERIC STABILITY & INSTABILITY

■ 3.2.18 INTRODUCTION: CONCEPT OF ATMOSPHERIC HUMIDITY

Atmospheric humidity refers to the content of water in gaseous form (water vapour, but generally quoted as only vapour) in a parcel of air having definite volume and temperature. The atmosphere gets moisture through the processes of evaporation from the land and water surfaces and transpiration. The humidity or vapour content in the atmosphere ranges between zero and 5 percent by volume. Climatically, water vapour is very important constituent of the atmosphere. Vapour depends on temperature and therefore it decreases from the equator poleward in response to decreasing temperature from the equator towards the poles. The content of vapour in the surface air in the moist tropical areas, at 50° and 70° latitudes is 2.6 per cent, 0.9 per cent and 0.2 per cent (by volume) respectively.

■ 3.2.19 OBJECTIVES

The content of atmospheric vapour also decreases upward. More than 90 per cent of the total atmospheric vapour (humidity) is found up to the altitude of 5 km. Water vapour in the atmosphere is responsible for various types of weather phenomena. The moisture content in the atmosphere creates several forms of condensation and precipitation *e.g.* dew, fog, cloud, rainfall, frost, ice, snowfall, hailstorms etc. Vapour is almost transparent for incoming shortwave solar radiation so that the electromagnetic radiation waves reach the earth's surface without much obstacles but the vapour is less transparent for outgoing shortwave terrestrial radiation and therefore it helps in heating the earth's surface because it absorbs terrestrial radiation and also reradiates terrestrial radiation back to the earth's surface. It, thus, helps in intensifying **green house effect** of the atmosphere.

The process of transformation of liquid (water) into gaseous form (vapour) is called **evaporation,** the amount and intensity of which depend on aridity, temperature and velocity of winds, the higher the rate and amount of evaporation, the higher the content of atmospheric vapour because dry air with high temperature is capable of retaining more vapour as dry air requires more time and moisture to become saturated. A stable air becomes saturated soon because there is no transfer of moisture while unstable air attains saturation quite late because there is much transfer of moisture. There is more evaporation from oceanic surfaces than from land surfaces. There is maximum evaporation from the lands between 10°Nand 10°S latitudes whereas maximum evaporation occurs from the oceans between 10°-20° latitudes in both the hemispheres.

The process of conversion of vapour into liquid (water) and solid form (ice, snow, frost) is called **condensation**. It is apparent that evaporation and condensation are opposite processes. Presence of water vapour in the atmosphere is climatologically significant.

This part of the module highlights the above issues.

■ 3.2.20 CHANGE OF STATE AND LATENT HEAT

Water is very important substance not only from the climatological point of view but also for the biosphere because (i) it is able to dissolve almost all substances, (ii) it has great ability to store heat, it takes part in the nourishment of organisms, (iv) it helps in the circulation of elements in the biosphere etc. Water has a number of unique and unusual attributes that enable it to play such important roles in the climate of the Earth.

Specific heat
Water has a high specific heat, the highest among liquids except ammonia Specific heat is the amount of energy needed to change the temperature of the substance. As a result of this high specific heat, a large amount of heat is involved when water changes temperature. Thus, water has a high latent heat. Specific heat of water has a tremendous impact in moderating Earth temperatures from day to night, from season to season and from Equator to Poles.

- **Surface tension**

Water has the highest surface tension among liquids except mercury. Surface tension is the attraction of molecules towards each other. This affinity manifests itself in many ways, such as, the formation of water droplets, dew, fog, raindrops and waves. Surface tension causes the formation of large waves in water.

- **Conductivity**

Water conducts heat more readily than any other liquid except mercury. It is through conduction and convection that uniformity of temperature is attained in water bodies.

- **Density differential**

Water changes density. It is less dense as solid (ice) than as liquid (water). Ice at 0°C has a density of 0.917 g cm^{-3} while water at that temperature has a density of 0.999 g cm3. Water has maximum density at 4°C (strictly 3.98°C). It expands at temperatures both above and below this point. When it freezes it expands rapidly adding 9 per cent by Volume. A fresh water body cools very slowly below 4°C. This property allows ice to float on water.

The water undergoes phase changes through the exchange or transfer of heat energy as follows:

(1) Liquid phase to gaseous phase requires absorption of 540-607 cal/g heat in the form of **latent heat of vaporization.**

(2) Solid (ice) phase to liquid phase (water) requires 79-80 cal/gram heat in the form of **latent heat of fusion.**

(3) Solid (ice) phase to gaseous phase (water vapour) requires the absorption of 680 cal/gram in the form of **latent** heat of **sublimation.**

(4) Gaseous phase (water vapour) to liquid phase (water) releases 540-607 cal/gram heat in the form of **latent heat of condensation.**

(5) Liquid phase (water) to solid phase (ice) releases 79-80 cal/gram heat in the form of **latent heat effusion.**

(6) Gaseous phase (water vapour) to solid phase (ice) releases 680 cal/gram heat in the form of **latent heat of sublimation**.

First three phases (1 to 3) absorb heat while the latter three phases (4 to 6) release heat. The latent heat/energy is further elaborated in the following section.

It is evident that the amount of heat spent during the process of evaporation is never lost; rather it is always associated with water vapour. On the other hand, heat energy is released at the time of condensation (conversion of vapour into liquid-water or solid form-ice). This energy, released after condensation, is called latent heat of condensation. When the heat energy is absorbed in conversion process, it is called latent energy (latent heat) and when the conversion phase is reversed, the latent energy is released and goes back to the atmosphere. The release of heat (latent) energy is climatically very important because it provides energy to form thunderstorms, tornadoes, and hurricanes. It also plays a critical role in the redistribution of heat energy over the earth's surface.

■ 3.2.21 MOISTURE HOLDING CAPACITY OF AIR: SATURATION, UNSATURATION AND SUPERSATURATION

The moisture content in the atmospheric air is measured in grain per cubic foot or in gram per cubic centimeter volume of air or in gram per kilogram of air at given temperature. The moisture retaining (holding) capacity or humidity capacity refers to the capacity of a parcel of air of certain volume at certain temperature at any point of time to retain or hold maximum amount of moisture content. Evaporation is the main mechanism through which water and ice are converted into water vapour (humidity). Since temperature and evaporation are directly positively related *(i.e.* evaporation increases with increasing temperature) and hence atmospheric humidity is also positively related to temperature *i.e.* higher the air temperature, higher the moisture holding capacity of the air and lower the temperature, lesser the moisture holding capacity. For example, the humidity capacity of an air having the volume of one cubic foot and temperature of 30°F is 1.9 grain whereas it becomes 2.9 grain when temperature becomes 40°F (an increase of 10°F). The ratio of increase of humidity capacity also increases with increasing temperature. For example, the net increase of humidity capacity from 30°F to 40°Fis one grain while it become 5 grain from 90°F to 100°F. Similarly, humidity capacity becomes higher during summer months than during winter months and during daytime than nights. The extents of land and water and wind velocity also influence humidity capacity. Oceanic and coastal areas record higher humidity capacity of air than the remote areas of the continents. Humidity capacity decreases from equator to poleward. The air having moisture content equal to its humidity capacity is called **saturated air.**

The difference between the moisture retaining capacity (humidity capacity) and actual humidity (absolute humidity) of a given volume of an air at given temperature and time is called **saturation**

deficit. For example, the saturation deficit of an air of one kilogram at 15°C temperature is 3 gram/kg as its absolute humidity is 4 grams against its humidity capacity of 7 grams. The temperature at which the given air is saturated *i. e.* the humidity capacity and absolute humidity become equal, is called **dew point.** It may be mentioned that the temperature of ascending air decreases (at the adiabatic rate of 10°C per 1000 meters) i.e. the ascending air cools aloft and hence its dew point also decreases with increasing altitude at the rate of 2°C per 1000 meters.

When an air parcel contains moisture less than its capacity, the air is called **unsaturated.** In this situation the partial pressure exerted by water vapour (vapour pressure) will be lower than that under saturated condition. Under some special conditions, an air parcel may contain moisture more than its capacity to hold. The air is, then, called **supersaturated.**

■ 3.2.22 TYPES OF HUMIDITY MEASUREMENT

The content of moisture in the atmosphere is measured and expressed in a number of ways, namely vapour pressure, absolute humidity, specific humidity, relative humidity, mixing ratio etc. These are briefly described below:

1. Vapour Pressure

Vapour pressure is simply the pressure exerted by water vapour in a sample of air. It is that part of the total atmospheric pressure that is contributed by the water vapour content. In normal air pressure, each of the molecules of different components exerts some pressure, e.g., normal air at sea level is 1013 mb, nitrogen has partial pressure of 750 mb, oxygen 230 mb and water vapour from 5 to 30 mb. This pressure is due to the activity of the molecules of water and is proportional to the number of molecules present in the atmosphere. When evaporation takes place, this vapour pressure decreases. When this pressure just balances that within the liquid, driving the molecules away from the water surface, and the vapour pressure at which this occurs is called the **saturation vapour pressure.** Its value increases as the temperature increases.

Water Vapour Pressure (e)

$$e = \frac{W}{W+E} \times P$$

The partial pressure of water vapour

where, W = Mixing ratio,

E = a constant (0.622),

P = air pressure

units : g, millibar.

Saturation Vapour Pressure (es)

It is the pressure exerted by water vapour when the air is saturated with respect to water, it is supersaturated with respect to ice.

2. Absolute Humidity

The total weight of moisture content (water vapour) per volume of air at definite temperature is called absolute humidity. Generally, absolute humidity does not change with increase or decrease of

temperature, if no additional vapour is added through additional evaporation, but it changes with contraction (after descent) or expansion (on ascent) of air. The absolute humidity decreases from equator towards the poles and from oceans to the continents. The possibility of precipitation largely depends on absolute humidity. In a simple term absolute humidity may be defined as a mass or weight of water vapour per unit volume of air at a given temperature. This is generally expressed in gram per cubic meter volume of air. It appears that vapour pressure and absolute humidity are more or less same measures of humidity.

Absolute humidity (PW)

$$Pw = \frac{P}{PT}$$

Mass or weight of water vapour per unit volume of air

where, P = *air pressure,*

R = gas constant for water vapour

T = temperature

Units : e.g.. g/m^3

3. Specific Humidity

Specific humidity is defined as the mass of water vapour in grams contained in a kilogram of moist air and it represents the actual quantity of moisture present in a definite moist air. In fact, specific humidity is a ratio of water vapour to the weight of moist air. Specific humidity is seldom affected by changes in air pressure or air temperature because it is measured in the units of weight (grams). It is directly proportional to vapour pressure, and inversely proportional to air pressure. Specific humidity decreases from equator poleward. For example, extremely cold and dry air over arctic region during winter generally has specific humidity of 0.2 gram per kilogram of air while it becomes as high as 18 grams per kilogram of extremely warm and moist air over equatorial regions. 'In a real sense, specific humidity is a geographer's yardstick of basic natural resource- water- to be applied from equatorial to polar regions. It is a measure of the quantity of water that can be extracted from the atmosphere as precipitation. Specific humidity is a more constant property of air and therefore, it is more frequently used in climatology

Specific humidity (q)

$$q = \frac{M_v}{(M_v + M_a)}$$

The proportion by mass of water vapour in moist air

where, M_v = Water vapour mass,

M_a = Mass of moistair

units : e.g., g/kg

4. Relative Humidity

Relative humidity is defined as a ratio of the amount of water vapour actually present in the air having definite volume and temperature (i.e. absolute humidity) to the maximum amount the air can hold (i. e. humidity capacity). In other words, relative humidity is the proportion of absolute humidity of an air of definite volume at a given temperature to the humidity capacity of that air. Relative humidity is generally expressed as percentage. There is inverse relationship between air temperature and relative humidity *i.e.,* relative humidity decreases with increasing temperature while it increases with decreasing temperature.

When the humidity capacity (saturation vapour pressure) and absolute humidity (vapour pressure) of the air are the same, the air is said to be saturated and the relative humidity becomes 100 per cent. Relative humidity changes in two ways viz., (i) if the absolute humidity increases due to additional evaporation or (ii) if the temperature of the air decreases so that humidity capacity also decreases. For example, the relative humidity of the air with 50°F temperature is 46% because humidity capacity and absolute humidity are 4.1 grins and 1.9 grains respectively but if the temperature of that air decreases due to ascent to 40°F, the relative humidity becomes 65.5% because the humidity capacity decreases to 2.9 grains per cubic foot.

• **Importance of Relative Humidity**—Relative humidity has a great climatic significance because the possibility of precipitation depends on it. High and low relative humidity is indicative of the possibility of wet (precipitation) and dry conditions respectively. The amount of evaporation also depends on relative humidity. Evaporation decreases with high relative humidity while it increases with low relative humidity. Relative humidity is directly related to human health and comfort. Very high (above 60%) and very low humidity is injurious to human health. This is why the equatorial regions with high temperature and high relative humidity and tropical hot deserts with very low relative humidity are unfavourable for human health. Relative humidity also affects the stability of different objects, buildings, electrical appliances, radio etc.

• **Distribution of Relative Humidity**— The horizontal distribution of relative humidity on the earth's surface is zonal in character. Equatorial regions are characterized by highest relative humidity. It gradually decreases towards subtropical high pressure belts where it becomes least (between 25°-35° latitudes). It further increases poleward. The zones of high and low relative humidity shift northward and southward with northward and southward migration of the sun respectively. Seasonal distribution of relative humidity is largely controlled by latitudes. Maximum relative humidity is found during summer season between 30°N and 30°S latitudes while high latitudes record relative humidity more than average value during winters. There is maximum relative humidity in the morning whereas lowest value is recorded in the evening.

Relative humidity is usually expressed as percentage and can be calculated approximately from either the vapour pressure or the mixing ratio. It is most useful in everyday life referring to humidity, but it cannot be used for direct comparison between air masses.

Rel: tive humidity (RH)

Ratio of actual amount of water vapour in the air to the maximum amount the air could hold at that temperature

$$RH = \left[\frac{e_a}{e_s} \times 100\right]\%$$

Where, e = *Vapour pressure,*

es = saturation vapour pressure

6. Mixing Ratio

The ratio of weight (mass) of water vapour to the weight of per unit volume of dry air is called mixing ratio because it specifies how much water vapour is mixed with other gases in the air. The concentration of maximum amount of water vapour in a dry air of certain volume and mass (weight) is called **saturation mixing ratio.** There is direct positive relationship between air temperature and mixing

ratio *i. e.* if air temperature increases the mixing ratio also increases and vice versa. This is why cold air mass has low mixing ratio while warm air mass carries high mixing ratio. Mixing ratio is expressed in gram per kilogram weight of dry air (g/kg). If we look into the definitions of specific **humidity** and mixing ratio, there is very little difference between these two measures of humidity. This difference is only in terms of dry or moist air. In other words, the **specific humidity** is defined as a ratio of weight of water vapour to the weight of unit moist air, while mixing ratio represents the ratio of weight of water vapour to the weight of unit dry air.

Mixing Ratio (W) :

$$W = \frac{Mv}{Md}$$

Ratio of mass of water vapour to a unit mass of dry air

where, Mv = water vapour mass,

Md = mass of dry air

Units : e.g., g/kg.

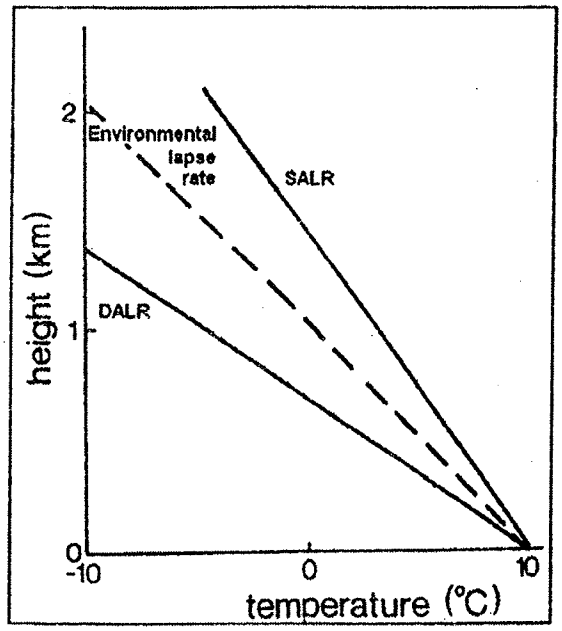
■ 3.2.23 ADIABATIC TEMPERATURE CHANGES

It is necessary at this point to consider the very important changes in the temperature of air which occurs as it is moved upward away from the earth or downward toward the earth. As air moves upward away from the earth, it comes under lower pressures, for there is less weight of air upon it, and consequently it expands. Conversely as air moves downward toward the earth from higher elevations it encounters higher pressures and contracts in volume. Thus if a mass of dry air at sea level, under an atmospheric pressure of approximately 1,016 mb., or 30 in., rises to an altitude of 17,500 ft., the pressure on it is reduced about one-half and consequently its volume is doubled. A cubic foot of air at sea level would then, if carried to that altitude, occupy 2 cu. ft. Through these expansion and contraction processes associated with changes in elevation the temperature of the moving air changes even though there is no actual addition or withdrawal of heat. This type of temperature change resulting from internal processes is called *adiabatic* change.

According to the molecular theory a gas such as air is composed of molecules which are in a state of constant motion, so that there are persistent collisions between individual molecules. The impact of the colliding gas molecules produces the pressure of the gas. The pressure, therefore, depends upon the number and mass of the molecules and the speed at which they are moving, which in turn is determined by temperature. If the temperature is high, the molecular velocity is greater and the number of collisions more frequent. Therefore, the gas pressure is greater at high temperatures than at low temperatures. Some of these principles indicating the relationship between pressure, temperature, and volume (hence also density) in gases may be expressed in the form of physical laws as follows:

- In a gas kept at constant temperature the volume is inversely proportional to the pressure. If pressure on the gas is doubled; its volume is reduced one-half.
- In a gas kept at constant pressure, volume varies directly with the absolute temperature

Therefore, as the temperature of a gas increases, its volume also increases, and as its temperature is lowered, its volume is decreased, In making use of the above gas laws, it becomes clear that a mass of air which is lifted will experience a decreased pressure upon it, so that its volume is increased. In addition, work is done by the expanding air in making room for itself and this work done in pushing aside the surrounding air requires energy which results in a lowering of the temperature of the rising air. Since the volume of the expanding air has been increased, the collision of the molecules is less frequent and temperature consequently falls; conversely when air descends, its volume is decreased by the greater air pressure and its temperature and density are increased.



Dry Adiabatic Lapse Rate **(DALR)**

The rate of adiabatic heating and cooling of dry or non-saturated air masses through vertical movement is constant, no matter what the temperature of the air. It is approximately 5.54°F. per 1,000 ft. change in altitude or 10°C. per 1,000 meters. This is known as the dry adiabatic lapse rate, for it applies only to air which is not saturated. The rate of cooling of ascending air, therefore, is considerably more rapid than is the normal vertical decrease in temperature (lapse rate) which is about 3.3°F. per 1,000 ft. or 6.4°C. per 1,000 meters (**Environmental lapse rate**). These two rates should be clearly distinguished as being very different things, for one represents the cooling of a rising and therefore vertically moving air mass, while the other applies to the change in air temperature that would be recorded by a thermometer carried up through the atmosphere.

- ***The Moist or Retarded or Saturated Adiabatic Lapse Rate*** **(SALR)**

As indicated previously, the adiabatic rate of cooling for unsaturated air is the same, no matter what the temperature. For this reason the three dry adiabats are all parallel. But as the unsaturated air continues to rise and cool, it is likely to reach a temperature at which condensation begins. This is called the condensation level. It will be noted that the condensation levels for the rising air masses, each of a different temperature, are not the same. This results from likely differences in relative humidity. Thus the cooler air, which normally would have the highest relative humidity, reaches condensation level first or at the lowest elevation. The warmest air, which has the lowest relative humidity, has to rise higher and reach a lower temperature before the saturation point is reached and condensation begins.

After the rising air reaches the condensation level, where clouds begin to form, the then saturated air as it continues to rise cools no longer at the previous dry adiabatic rate, but at one which is somewhat slower. This is called the *retarded* or *wet adiabatic lapse* rate. Above condensation level where water vapor is being converted into clouds composed of liquid and ice particles, heat of condensation is released into the atmosphere. It is this added source of energy which slows up the rate of cooling in the rising air. Two counteracting processes, one resulting in cooling and the other in heating are proceeding simultaneously, for while the saturated air continues to cool by expansion, the heat liberated as a result of condensation acts as a brake on the cooling process. Of the two processes, the cooling due to expansion is the primary one, with the result that the rising saturated air continues to cool but at a slower rate.

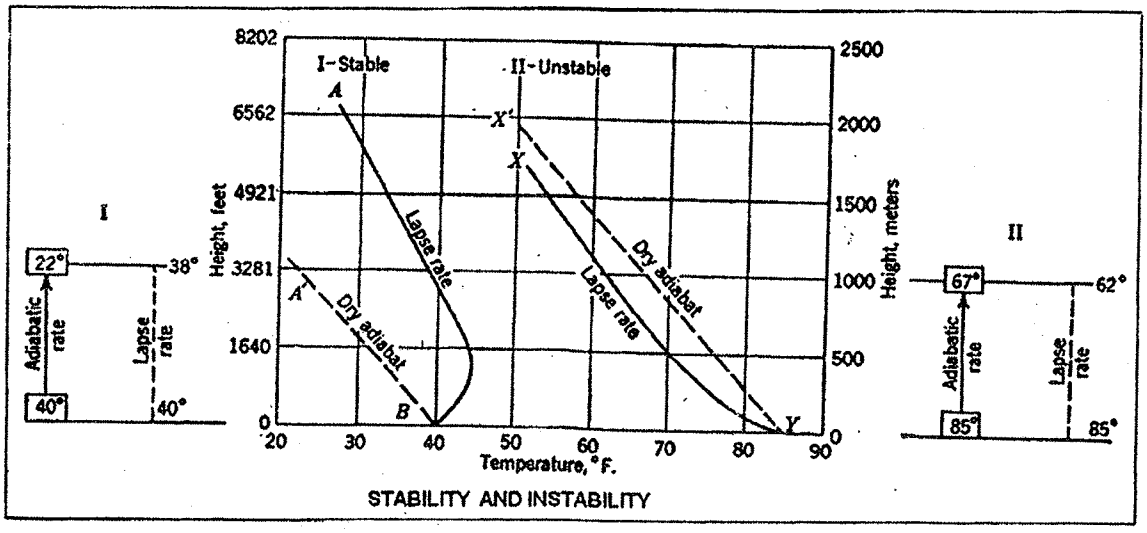
The retarded, or wet adiabatic, rate is not constant, but varies with the temperature of the air. The same amount of cooling will result in the condensation of a greater amount of moisture when air temperature is high because the specific humidity of warm air is higher than that of cool air. As a result,

the amount of liberated heat of condensation is much greater at high temperatures and as a consequence the wet adiabatic lapse rate is smaller in 90°F air than in 30°F air. When air temperatures are extremely low, the moisture content is so low that the wet adiabatic lapse rate is almost the same as the dry adiabatic rate. At high temperatures the wet adiabatic rate may be in the neighborhood of one-half the dry adiabatic rate, or about 3° F per 1,000 ft.

■ 3.2.24 STABILITY AND INSTABILITY IN THE ATMOSPHERE

Vertical movements in an air mass are of great significance because nearly all precipitation is associated with adiabatic cooling and condensation in rising air. The external causes of lifting that leads to cloud formation have been discussed earlier. Let us now examine the conditions within large bodies of air that affect the buoyancy of smaller portions and their tendency to exhibit vertical motion. If a parcel of air tends to remain in its position, or to return to that position when displaced by an outside force, the larger air mass is said to be ***stable.*** If vertical displacement results in a tendency to further movement, the air mass is termed ***unstable.*** If conditions are such that a parcel neither resists nor aids vertical motion, the ***air mass is in a state of neutral equilibrium.*** In each of these cases it is assumed that the air of the parcel does not mix with its surroundings and that there are no compensating motions in the parent air mass.

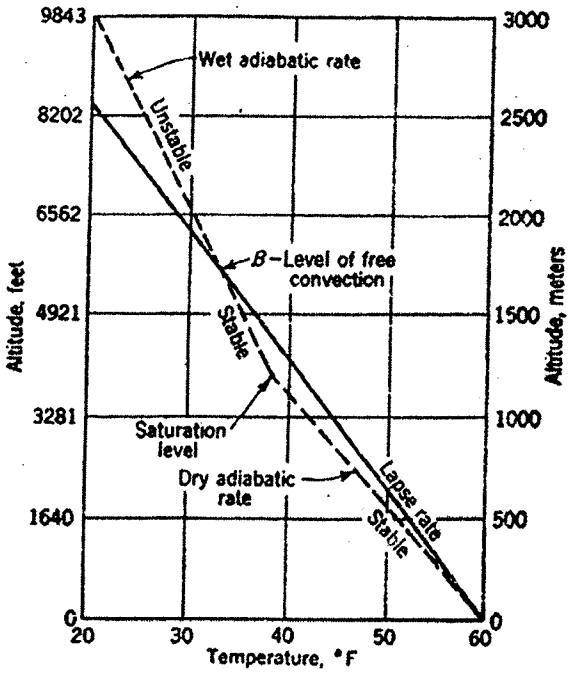
Air is said to be stable, and consequently antagonistic to precipitation, if it resists vertical displacement, or if, following forced vertical displacement, it tends to return to its former position. A rocking chair at rest is in stable equilibrium, for, if it is rocked slightly, it immediately returns to its original position. Vertical motions are largely absent in stable air. On the other hand, if displacement results in a tendency to further movement away from the original position, a condition of instability prevails. Under such conditions vertical movement is prevalent. A cone balanced upon its apex is in unstable equilibrium, for the slightest impulse would cause it to move farther away from its original position. Whether an air mass is stable or unstable depends upon a comparison of its lapse rate with the adiabatic rate. When the lapse rate exceeds the dry adiabatic (5°F. per 1,000 ft.), as it may possibly do on a bright, hot afternoon, the surface air is unstable and inclined to rise. But when, for example, over a cold middle-latitude continent in winter, the lapse rate is less than the adiabatic, the air is stable, and it resists displacement and tends to remain in its original position. Note that it is the lapse rate which is the variable. The dry adiabatic rate is the same at all times and under all conditions.. In Fig, the solid lines *AB* and *XY* represent conditions of stability and instability, respectively. The dashed lines *X'Y* and *A'B* indicate the dry adiabatic rate, which, of course, is the same for unsaturated air, no matter what the temperature. These latter lines are therefore parallel.



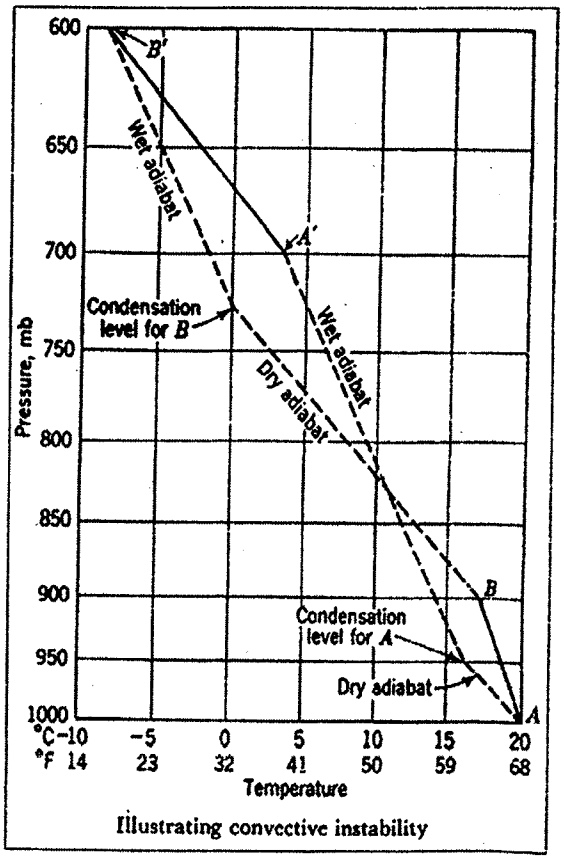
STABILITY AND INSTABILITY

• ***Instability***

If a particle of air from point *Y* with a temperature of 85° is caused to rise, its rate of cooling will be represented by the line *X'Y*. At any point along this line it will be warmer and therefore less dense than the surrounding air represented by *XY*, and it will therefore continue to rise freely of its own accord after an initial upward impetus has been given it. The condition when the lapse rate throughout is greater than the dry adiabatic rate of 5.5°F per 1,000 ft. illustrates what is known as ***absolute instability***. Moderately unstable air will not begin to rise voluntarily, but, if an updraft is once started, or "triggered off," by intense surface heating by the sun or by upward deflection by a mountain slope or a cold air mass, the ascent will continue of its own accord because of the buoyancy forces involved. When the lapse rate exceeds 19°F per 1,000 ft., the upper air is actually denser than that underneath, and automatic overturning occurs without any initial forced displacement. This condition, known as ***mechanical instability***, is of rare occurrence in nature. It may play a part in violent line squalls or tornado weather.



• ***Conditional Instability***- It has been pointed out in the previous discussion that a lapse rate greater than 5.5°F per 1,000 ft. represents *instability*, while a lapse rate of less than about 2.5°F indicates absolute *stability*. If an air layer has an actual lapse rate between the dry adiabatic (5.5°F. per 1,000 ft.) and the wet adiabatic (2.5°F. per 1,000 ft.) rates of cooling, its instability is conditional upon the relative humidity of the air at all levels. The rising air particle while still unsaturated follows the dry adiabatic rate of cooling. The lapse rate is less than the dry adiabatic rate, so that during this phase the rising air is cooler than its surroundings. It is, therefore, stable and resists lifting, and any rising is the result of forced ascent. But, when the rising air reaches condensation level and latent heat is added, any further cooling takes place at the retarded, or wet adiabatic, rate, which is less than the lapse rate. As a result of the lapse rate being greater than the wet adiabatic rate, from point *B* upward the rising air is warmer than the surrounding air and consequently is unstable so that it rises f/eely of its o' n accord.



Illustrating convective instability

• ***Connective Instability***

It frequently happens that the lower layers of an air mass have a much higher relative humidity than those aloft. When lifting takes place in an air mass in which relative humidity decreases rapidly with elevation, the lower part reaches condensation level first, and as a result of added heat of condensation it cools much more slowly than the upper layers,

which are following the dry rather than the wet adiabatic rate. A greatly steepened lapse rate within the air mass follows; so much so that it becomes unstable. Such an air mass is said to be *convectively unstable.* In Fig. 3.14 the air mass lying between the 1,000- and 900-mb. levels has a lapse rate as indicated by line *AB.* Because the air at *A* has a higher relative humidity than that at *B,* after ascent begins it reaches condensation level sooner than *B* and therefore cools at a retarded rate. If the air mass with lapse rate *AB* is lifted so that its pressure is reduced 300 mb., *A* will have cooled to *A'* and *B* to *B'. A'B',* which represents the new lapse rate of the ascending air layer, is considerably steeper than the old lapse rate *AB* and represents a condition of greater instability.

The importance of convective instability lies in the fact that even masses of air that were originally stable may be converted into convectively unstable air masses, provided there are marked vertical contrasts in water-vapor content, through a forced vertical motion of the air mass as a whole. Such forced vertical displacement of extensive air masses takes place along the windward sides of mountain ranges, and also along frontal surfaces in cyclonic storms where cold and stable air masses act as the obstacle to produce forced ascent. Widespread and abundant rainfall is commonly associated with the vertical displacement of convectively unstable air masses.

• ***Stability***

When an air layer has a lapse rate that is less than the dry adiabatic, say 3-2°F per 1,000 ft—a *stable* condition is present, and there is opposition to vertical movement. If an air particle from point *B,* temperature 40°, is forced to ascend, at any point along dry adiabat *A'B* it will be cooler than the surrounding air whose vertical temperature structure is represented by line *AB,* and consequently it will tend to sink back to its former position. It would never have risen except under compulsion. If the lapse rate is less than about 2.5°F per 1,000 ft. the air is said to be *absolutely stable.* This air resists vertical displacement even when condensation takes place. A common instance of absolute stability is the temperature inversion. An inversion is so stable that it acts as an aerial "lid" to halt ordinary rising currents. Rising columns of smoke or growing clouds are forced to spread out horizontally beneath the base of the inversion.

• **Adiabatic Cooling and Precipitation**

Air which because of its instability and buoyancy rises voluntarily, will continue to rise until it reaches air layers having its own temperature and density. *This process of cooling, by the expansion associated with rising air, is the only one capable of reducing the temperature of extensive and thick masses of air below the dew point.* It is the only one, therefore, which is capable of producing condensation on such a large scale that abundant precipitation results. There is no doubt that nearly all the earth's precipitation is the result of expansion and cooling in rising air currents. The direct result of cooling due to ascent is *clouds,* a form of condensation characteristic of air at altitudes usually well above the earth's surface, just as dew, white frost, and fog are forms characteristic of the surface air. Fog and cloud are identical except for differences in height above the ground. Not all clouds, to be sure, give rise to precipitation, but all precipitation has its origin in clouds and is the result of processes that are additional to those causing condensation.

■ 3.2.25 SUMMARY

Atmospheric moisture is the most important ingredient that makes most of the weather phenomena to happen. The conditions of atmospheric stability and instability control day to day weather conditions in terms of dry or moist weather. Atmospheric stability (equilibrium) and instability (non-equilibrium) conditions may be achieved by various processes under different conditions. Atmospheric stability disfavours vertical movement in

the air and hence resists saturation of air and condensation rather causes dry weather. On the other hand, instability of the atmosphere causes wet weather.

The stability of the atmosphere is caused mainly by inversion of temperature conditions. The stability of the atmosphere stops vertical movement of air and hence does not allow mixing of air and moisture. In the absence of vertical movement of air i.e. no ascent, the air is not saturated and hence condensation does not occur and there is no cloud formation. On the other hand, atmospheric instability favours vertical movement of air which is cooled on expansion and ascent and is ultimately supersaturated resulting into condensation and cloud formation. The clouds so formed are thick and cumulonimbus which yield heavy downpour. It is apparent that the formation of cumulonimbus clouds and heavy showers there from are indicators of atmospheric instability.

3.2.26 SELF-ASSESSMENT QUESTIONS

1. What is the earth's global energy balance? Mention the role of cloud in scattering and absorption of incoming solar radiation.
2. What is 'insolation'? What are the factors controlling the amount of insolation received at a place on earth's surface?
3. What are the different processes of heat transfer within the earth-atmospheric system? Explain the spatial pattern of temperature distribution on the earth's surface and its seasonal variation.
4. What do you mean by 'inversion of temperature'? Mention the conditions under which different types of temperature inversion occur.
5. Bring out the energy cascade through the earth-atmospheric system.
6. Describe the nature of radiation received from the sun? Elaborate the physical principles that govern blackbody radiations.
7. How does the atmosphere interact with the incoming solar radiation?
8. How is the balance in inflow and outflow of solar radiation achieved in the earth-atmospheric system?
9. Explain the factors which control the horizontal distribution of temperature over the earth's surface.
10. What are the different measures to express the moisture content of the air? Explain them briefly.
11. What are the different types of atmospheric instability? Explain their modes of occurrence along with the favourable conditions in which they develop.

3.2.27 REFERENCES

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M.A./M.Sc. PART – I

Paper - II : Module - III

Unit – 03

Module Structure

- 3.3.1 Introduction
- 3.3.2 Objectives
- 3.3.3 Factors influencing air motion
  - 3.3.3.1 Divergence, Convergence and Vorticity
  - 3.3.3.2 Global Scale Atmospheric Circulation
  - 3.3.3.3 Surface Winds
- 3.3.4 Agro-meteorological terms : methods and measurements
- 3.3.5 Mechanism of precipitation
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- 3.3.7 Self Assessment Questions
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M.A./M.Sc. Part - I

PAPER - II, MODULE - III

Unit – 03

Climatology

1. Factors influencing air motion; Surface and upper air circulations-thermal wind and jet streams
2. Agro-meteorological terms- Methods & measurements
3. Mechanism of precipitation.

■ 3.3.1 INTRUDUCTION:

Earth's atmosphere is in perpetual motion: movement which is striving to eradicate the differences in temperature and pressure between different pars of the globe. It is this motion that produces the winds and storms with which we are familiar. This circulation plays basic role in maintaining a steady state in the atmosphere and generating the climate zones which is in turn, the basic characteristics of the Earth. The *general circulation of the atmosphere* refers to the large-scale air flow pattern of the whole globe. In addition to producing the wind and thus controlling horizontal motions such as cloud movement, the general circulation serves to redistribute energy and moisture, modifying their latitudinal imbalances and thus establishing the climate. The basic description of this circulation comes mainly from the numerous surface-based observations that have accumulated over the years. Our knowledge of the processes operating is rapidly expanding as the result of satellite observations which encompass the globe.

The general circulation can be divided into two components: the *primary circulation* features; the persistent large-scale features which cover large areas of the globe, which, though vary at small scale perspectives, but exist at all times; and the *secondary circulation* features, the short-lived, rapidly moving cyclones (depressions) and the much slower moving anticyclones which are superimposed on the former and are responsible for day to day weather changes over large portions of the Earth. This is to be borne in mind that, in the oceans there is also a somewhat similar 'general circulation' which assists the atmosphere in the redistribution of energy and moisture.

Any treatment of winds as a background for explanatory climatology must absorb not only the surface winds of the earth but in addition the major circulation patterns of the free atmosphere. The surface winds, affected as they are by surface friction, may depart markedly in direction, speed, humidity characteristics, and vertical movement from those aloft. Surface winds have a velocity which ordinarily is much less than those of the winds aloft, where friction is greatly reduced. In addition the frictional effects tend to cause the surface air currents to cross the isobars at fairly large angles, especially over the continents, so that wind direction at the surface may depart markedly from that aloft. Also, surface irregularities of the lands greatly modify the direction and speed of winds in the lower atmosphere. The air flow aloft, on the other hand, where the frictional effects are small, tends to approach the geostrophic wind, i.e., it closely parallels the isobars, usually departing only 1° to 3° from them. This means that the circulation of the free atmosphere is predominantly zonal and only to a slight extent meridional.

■ 3.3.2 OBJECTIVES:

The basic objectives of this module are to analyze the atmospheric circulations as controlled by the pressure gradient force, which act as the driving force of atmospheric motion, along with the impacts of earth's rotation, acting through the coriolis force. It also deals with the modifications of the winds due to friction and centripetal acceleration. The study of the atmospheric circulation is vital for number of reasons. Many of the world's climates are dependent upon the characteristics of atmospheric circulation. Seasonal and daily variations in the circulation affect our lives directly, and extreme events have dramatic impacts on humanity.

Climatically speaking, surface air movement is chiefly important in terms of its effects upon surface air temperature as caused by advective processes. On the other hand, surface air movement may be of less assistance in understanding precipitation characteristics, for only thick air masses are capable of yielding large amounts of precipitation. Hence, it is principally in the winds in the free atmosphere that explanations of precipitation characteristics are to be sought.

Moreover, weather events also cause damages or losses to life. Floods, gales, blizzards, tornadoes, hurricanes etc creates economic stresses. But at the same time atmospheric circulations and the resultant climate and weather phenomena influence agricultural practices by determining the sowing, ploughing or harvesting seasons of the agricultural crops. Proper understanding of the general circulation pattern of the atmosphere also forms the key to long-term and short-term weather predictions.

■ 3.3.3 FACTORS INFLUENCING AIR MOTION

In accordance with the Newton's First law of motion, the atmosphere will remain in a state of rest of uniform motion unless a horizontal force is applied to it. The nature of the motion that ensues when such forces are applied is related very closely to their magnitude and direction of operation. AS the atmosphere is rarely in a state of rest, hence, it is subjected to number of forces. These forces are particularly important for movement in the atmosphere because forces are continuously acting on particles of air, causing them to accelerate or decelerate and change their direction. Principal of such forces are-

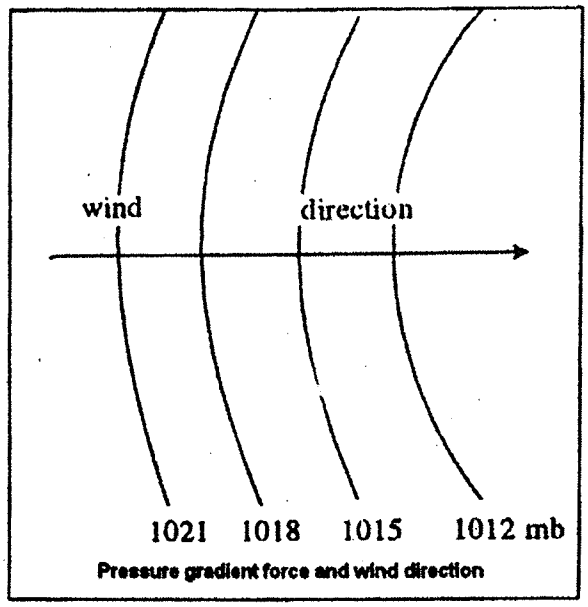
i) Pressure gradient force
ii) Coriolis force
iii) Centrifugal force &
iv) Frictional force.

i) Pressure Gradient Force: A difference in atmospheric pressure between two points on the same horizontal plane implies that a greater force is being exerted on one point that the other. In order to compensate this imbalance, air is accelerated from the higher to the lower pressure, in accordance with the Newton's Second Law of Motion. The same law states that this acceleration is proportional to the magnitude of the force. In this case the magnitude of the force is expressed in terms of the difference in pressure between the two points, or more precisely, in terms of the pressure gradient between them.

The pressure gradient force operates from high to low pressure at right-angles to the isobars and given by-

$$F_P = -\frac{1}{\rho}\frac{dP}{dx}$$

Where, F_P = pressure gradient force, ρ = density of the atmosphere, dP/dx = rate of change of pressure (P) over distance (x). Hence the closer the isobar spacing the more intense is the pressure gradient and the greater the wind speed. The pressure-gradient force is also inversely proportional to air density, and this relationship is of particular importance in understanding the behaviour of upper winds.



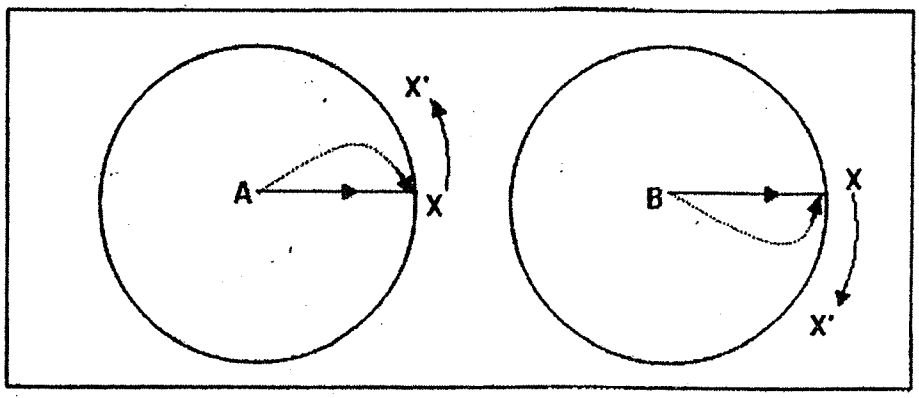
Pressure gradient force and wind direction

The pressure-gradient force has vertical and horizontal components but, as already noted, the vertical component is more or less in balance with the force of gravity. Horizontal differences in pressure can be due to thermal or mechanical causes (often not easily distinguishable), and these differences control the horizontal movement of an air mass. In effect the pressure gradient serves as the motivating force that causes the movement of air away from areas of high pressure and towards areas where it is lower, although other forces prevent air from moving directly across the isobars (lines of equal pressure).

If pressure gradient force was the only force in operation, air would flow directly from high to low pressure, and equalization of pressure differences would be extremely rapid. The fact that neither takes place indicates the existence of other forces operating upon the air, modifying the effects of the pressure gradient force.

ii) Coriolis Force: The earth is rotating at15° longitude per hour. Newton's law shows that if a parcel of air moving southwards and there is no force acting upon it, it will continue to move in the same absolute direction (i.e. in a straight line as viewed from space). However, as the Earth is gradually turning, relative to the ground surface, the parcel will appear to follow a curved path towards the right in the northern hemisphere and to the left in the southern hemisphere. To explain this apparent deflection in Newtonian terms, we have to introduce a force to account for the movement as observed from ground. This force is called Coriolis force, after the French mathematician who formalized the concept. Therefore, the Coriolis force arises from the fact that the movement of masses over the earth's surface is usually referred to a moving co-ordinate system (i.e. the latitude and longitude grid which rotates with the earth).

The simplest way to begin to visualize the manner in which this deflecting force operates is to picture a rotating disc on which moving objects are deflected.



The figure shows the effect of such a deflective force operating on a mass moving outward from the centre of a spinning disc. The body follows a straight path in relation to a fixed frame of reference (for instance, a box which contains a spinning disc), but viewed relative to coordinates rotating with the disc the body swings to the right of its initial line of motion. Similarly, if the North and the South poles are viewed the upper atmosphere, the earth would appear as a disc, rotating anticlockwise around the former and clockwise around the latter. Applying our observations from the disc, Coriolis deflection will be to the right around the North Pole and to the left around the South Pole. Coriolis force operates at right angles to the direction of motion. The deflective force (per unit mass) is expressed by:

$$F_C = -2 v \omega \sin\varphi$$

Where, F_C = Coriolis force per unit mass; v = Velocity at which the air is moving; ω = angular velocity of the Earth (7.29×10^{-5} radians s^{-1}) and φ = angle of latitude. Therefore, at the poles $\varphi = 90°$, so, $F_C = -2v\omega$, its maximum value. At the equator, $\varphi = 0°$ so, $F_C = 0$, its minimum value. The effect is thus a maximum at the poles (i.e. where the plane of the deflecting force is parallel with the earth's surface) and decreases with the sine of the latitude, becoming zero at the equator (i.e. where there is no component of the deflection in a plane parallel to the surface). The Coriolis force is directly proportional to the mass, the straight-line velocity, and the angular velocity of the earth. It is always the same, no matter what the horizontal direction of movement, and, since it is at right angles to the direction of motion of the particles of air, it influences the direction but never the velocity of the movement.

Geostrophic Wind: When air is set in motion by a pressure gradient, it is immediately acted upon by a number of forces that tend to deviate it from its initial path. One of these is the Coriolis force, or deflective force of earth rotation, and another is frictional force. If for the moment friction is omitted, then air flowing in a straight path over the earth is apparently deflected more and more to the right (Northern Hemisphere) of its original path until it blows exactly parallel with the isobars. Any further turning would make the wind blow from low to high pressure or up the gradient, and this is impossible. When air is blowing parallel to the isobars, it is called geostrophic winds. The Coriolis force is just balanced by the pressure gradient.

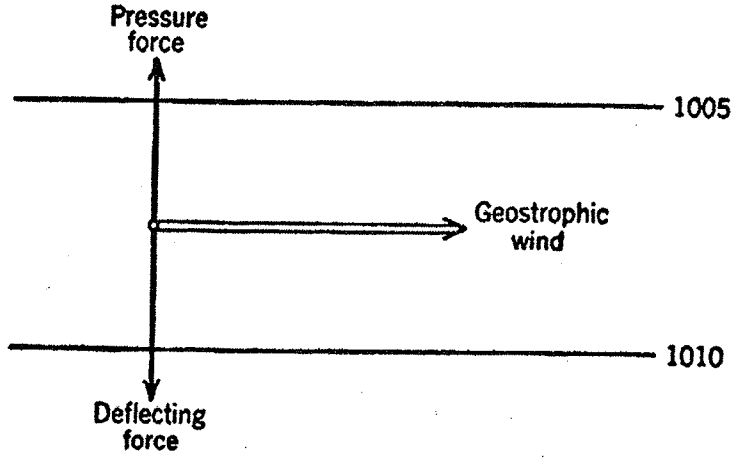
Hence,

$$2\omega v_g \sin\varphi = \frac{1}{\rho}\frac{dP}{dx}$$

Where, v_g = geostrophic wind velocity.

Then,

$$v_g = \frac{1}{\rho}\frac{dP}{dx}\frac{1}{2\omega\sin\varphi}$$



A geostrophic wind results when pressure gradient is balanced by deflective force. The geostrophic wind blows parallel with the isobars with high pressure to the right (Northern Hemisphere). Its velocity is inversely proportional to the distance between the isobars. Winds are essentially geostrophic in character above 1,000 meters elevation.

The velocity is thus inversely dependent on latitude, such that the same pressure gradient which will be associated with geostrophic wind speeds of 15 m s^{-1} {34 mph) at latitude 43° will produce a velocity of only 10 m s^{-1} (23 mph) at latitude 90°. Except in low latitudes, where the Coriolis deflection approaches zero, the geostrophic wind is a close approximation to the observed air motion in the free atmosphere. Since pressure systems are rarely stationary this fact implies that air motion must continually change towards a new balance. In other words mutual adjustments of the wind and pressure fields are constantly taking place.

iii) Centrifugal Force: When there is marked curvature in the isobars a third force, the centrifugal force, must be introduced. This acts outwards from the centre in any curved motion. It can readily be demonstrated by whirling a stone on a string. The tension felt in the arm during this activity is an expression of this force. In the case of rotation around a high pressure area this force is in the same direction as the pressure gradient force and hence leads to an increase in wind speed over that calculated for the geostrophic wind. Around a low pressure centre the centrifugal force opposes the pressure gradient force and decreases the wind speed. The wind that results from a balance of the three forces is known as the ***gradient wind***. The direction of this wind, like the geostrophic wind, is parallel to the isobars. The speed of the gradient wind differs significantly from that of the geostrophic wind only when there is severe curvature at very large pressure gradients. For instance, in the case of a tropical hurricane the calculated geostrophic flow might be 500 m s^{-1}, but the gradient wind speed is only 75 m s^{-1}.

This acceleration (c} is expressed by:

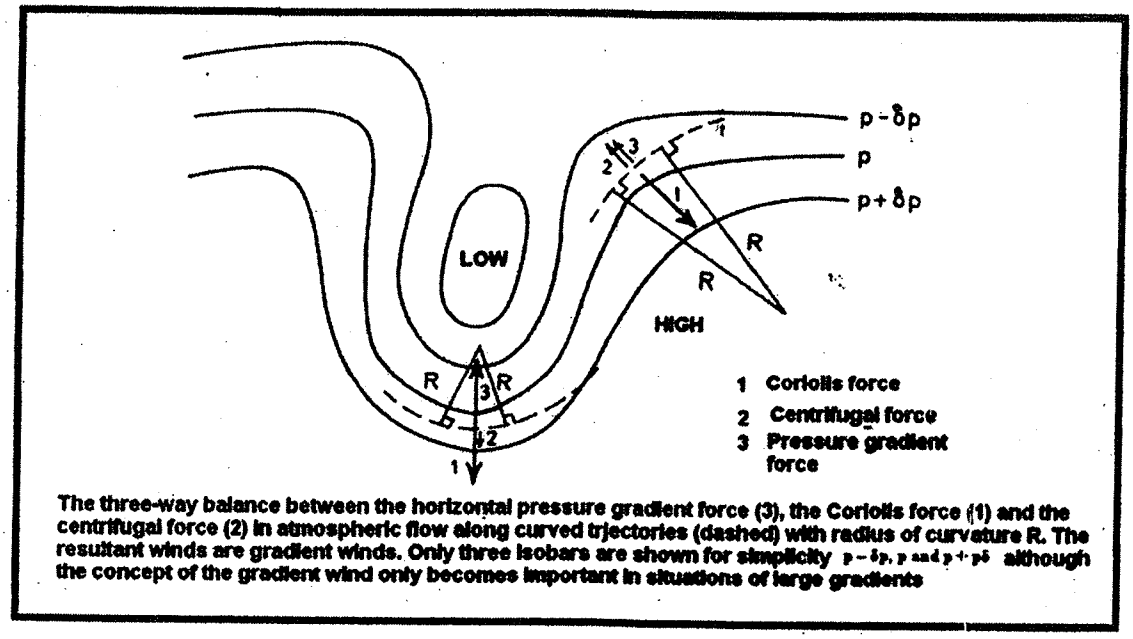
$$C = -\frac{mv^2}{r}$$

Where **m** = the moving mass, **v** = its velocity and **r** = the radius of curvature. This factor is sometimes regarded for convenience as a centrifugal force operating radially outward. In the case of the earth itself this is valid. The centrifugal effect due to rotation has in fact resulted in a slight bulging of the earth's mass in low latitudes and a flattening near the poles. The small decrease in apparent gravity towards the equator reflects the effect of the centrifugal force working against the gravitational attraction directed towards the earth's centre. It is only necessary therefore to consider the forces involved in the rotation of the air about a local axis of high or low pressure. Here the curved path of the air (parallel to the isobars) is maintained by an inward-acting or centripetal acceleration.

For the northern hemisphere that in a low-pressure system balanced flow is maintained in a curved path (gradient wind) by the Coriolis force being weaker than the pressure force. The difference between

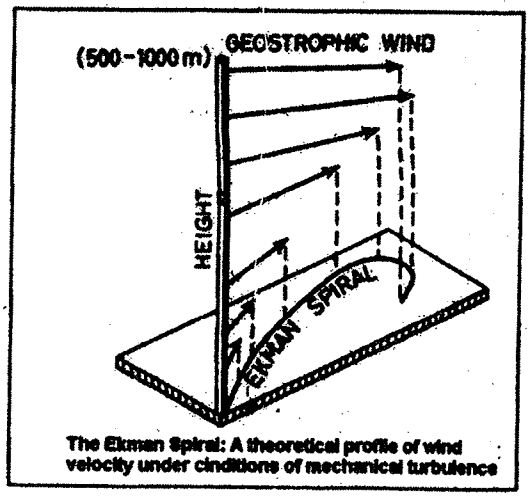
the two gives the net centripetal acceleration inward. In the high-pressure case the inward acceleration is provided by the Coriolis force exceeding the pressure force. Since the pressure gradients are assumed to be equal, the different contributions of the Coriolis force in each case imply that the wind speed around the low-pressure must be less than the geostrophic value (*subgeostropbic*), whereas in the high-pressure case it is *supergeostrophic*. In reality this effect is obscured by the fact that the pressure gradient in a high is usually much weaker than in a low. Moreover, the fact that the earth's rotation is cyclonic imposes a limit on the speed of anticyclonic flow. The maximum occurs when the angular velocity is $f/2 = \omega \sin \varphi$, at which value the absolute rotation of the air (viewed from space) is just cyclonic. Beyond this point anticyclonic flow breaks down ('dynamic instability'). There is no maximum speed in the case of cyclonic rotation.

The magnitude of the centripetal acceleration is generally small, but it becomes important where high-velocity winds are moving in much curved paths (i.e. about intense low-pressure system). Two cases are of meteorological significance: first, in intense cyclones near the equator where the Coriolis force is negligible; and, second in a narrow vortex such as a tornado. Under these conditions, when the large pressure gradient force provides the necessary centripetal acceleration for balanced flow parallel to the isobars, the motion is called cyclostrophic.



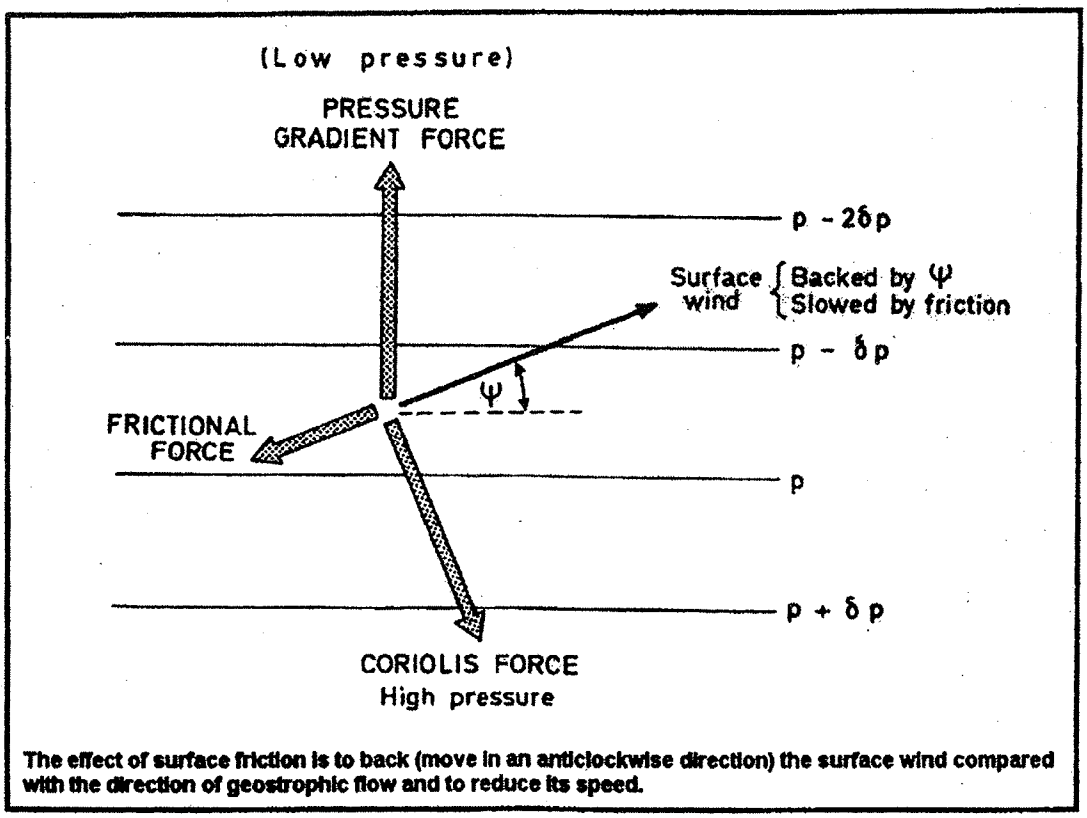
The three-way balance between the horizontal pressure gradient force (3), the Coriolis force (1) and the centrifugal force (2) in atmospheric flow along curved trjectories (dashed) with radius of curvature R. The resultant winds are gradient winds. Only three isobars are shown for simplicity $p - \delta p$, p and $p + p\delta$ although the concept of the gradient wind only becomes important in situations of large gradients

Latitudinal motion changes the Coriolis parameter and the movement or changing intensity of a pressure system leads to acceleration or deceleration of the air, causing some degree of cross-isobaric flow. Pressure change itself depends on air displacement through the breakdown of the balanced state. If air movement were purely geostrophic there would be no growth or decay of pressure systems. The acceleration of air, moving at upper levels, from a region of cyclonic isobaric curvature (subgeostrophic wind} to one of anticyclonic curvature (supergeostraphic wind), causes a fall of pressure at lower levels in the atmosphere through the removal of air aloft.



The Ekman Spiral: A theoretical profile of wind velocity under cinditions of mechanical turbulence

iv) Frictional Force: The last force which has an important effect on air movement is that due to friction with the earth's surface. The earth exerts a retarding effect on air motion across it, which due to the transfer of energy into the surface. Such frictional resistance reduces wind velocity in the lowest 1000 m of the atmosphere. The greatest reduction occurs in the air layer in immediate contact with the surface, where wind speed will tend towards zero. Away from the surface, frictional effects decrease and there is an approximately exponential increase in wind speed with height.



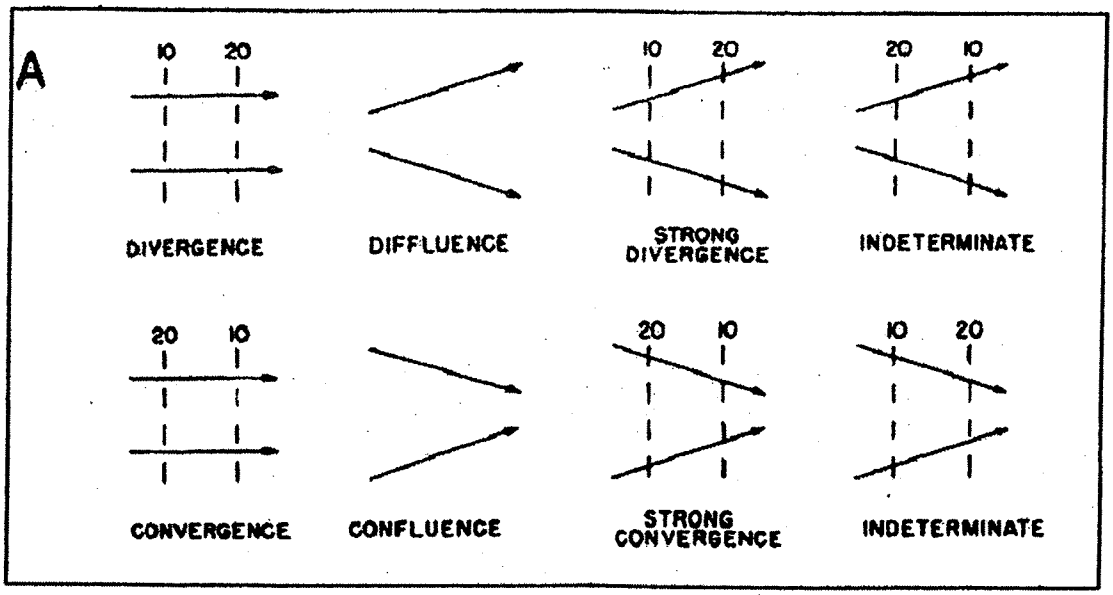
The effect of surface friction is to back (move in an anticlockwise direction) the surface wind compared with the direction of geostrophic flow and to reduce its speed.

If we follow our study of geostrophic wind a little further we find that towards the surface (i.e. below about 500 m for flat terrain) friction begins to decrease the wind velocity below its geostrophic value. This has an effect on the deflective force (which is dependent on velocity) causing it also to decrease. As these two tendencies continue the wind consequently blows more and more obliquely across the isobars in the direction of the pressure gradient. The angle of obliqueness increases with the growing effect of frictional drag due to the earth's surface and it averages about 10°-20° at the surface over the sea and 25°-35° over land. The result is to produce a wind spiral with height, analogous to the turning of ocean currents as the effect of wind stress diminishes with increasing depth. Both are referred to as '***Ekman spirals***', after Ekman who investigated the variation of ocean currents with depth.

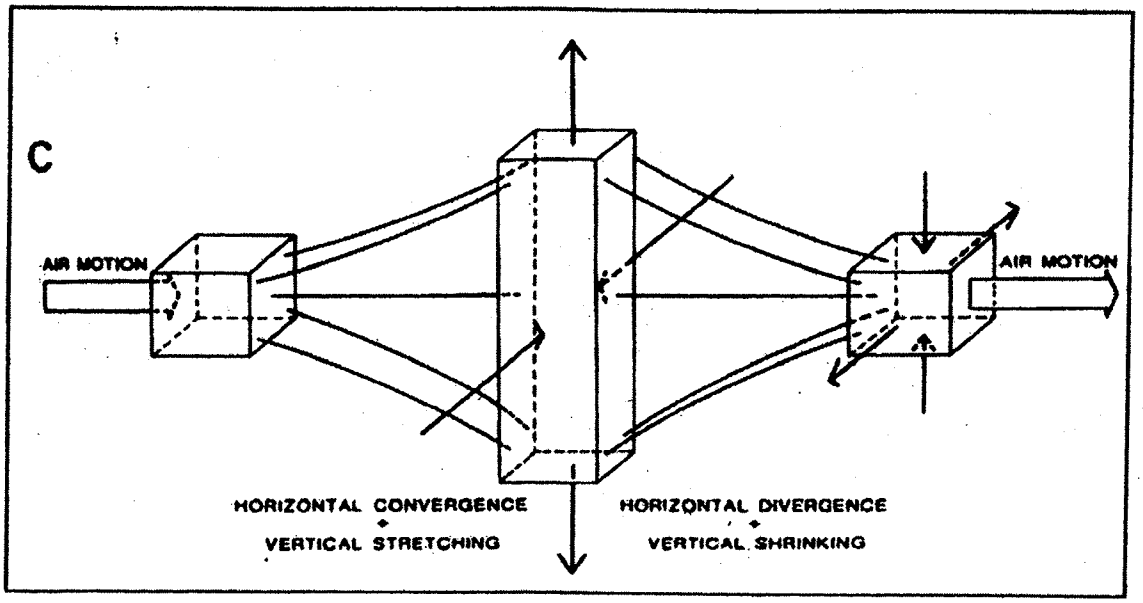
■ 3.3.3.1 *Divergence, Convergence and Vorticity*

Air may accelerate (decelerate) leading to velocity *divergence* (*convergence*). When streamlines (lines of instantaneous air motion) spread out or squeeze together, this is termed *diffluence* or *confluence* respectively. If the streamline pattern is strengthened by that of the isotachs (lines of equal wind speed), as shown in the third panels of the figure, then there may be mass divergence or convergence at a point.

In this case the compressibility of the air causes the density to decrease, or increase, respectively. Usually, however, confluence is associated with an increase in air velocity and diffluence with a decrease. In the intermediate case confluence is balanced by an increase in wind velocity and diffluence by a decrease in velocity.



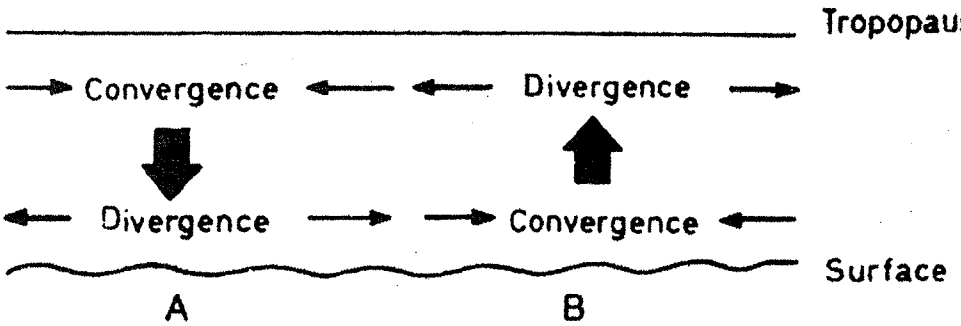
It is a simple extension of the necessity to conserve mass that if a constant volume of fluid extends its horizontal dimensions, or diverges, its vertical extent must decrease. Similarly a vertical column experiencing convergence, for example through a decrease in downstream velocity, is constricted in the horizontal and must therefore be extended vertically. Hence, convergence (divergence) may give rise to



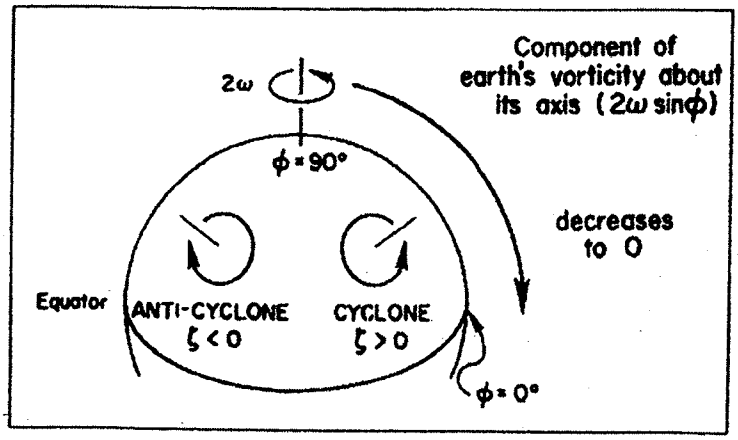
vertical stretching (shrinking) as illustrated in the following figure. It is important to note that if all winds were geostrophic, there could be no convergence or divergence and hence no weather.

Following figure is a schematic representation of the vertical velocities associated with the situations of convergence and divergence at the surface and aloft. In the case of the free atmosphere, convergence aloft

at point A reinforces the sinking motion while high level divergence near point B enhances the upward motions. Thus the near-surface conditions are of sinking and diverging air at A and converging and rising air at point B.



Vorticity implies the rotation or angular velocity of minute (imaginary) particles in any fluid system. The air within a depression can be regarded as comprising an infinite number of small air parcels, each rotating cyclonically about an axis vertical to the earth's surface. Vorticity has three elements -magnitude (defined as twice the angular velocity, ω); direction (the horizontal or vertical axis about which the rotation occurs) and the sense of rotation. Rotation in the same sense as the earth's rotation - cyclonic in the northern hemisphere - is defined as positive. Cyclonic vorticity may result from cyclonic curvature of the streamlines, from cyclonic shear (stronger winds on the right side of the current, viewed downwind in the northern hemisphere), or a combination of the two. Lateral shear results from changes in isobar spacing. Anti-cyclonic vorticity occurs with the corresponding anticyclonic situation. The component of vorticity about a vertical axis is referred to as the *vertical vorticity*. This is generally the most important, but near the ground surface frictional shear causes vorticity about an axis parallel to the surface and normal to the wind direction.



Vorticity is related not only to air motion about a cyclone or anticyclone (*relative vorticity*), but also to the location of that system on the rotating earth. The vertical component of absolute vorticity consists of the relative vorticity (ζ) and the latitudinal value of the Coriolis parameter, $f = 2\omega \sin\varphi$. At the equator the local vertical is at right angles to the earth's axis so that $f = 0$, but at the North Pole cyclonic relative vorticity and the earth's rotation act in the same sense.

In the figure, the relative vertical vorticity (ζ) about a cyclone and an anticyclone in the northern hemisphere, the component of the earth's vorticity about its axis of rotation (or, the Coriolis parameter, f), is equal to twice the angular velocity (ω) times the sine of the latitude (φ)). At the pole $f = 2\omega$, diminishing to 0 at the equator. Cyclonic vorticity is in the same sense as the earth's rotation about its own axis, viewed from top in the northern hemisphere, this cyclonic vorticity is defined as positive ($\zeta > 0$).

■ 3.3.3.2 GLOBAL SCALE ATOSPHERIC CIRCULATION

Atmospheric circulation is the large-scale movement of air, and the means by which heat is distributed on the surface of the Earth. The large-scale structure of the atmospheric circulation varies from year to year, but the basic structure remains fairly constant. However, individual weather systems - midlatitude depressions or tropical convective cells - occur "randomly", and it is accepted that weather cannot be predicted beyond a fairly short limit: perhaps a month in theory, or (currently) about ten days in practice. Nonetheless, the average of these systems - the climate - is stable over longer periods of time.

Attempts have been made to explain the mechanism of general circulation of the atmosphere. It has been tired to take up the flowing issues in regard to the global circulation which require proper explanation.

1. There are rich databases related to the wind direction, velocity etc. for the entire depth of the troposphere. They are required to be properly explained.

2. The mechamsms of heat transfer from the surplus region to the deficit region so that the observed energy balance can be explained.

3. The circulation must take into account the Earth's angular momentum balance. There must not be either speeding up of slowing down of the Earth's rotation due to friction at the earth-atmosphere interface.

Momentum is a property which a body possesses due to its motion and is given by-

Momentum = Mass X Velocity

Similarly, Angular Momentum is a property which a body possesses due to its motion around a central point. It is given by-

Angular Momentum = Mvr
r = distance of the mass M from the centre of rotation and v_r= linear velocity due to the rotational velocity.
According to the law of conservation of momentum, Mvr = Constant.
As the air moves pole ward, the radius of its rotation about Earth's axis decreases. In order to conserve angular momentum, the air would have to experience a progressive increase in eastward velocity relative to the Earth's surface. This pole ward increase in velocity is masked dominantly by surface friction along with other forces of circulation. This poleward transfer of eastward (westerly) angular momentum has undoubtedly greater influence on the global atmospheric circulation.

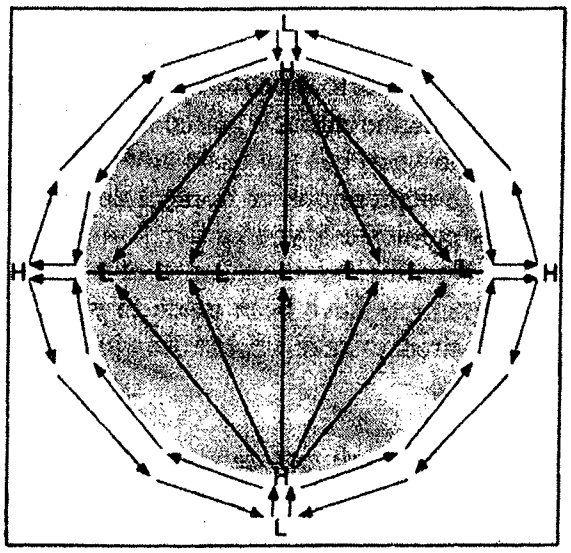
4. Condition of continuity must be adhered to, so that no vacuum is created. Convergence at the surface must be compensated divergence aloft.

■ Simple Model of Global Circulation:

In 1735, ***George Hadley*** designed a cellular model to elucidate the primary circulation of the atmosphere. He based the model on the basic pressure disparity brought about by uneven heating of the

earth's surface. Hadley hypothesized that cold air descended at the poles and flowed along the earth's surface toward the warmer equator. This flow would be countered by rising warm air at the equator and a flow aloft toward the poles so that two large Hadley cells existed in each hemisphere.

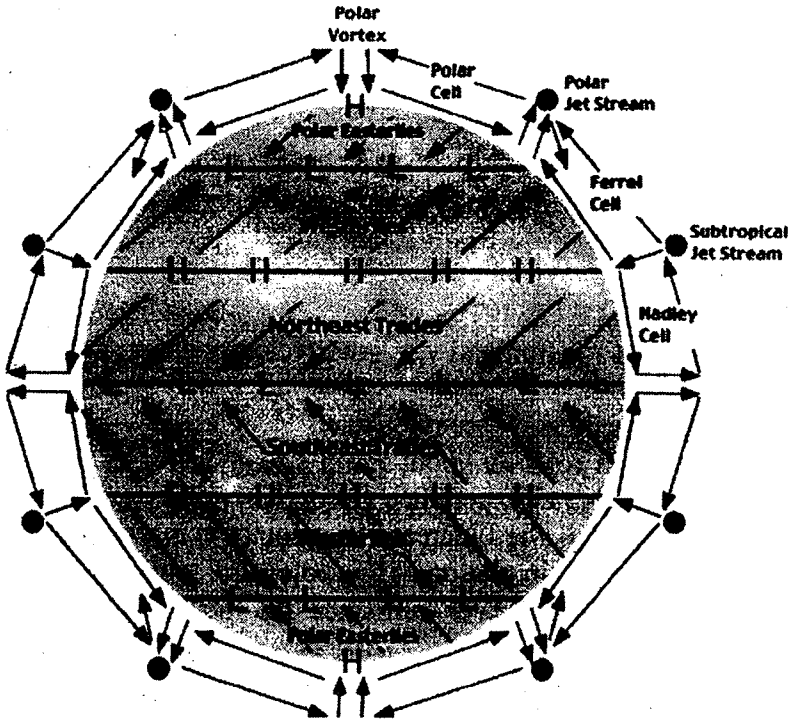
Observation of global wind patterns and, later, theoretical work showing that the rotation of the earth inhibits the development of a single convective cell led to a modified view. Hadley's model was gradually altered to include a three-cell structure between the poles and the equator.



Simplified one-cell global air circulation

■ Three Cell Model of Global Circulation:

The atmosphere operates as a large heat engine transferring heat from a source (the tropics) to a sink (the poles). Unfortunately this single-cell model does not fully explain the surface distribution of winds. The main flaw lies in its consideration of the effects of the Earth's rotation. As air moves polewards the radius of its rotation about the Earth's axis decreases. In order to conserve angular momentum the air would have to experience a progressive increase in eastward velocity relative to the Earth's surface. If there were only one cell, poleward-moving air would be flowing at such extreme velocity by latitude 30° that it would become turbulent, the meridional flow breaking down into eddies. The Hadley cell must, therefore, be limited to low latitudes, and alternative mechanisms must be found to achieve the necessary poleward transport of angular momentum. An alternative to the single-cell model view of the circulation of the atmosphere is the three-cell model where, in place of a single convectional cell, there are three interlocking cells between the tropics and the poles.



Simplified global three-cell surface and upper air circulation patterns

♦ ***Hadley Cell:*** The first of these is the low-latitude Hadley cell operating between equatorial regions and 30° north and south, which is a convectional or thermally direct cell. Warm air rises in the Intertropical Convergence Zone, travels polewards and subsides in the subtropical anticyclones, whence it returns westwards to low latitudes. Winds on the surface would be the easterly trades and. in the upper atmosphere, the westerly antitrades.

The Hadley cell mechanism is well understood. The atmospheric circulation pattern that George Hadley described to provide an explanation for the trade winds matches observations very well. It is a closed circulation loop, which begins at the equator with warm, moist air lifted aloft in equatorial low pressure areas to the tropopause and carried poleward. At about 30°N/S latitude, it descends in a high pressure area. Some of the descending air travels equatorially along the surface, closing the loop of the Hadley cell and creating the Trade Winds.

♦ ***Ferrel Cell:*** The second cell is a middle-latitude cell or Ferrel cell, operating between latitudes 30° and 60°. Air diverges from the subtropics and flows polewards and eastwards across the surface, eventually converging with cold polar air at the polar front where it rises to the upper troposphere. From here it returns equatorwards aloft. As warm air is effectively sinking at 30° and cold air rising at 60; this cell is thermally indirect.

The Ferrel cell, theorized by **William Ferrel** (1817-1891), is a secondary circulation feature, dependent for its existence upon the Hadley cell and the Polar cell. It behaves much as an atmospheric ball bearing between the Hadley cell and the Polar cell, and comes about as a result of the eddy circulations (the high and low pressure areas) of the midlatitudes. For this reason it is sometimes known as the "zone of mixing." At its southern extent (in the Northern hemisphere), it overrides the Hadley cell, and at its northern extent, it overrides the Polar cell. Just as the Trade Winds can be found below the Hadley cell, the Westerlies can be found beneath the Ferrel cell. Thus, strong high pressure areas which divert the prevailing westerlies, such as a Siberian high (which could be considered an extension of the Arctic high), could be said to override the Ferrel cell, making it discontinuous.

While the Hadley and Polar cells are truly closed loops, the Ferrel cell is not, and the telling point is in the Westerlies, which are more formally known as "the Prevailing Westerlies". While the Trade Winds and the Polar Easterlies have nothing over which to prevail, their parent circulation cells having taken care of any competition they might have to face, the Westerlies are at the mercy of passing weather systems. While upper-level winds are essentially westerly, surface winds can vary sharply and abruptly in direction. A low passing to the north or a high passing to the south (from a Northern Hemisphere frame of reference) maintains or even accelerates a westerly flow; the local passage of a cold front may change that in a matter of minutes, and frequently does. A strong high passing to the north may bring easterly winds for days.

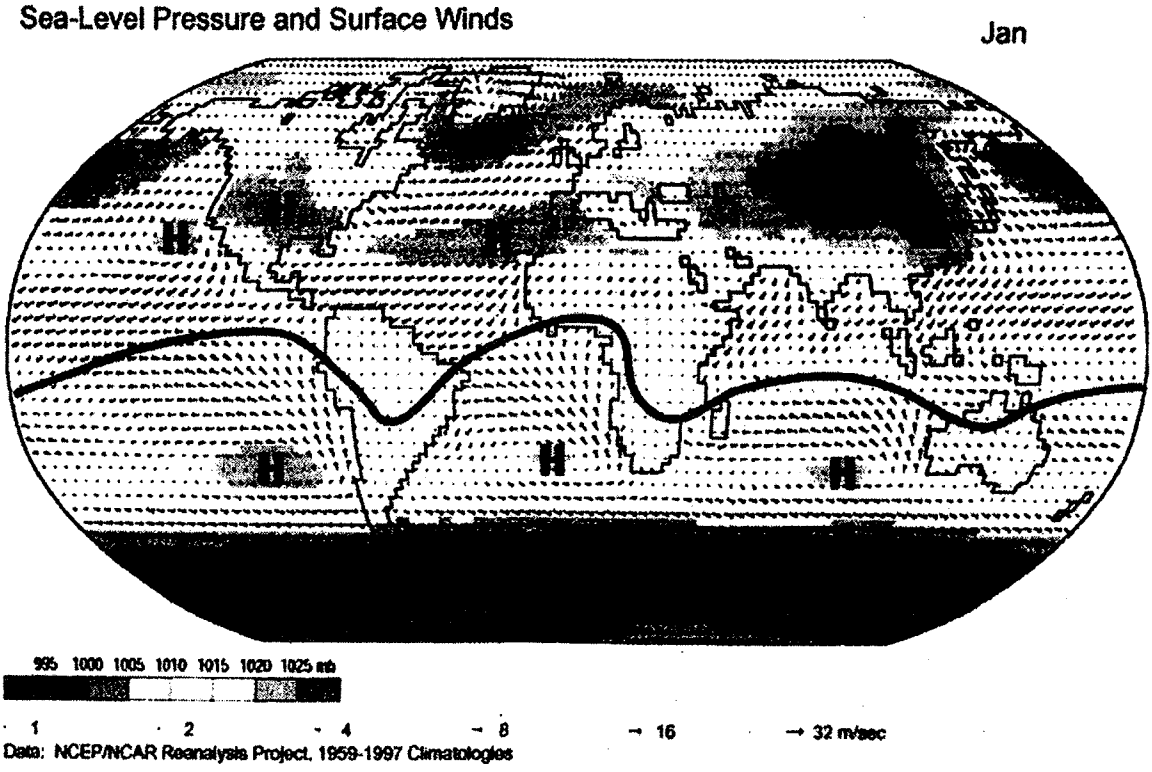
The base of the Ferrel cell is characterized by the movement of air masses, and the location of these air masses is influenced in part by the location of the jet stream, which acts as a collector for the air carried aloft by surface lows. The overall movement of surface air is from the 30th latitude to the 60th. However, the upper flow of the Ferrel cell is not well defined. This is in part because it is intermediary between the Hadley and Polar cells, with neither a strong heat source nor a strong cold source to drive convection, and in part because of the effects on the upper atmosphere of surface eddies, which act as destabilizing influences.

♦***Polar Cell***: The Polar cell is likewise a simple system. Though cool and dry relative to equatorial air, air masses at the 60th parallel are still sufficiently warm and moist to undergo convection and drive a thermal loop. Air circulates within the troposphere, limited vertically by the tropopause at about 8 km. Warm air rises at lower latitudes and moves poleward through the upper troposphere at both the north and south poles. When the air reaches the polar areas, it has cooled considerably, and descends as a cold, dry high pressure area, moving away from the pole along the surface but twisting westward as a result of the Coriolis effect to produce the Polar easterlies.

■ Surface Pressure Conditions and Actual Surface Circulation

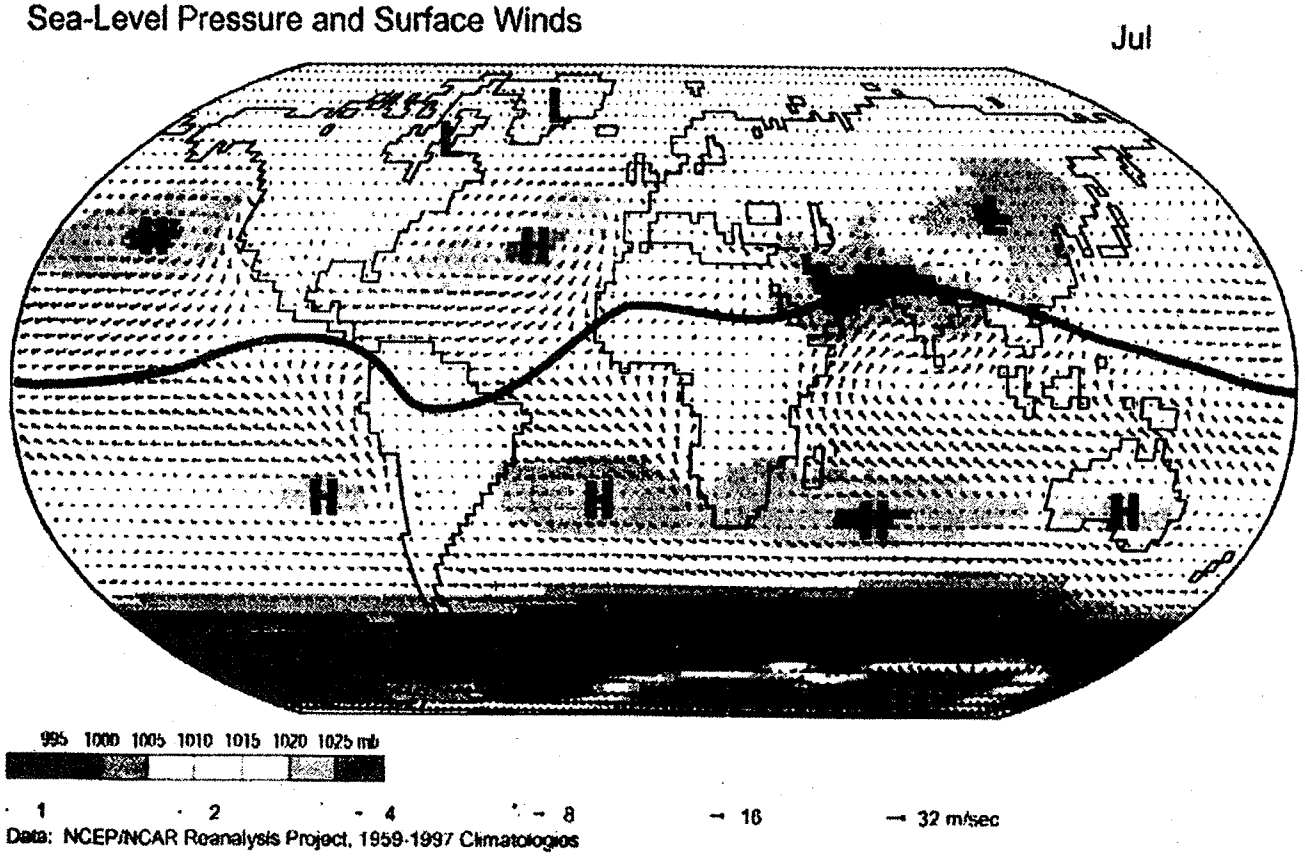
The actual surface circulation for the Earth has been determined from 39 years of record. The circulation patterns seen differ somewhat from the three cell model. These differences are caused primarily by two factors. First, the Earth's surface is not composed of uniform materials. The two surface materials that dominate are water and land. These two materials behave differently in terms of heating and cooling causing latitudinal pressure zones to be less uniform. The second factor influencing actual circulation patterns is elevation. Elevation tends to cause pressure centers to become intensified when altitude is increased. This is especially true of high pressure systems.

The figures visualize the intertropical convergence zone (ITCZ), subtropical high pressure zone, and the subpolar lows. *The intertropical convergence zone* is shown in the figures by a red line. The formation of this band of low pressure is the result of solar heating and the convergence of the trade winds. In January, the intertropical convergence zone is found south of the equator. During this time period, the Southern Hemisphere is tilted towards the Sun and receives higher inputs of shortwave radiation. The line representing the intertropical convergence zone is not straight and parallel to the lines of latitude. Bends in the line occur because of the different heating characteristics of land and water. Over the continents of Africa, South America, and Australia, these bends are toward the South Pole. This phenomenon occurs because land heats up faster then ocean.



During July, the intertropical convergence zone (ITCZ) is generally found north of the equator. This shift in position occurs because the altitude of the Sun is now higher in the Northern Hemisphere. The greatest spatial shift in the ITCZ, from January to July, occurs in the eastern half of the image. This shift is about 40° of latitude in some places. The more intense July Sun causes land areas of Northern Africa and Asia rapidly warm creating the Asiatic Low which becomes part of the ITCZ. In the winter months, the intertropical convergence zone is pushed south by the development of an intense high pressure system over central Asia (compare Figures). The extreme movement of the ITCZ in this part of the world also helps to intensify the development of a regional winds system called the Asian monsoon.

The subtropical high pressure zone does not form a uniform area of high pressure stretching around the world in reality. Instead, the system consists of several localized anticyclonic cells of high pressure. These systems are located roughly at about 20 to 30° of latitude and are labeled with the letter H on Figures. The subtropical high pressure systems develop because of the presence of descending air currents from the Hadley cell. These systems intensify over the ocean during the summer or high Sun season. During this season, the air over the ocean bodies remains relatively cool because of the slower heating of water relative to land surfaces. Over land, intensification takes place in the winter months. At this time, land cools off quickly, relative to ocean, forming large cold continental air masses.



The subpolar lows form a continuous zone of low pressure in the Southern Hemisphere at latitudes between 50 and 70°. The intensity of the subpolar lows varies with season. This zone is most intense during Southern Hemisphere summer. At this time, greater differences in temperature exist between air masses found either side of this zone. North of subpolar low belt, summer heating warms subtropical air masses. South of the zone, the ice covered surface of Antarctica reflects much of the incoming solar

radiation back to space. As a consequence, air masses above Antarctica remain cold because very little heating of the ground surface takes place. The meeting of the warm subtropical and cold polar air masses at the subpolar low zone enhances frontal uplift and the formation of intense low pressure systems.

In the Northern Hemisphere, the subpolar lows do not form a continuous belt circling the globe. Instead, they exist as localized cyclonic centers of low pressure. In the Northern Hemisphere winter, these pressure centers are intense and located over the oceans just to the south of Greenland and the Aleutian Islands. These areas of low pressure are responsible for spawning many mid-latitude cyclones. The development of the subpolar lows in summer only occurs weakly (over Greenland and Baffin Island, Canada), unlike the Southern Hemisphere. The reason for this phenomenon is that considerable heating of the Earth's surface occurs from 60 to 90° north. As a result, cold polar air masses generally do not form.

▲ 3.3.3 .3 SURFACE WINDS:

Therefore, four main surface wind belts are distinguished. Around the equator, in the low pressure equatorial trough occurs a zone of convergence where north-easterly trade winds blowing from the Tropic of cancer meet the south-easterly trade winds blowing from Tropic of Capricorn. Polewards of the tropics, in the temperate latitudes, there is a zone of prevailing westerlies, while around the poles occur a belt of easterlies. These zones do not operate separately, but are closely interrelated.

●***The Trade Winds:*** The trade wind belts lie between the equatorial trough and the subtropical highs. This zone occupies nearly half of the globe, much of it is ocean, and within this area the steady trade winds provide a stable and relatively constant climate. At the surface the wind has a component towards the equator. Above the surface friction layer the winds become more easterly. Viewed from the above, the oceanic trade winds contain innumerable uniform small clouds. These are visible expression of transfer of latent heat from the sea surface, through evaporation, before condensation at higher level.

As the seasonal movement of the equatorial trough is slight over the oceans, so the oceanic tropical areas are dominated by the trades. On the continents the trades are far more restricted in extent, and the equatorial westerlies and monsoons are more important. The two belts interact closely; it is the convergence of moisture in the trade winds that feeds the equatorial trough. The shift in the position of the trough thus determines the relative extent of the easterlies and westerlies. When the sun is farther north, in July, the trades are restricted in the northern hemisphere, particularly over the land. In January, the trough is at its most southerly position and the trades extend to the equator. In the southern hemisphere less marked variation occurs, for predominance of oceans means that the southern limit of the trough remains close to equator.

●***The Westerlies*:** In comparison with the winds of the tropics, the westerlies of the mid latitudes seem unreliable and fickle. They are westerlies only on average.

Polewards of the subtropical anticyclones, rotating storms are the main mechanism of energy transfer. Unlike hurricanes, these systems cover vast areas and can be seen clearly from space, identified by their characteristic spiral of clouds. In the northern hemisphere they tend to move north eastwards, although directions vary from north to south east, typically, they follow an evolutional pattern. The storms are initiated in areas of strong temperature gradients, such as off Newfoundland, where the cold Labrador Current and warm (Gulf Stream are in dose proximity, forming roughly circular patterns of low pressure and a rotational movement of winds, which are often strong. They are known as lows, cyclones or depressions. As they evolve they become initially more intense the central pressure has been known to fall as low as 930 hPa - before filling as the storm declines. On average the location of maximum intensity is in the areas of Iceland in the Atlantic and the Aleutian Islands in the Pacific. Thus

climatologists speak of the Icelandic Low and the Aleutian Low. In the southern hemisphere there are no distinct areas of the genesis of storms, so lows form throughout a wide- belt.

As a low approaches in the northern (southern) hemi sphere, winds increase in strength, initially from a southerly (northerly) direction, then become westerly and, finally, as the low moves away, they veer to north westerly (south-westerly) or even northerly (southerly). The tracks of the lows reach farther poleward in summer than in winter, so the area affected by the storms varies seasonally. Nowhere is this seasonal pattern more clearly seen than over the Mediterranean basin, in California and at equivalent latitudes in the southern hemisphere such as central Chile or parts of West and South Australia. In winter, when the cyclones follow tracks at lower latitudes, they bring rain to these areas. In summer the cyclones move away, to be replaced by the subtropical anticyclones and dry, hot weather. The regular march of cyclones and anticyclones through the temperate latitudes produces a majority of winds between north-west and south in the northern hemisphere and between south west and north in the southern hemisphere. This pattern is far from invariable, however, and depending upon the precise tracks taken by the lows, and the local topography, winds from any direction are possible. The prevailing westerlies, therefore, are anything but prevalent. Moreover, the strong north -south component of winds in these areas allows a more effective transfer of energy between the tropics and the Polar Regions.

● ***Polar Easterlies***: Around the poles, beyond the main westerly belt, there is some evidence of prevailing easterlies. The winds are variable and linked with the- shallow polar anticyclones, in the northern hemisphere they are often influenced in the circulation around the northern edge of cyclones. As a result they change direction according to the local weather and topography.

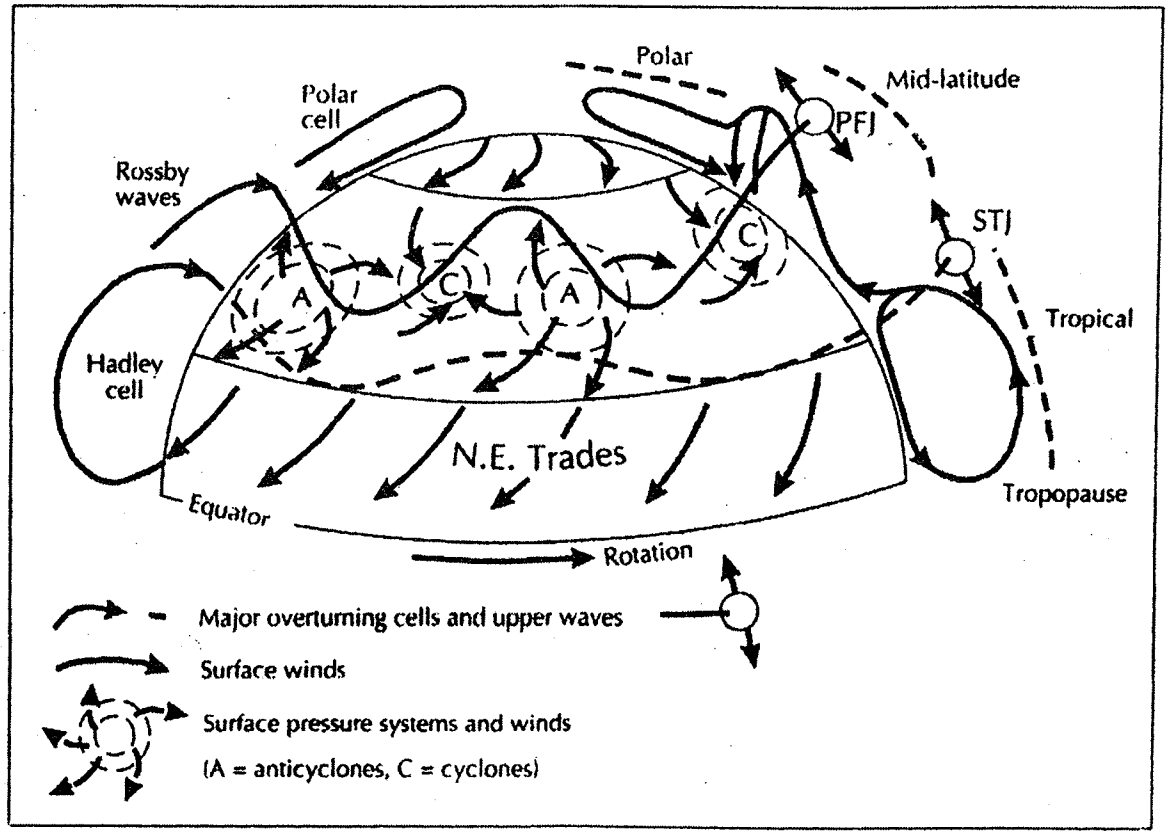
In the southern hemisphere the- vast Antarctic ice cap controls the- atmospheric circulation around the pole. Anticyclones develop frequently over eastern Antarctica, and strong south-easterly winds develop around the-margins of the- ice- plateau with consistencies similar to those- of the trades, and occasionally of great strength.

● **UPPER WINDS:**

The Nature of The Upper Winds

The direction of their movement is different from that of the surface winds. Winds in the upper atmosphere can be affected by front's operating in a different direction from those at the surface and may appear to be part of a different system of circulation. The change from surface to upper atmosphere conditions is not abrupt but transitional. With increasing height, the winds tend to follow a gradually more distinct zonal (east west) direction and they become stronger. The main reason for this change is the disappearance of the (frictional influence of the ground surface upon the winds. In other words, the flow more nearly approximates to the geostrophic winds that, it will be remembered, result from the interaction of the pressure gradient and the Coriolis force.

The zonal flow of the upper winds can be shown on average as a cross-section from north to south. In fact variations around this average picture are slight, except in the monsoon areas of Asia. At each season the same basic pattern exists, with slight shifts in position and intensity. Between about 30° N and 30° S there is a zone of easterly winds which are relatively weak, reaching a maximum speed of 4 - 5 m s^{-1} (about 17 km hr^{-1}) at about 3 km. On either side of this belt occurs a ring or vortex of much stronger westerly winds.



GENERAL CIRCULATION OF THE NORTHERN HEMISPHERE

●*The Upper Westerlies*

These high-altitude westerly winds are a major feature of our atmosphere. They reach their maximum speed at approximately 12 km between 30° and 40° latitude. The mean speed is as much as 35 m s^{-1} and maximum speeds of .several hundred kilometres per hour are not uncommon.

Although these wind patterns are steady, seasonal variations do take place, especially in the northern hemisphere. The upper westerlies are strongest in the winter, when the temperature difference between the tropics and temperate latitudes is at its greatest. From June to August temperatures in the northern hemisphere are relatively warm, even in polar regions, so the pressure gradient is reduced and the upper westerlies decline to speeds of as low as 15 ms^{-1}. Changes in the southern hemisphere are less pronounced, largely owing to the greater thermal stability there. The vast areas of ocean absorb large quantities of heat without any significant increase in temperature. The ice plateau of Antarctica also stays very cool, so the temperature gradients do not change very much from winter to summer.

The position of the boundary between the westerlies and easterlies (of both the upper and the surface winds) varies throughout the year. From December to February the polar vortex of the winter (northern) hemisphere expands, pushing the belts southwards so that, at the surface, the boundaries are at about 30° N and 35° S. As the year progresses, the other polar vortex begin to expand as winter sets in over the southern hemisphere. The boundaries eventually reach about 35° N and 30° S by June to August. The separation between the two systems is not vertical. As a result, some parts of the tropics have

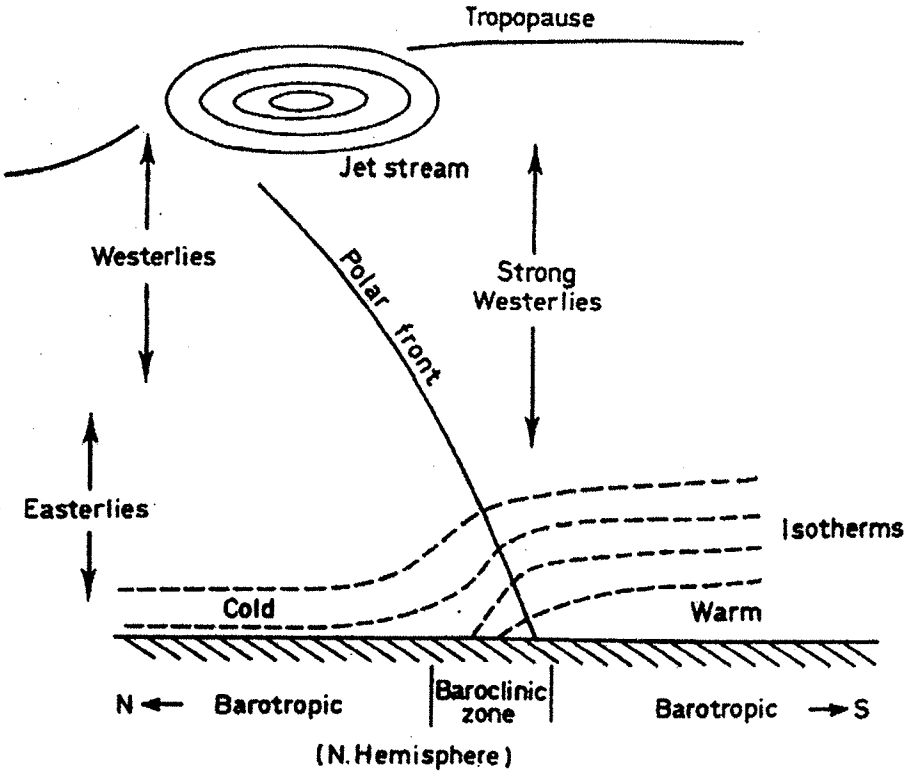
easterlies in the lower atmosphere and westerlies above. Only over a small area of the globe do easterlies occur at all levels, whereas westerlies extend throughout the atmosphere over a large proportion of Earth.

● ***The Rossby Waves***

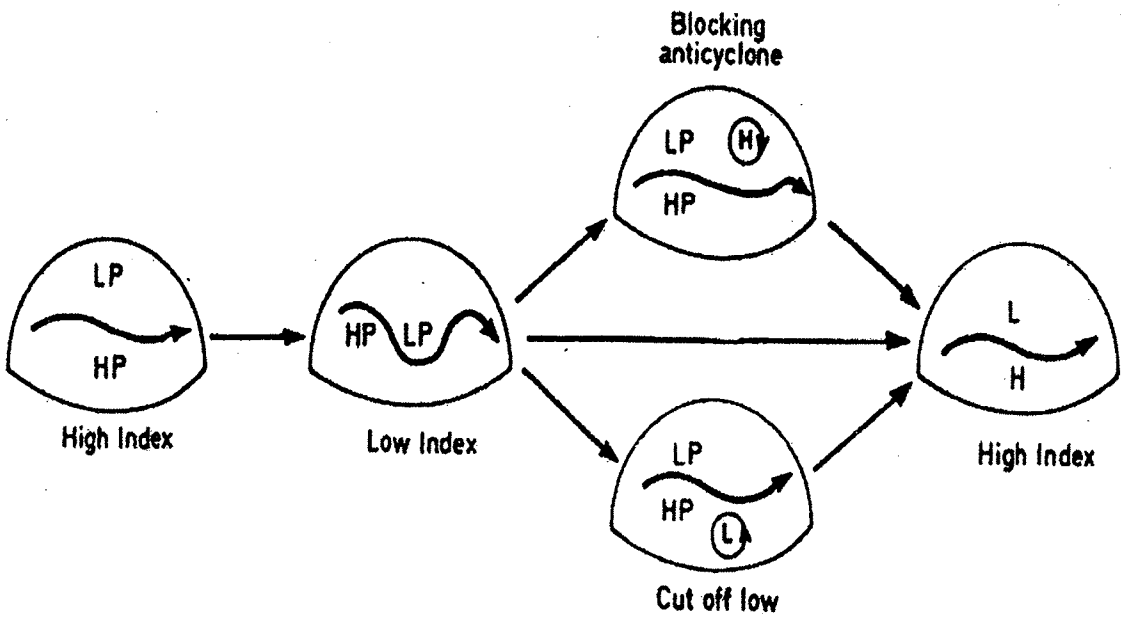
The pattern of easterlies and westerlies in the upper atmosphere is only part of the total picture. In addition to the marked zonal flows there are less apparent but none the less important meridional flows. In the circumpolar areas, for example, there occur wave-like patterns of flow called *Rossby waves* (after ***C. F. Rossby***, a Swedish meteorologist) that play a vital role in the energy exchange between the temperate and polar areas.

We know, the geostrophic winds blow parallel to the isobars, at a speed inversely proportional to the distance between the isobars. Similarly the winds blow parallel to the contours of the pressure surface. Where the contours are close together, the winds are rapid. Irregularities in the pressure surface indicate local patterns of wind movement. The flow of Rossby wave is not perfectly circular around the North Pole. Areas occur, even on this monthly chart, where the mean flow has a northward component, and other areas occur where it is southwards. Effectively the air is flowing in a series of waves around the pole, carrying warmer air northwards on parts of its track and cold air southwards elsewhere. These are the Rossby waves. In January the most prominent features of the waves are the pronounced troughs in the pressure surface near 80° W and 140° E, with a weaker trough between 10° E and 60° E. In July the circulation is less intense and the troughs less well marked. Many experiments have been conducted to determine the reasons for this pattern. Clearly surface features play an important part, even at this height. The presence of the Rocky Mountains and the Himalayas is believed to 'lock' the troughs at 80° W and 140° E respectively. The distribution of land and sea is also thought to be of importance. In the southern hemisphere there are no mountain ranges of comparable size, nor such marked land and sea temperature contrasts. As a result the mean circulation is much more symmetrical around the South Pole. Even on a shorter time period, waves may exist in the upper easterlies, though their shape is less regular. The smaller waves tend to be associated with an individual depression and move more rapidly, perhaps up to15° longitude per day. The longer waves usually between four and six are apparent - move more slowly and can even retrogress against the westerly flow. They are linked with the major circulation features such as the subtropical highs and Icelandic lows. The long-wave flow tends to steer shorter waves, moving them northwards when ahead o trough and southwards when to the rear of a trough.

The Rossby waves are probably the most important feature of the mid-latitude circulation. This flow pattern influences the whole depth of the troposphere and covers most of the mid-latitude region. However, the waves are usually best developed, and well defined, in a relatively narrow band at restricted latitudes. It is in this band that the major poleward temperature gradient is established and thus that baroclinic conditions are likely to occur. This has several consequences. A marked horizontal temperature gradient is set up at the surface, leading to the development of the polar front. This major temperature discontinuity, although not continuous around the hemisphere, usually covers a significant portion of it. It extends upwards, as a frontal surface, through much of the depth of the troposphere. In this region the atmosphere is at least equivalent barotropic and may be baroclinic. In any event, there is an increase in wind speed with height which leads to the development of a. jet stream at or just below the tropopause. This is a ribbon-like belt of rapidly moving air, a few hundred metres in depth, a few kilometres wide and hundreds, or even thousands, of kilometres long.



Cross section of the mid-latitude atmosphere showing the position of polar front, the jet stream and barotropic and baroclinic zones



Change in Rossby Wave Flow Pattern in the Transition from High to Low Index and then from Low to High Index Regimes

♦ *Index cycle*

In general there is a tendency for a pseudo-cyclic change in the Rossby wave amplitude. This can be conveniently characterized by the zonally averaged pressure difference between two latitude circles a difference known simply as the index. The latitude circles usually, chosen for the Northern Hemisphere are 35° and 35°, latitudes which approximately correspond to the southern and northern limits of the main Rossby flow and which have an adequate spacing of observing stations. As the wave amplitude changes there is an index cycle. Starting with a strong zonal flow, there is a high index and a small number of relatively smooth Rossby waves. As the amplitude of the waves increases and the index decreases the main axis of the strong westerlies is displaced southward and may become discontinuous. Distinct high and low pressure centres are formed. Thereafter the amplitude may slowly decrease again, or a 'cut-off may occur, leaving either a blocking anticyclone as a stationary atmospheric feature, or a non-frontal depression as a feature that usually moves eastwards slowly. The whole cycle may take 20 to 60 days to complete, but it is very irregular in length and in the speed with which each stage progresses.

Changes in the polar front position will arise because of the baroclinic nature of this feature. In such baroclinic conditions vertical motions associated with convergence and vorticity will be developed. In particular, these will lead to the development of frontal depressions, features with cyclonic motion around a low pressure centre. These probably originate near the 500 hPa flow. As they develop and extend down through the atmosphere to become 'surface features', they will not only move in response to the Rossby wave motion, but will also become sufficiently large to affect this flow themselves. They are not only responsible for rapid weather changes in the areas over which they pass, but they also play a significant role in the poleward energy transport. They are responsible for energy transport by transient eddies, supplementing the energy transport provided by the Rossby waves. In general terms, a high index circulation with strong zonal flows is likely to be a period with deep, vigorous depressions which are the main transporters of energy northward. With a low index the depression circulation is much weaker and the Rossby waves transport the energy directly.

Away from the main line of the Rossby waves are areas where conditions are barotropic. Such regions serve as the sources for air masses, regions of horizontally uniform and relatively calm conditions. The air in these regions remains over the same surface for several days and can take on the temperature and moisture characteristics of that surface. Eventually these air masses will move, either because they have become sufficiently strong to influence the general circulation in mid-latitudes, or because changes in the wave circulation allow them to move into a new area. In either case they take their inherent characteristics with them into the new area and thus affect the weather there.

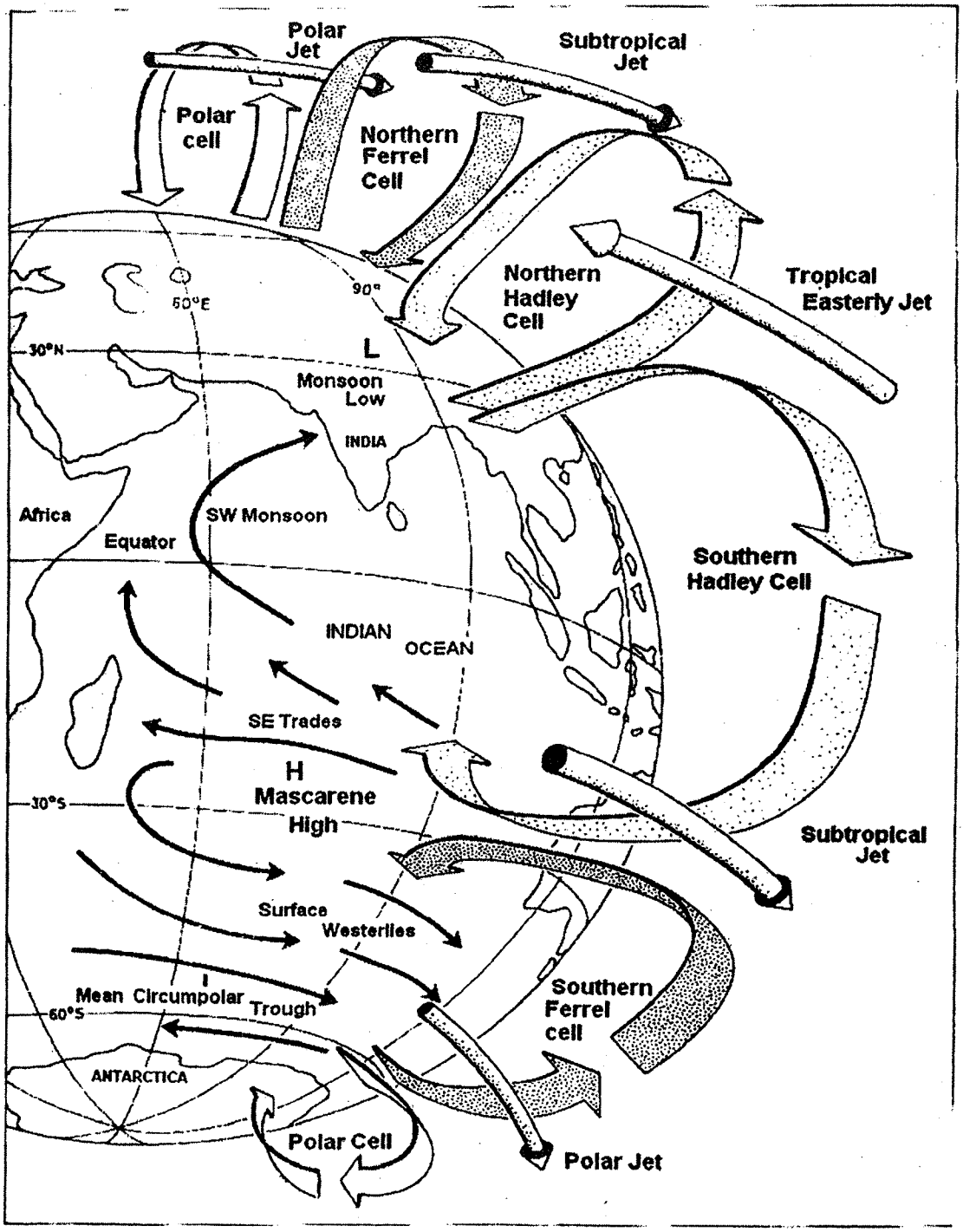
●*The Jet Streams*

In both hemispheres the mean upper geostrophic winds are dominantly westerly between the subtropical high-pressure cells (centred aloft about 15° latitude) and the polar low-pressure centre aloft. Between the subtropical high-pressure cells and the equator they are easterly. This dominant, westerly circulation reaches maximum speeds of 45-67 m s^{-1} (100-150 mph), which even increase to 135 m s^{-1} (300 mph) in winter. These maximum speeds are concentrated in a narrow band often situated at about 30° latitude, between 9000 and 15,000m, called the ***jet stream***. This stream, which is essentially a fast-moving mass of laterally concentrated air, is connected with the zone of maximum slope, folding, or fragmentation of the tropopause, which in turn coincides with the latitude of maximum poleward temperature gradient and energy transfer. The thermal wind, as described above, is a major component of the jet stream, but the basic reason for the concentration of the meridional temperature gradient in a

narrow zone (or zones} is still uncertain. One theory is that the temperature gradient becomes accentuated when the upper wind pattern is confluent. The following figure, giving a generalized view of the wind and temperature distribution in the northern hemisphere troposphere in winter, shows that there are two

Meridional Distribution of Zonally Averaged Circulation

jet

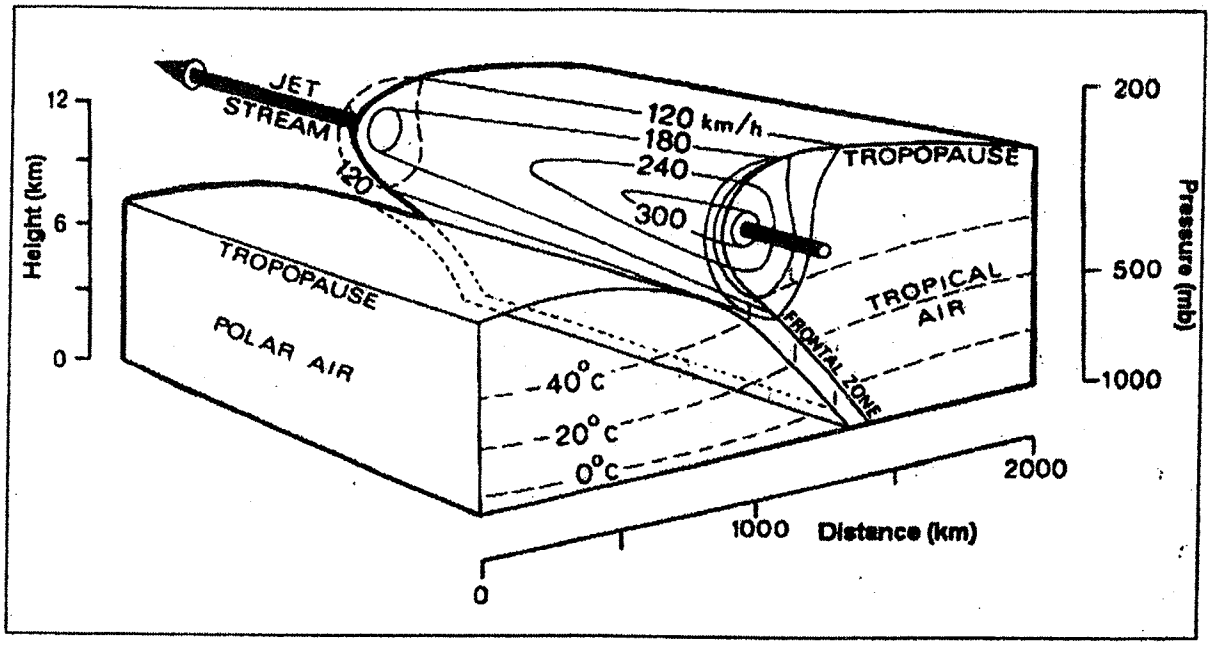


westerly streams.

Types of Jet Streams

The more northerly one, termed the *Polar Front Jet Stream*, is associated with the steep temperature gradient where polar and tropical air interact, but the *Subtropical Jet Stream* is related to a temperature gradient confined to the upper troposphere. The Polar Front Jet Stream is very irregular in its longitudinal location and is commonly discontinuous, whereas the Sub-tropical Jet Stream is much more persistent. For these reasons the location of the mean jet stream primarily reflects the position of the Subtropical Jet Stream. In summer, an *Easterly Tropical Jet Stream* forms in the upper troposphere over India and Africa due to regional reversal of the S-N temperature gradient.

In the southern hemisphere, the mean jet stream m winter is similar in strength to its northern hemisphere winter counterpart and it weakens less in summer, because the meridional temperature gradient between 30° and 50°S is reinforced by heating over the southern continents. Upper air temperature gradients in the northern hemisphere, in contrast, are much stronger in winter.



●*Functioning of the Three-cell Model:*

In order for the three-cell model to work, it requires that the middle-latitude cell be driven by the polar and Hadley cells. Not only is the polar cell too weak to fulfill this function, but meridional pressure gradients are at their steepest in both the lower and upper troposphere in middle latitudes. The middle-latitude cell is thus, in contradiction of the three-cell model, the strongest element of the atmospheric circulation and is fundamental to the pole ward redistribution of energy. Examination of the isobaric surfaces in the upper troposphere has revealed a pressure distribution in the form of the circumpolar vortex, in which pressure decreases away from the poles. Pressure reaches a maximum at latitude 20°, whence there is a small decrease into equatorial latitudes. Geostrophic winds blow as circumpolar westerlies between the poles and latitude 20° and as an easterly flow over equatorial latitudes.

Within the circumpolar westerlies there are two well defined bands of extremely strong winds referred to as the jet streams. One of these, the subtropical jet stream, has a circumpolar path between

latitudes 20° and 35°. The other, the polar jet stream has a path between latitudes 35° and 65° (Fig). The subtropical jet stream blows between 12 km and 15 km above the Earth's and within its narrow core. During winter it well defined, but in summer it is considerably weak and may become discontinuous. The upper air moves polewards in the Hadley cells. It gains an increased eastward velocity of the order of 60m s^{-1} by latitude 30° in conserving angular momentum, relative to the Earth's surface. The poleward transfer of angular momentum by increasing velocity of air flowing in this way must be limited to lower latitudes, the high-velocity subtropical jet stream marking this limit. As the subtropical jet stream lies above high surface pressure, the air within it subsides towards the surface, where its energy is either dissipated by friction or transferred polewards or equatorwards. The polar front jet stream is located where meridional temperature gradients are steep in higher latitudes, generating a strong upper westerly flow. Mean wind speeds in the jet stream core at a height between 10 and 12 km above the ground surface, are 25 m s^{-1}. It tends to be discontinuous and follows a meandering and highly variable path.

Thus a more realistic representation of the atmospheric circulation in its meridional plane is shown in figure (page-24). In the northern hemisphere the major feature of the circulation is the Hadley cell, while north of this the thermally indirect cell of the middle latitudes is now much smaller and is confined to the middle and upper troposphere. However, this circulation in itself does not entirely explain how poleward transport of angular momentum and heat energy is achieved beyond latitude 30°. Beyond this, the atmosphere develops eddying motions. It is these which effect the poleward transport of heat and momentum.

The isobaric surfaces for the upper troposphere reveal a number of identifiable waves in the upper westerlies, referred to as Rossby waves. The number of these waves and the degree of their latitudinal oscillation vary considerably over time. They can develop and decay over relatively short periods of time - as little as a month or two. However, it is possible to identify average positions of the waves over extended periods of time, and this wave pattern is essential to the atmospheric circulation. Although net meridian airflow is zero in these waves, they fulfill the functions of transferring heat energy and angular momentum away from the subtropics. The primary circulation system of the atmosphere is thus considerably more complex that is implied by the single- and three-cell model However, whatever the model, it can never full represent what is in reality, an extremely efficient yet mechanically complex heat engine. The atmosphere manages to maintain a global heat energy balance by effectively redistributing the surplus from lower latitudes. That it does so above a surface whose physical characteristics are highly vat able over both time and space adds further to it intricacy of its mechanism.

■ 3.3.4 AGRO-METEOROLOGICAL TERMS- METHODS & MEASUREMENTS

In spite of recent technological and scientific advances, weather is still the most important variable in agricultural production. The climatic factor affects agriculture in two different ways- (i) through weather hazards to crops and (ii) through the control exercised by climate on the type of agriculture feasible or viable in a given area. Climatic variables have an influence on every stages of the agricultural production including land preparation, sowing, crop growth, management, harvesting, storage, transport, and marketing.

● *Climate crop relations*

Any agricultural system is a man-made ecosystem that depends on climate to function just like the natural ecosystem. The main climatic elements that affect crop production are- solar radiation, temperature, and moisture. These climatic parameters and others dependent on them largely determine the global

distribution of crops and livestock as well as crop yield and livestock productivity within a given climatic zone. All crops have their climatic limits for economic production. These limits can be extended to some extent by plant breeding and selection and by cultivation methods in respect of crops. Two important points must be emphasized at the outset. The first point is that climatic variables are closely interrelated in their influence of crops. The effect of a given climatic variable is modified by the others. Also, daily, seasonal, or annual variations in the values of the climatic element are of great importance in determining the efficiency of crop growth. The second point is that in considering the climatic environment in which crops grow, the microclimate immediately around the crop is of vital importance. Climatic conditions within the soil where germination takes place and very dose to the ground where the crops grow may be quite different from those prevailing in the free air above the crops.

● Solar radiation

Solar radiation is of vital importance in agriculture since it is this energy that powers the agricultural ecosystem. Solar radiation determines the thermal characteristics of the environment, namely the air and soil temperatures, sunshine and day length or the photoperiod. Photosynthesis, the basic process of food manufacture in nature, and photoperiodism, the flowering response to daylight, are both controlled by solar radiation. The maximum amount of plant tissue which can be photosynthesized within a crop depends on the availability of suitable radiation.

In photosynthesis the visible rays are the most effective although ultra rays can influence germination and the energy and quality of seeds. Rad. intensity is also an important factor. The optimum light values for normal crop growth and development are generally around 8-20 kilolux. Light values for optimum flowering and fruiting determined for some crops are as follows:

Pea	850-1100 lux
Corn	1400-1800 lux
Barley and wheat	1800- 2000 lux
Bean and cucumber	2400 lux
Tomatoes	4000 lux

If there is insufficient radiation the root system of the crop is underdeveloped, the foliage is yellowish and there is a tendency for the stalk to grow at the expense of the foliage. According to Griffiths (1976) the average plant begins to accumulate organic matter at about 0° C increasing in amount to 25° C then decreasing to zero at 40° C. This indicates that too little radiation or too much radiation is harmful to the process of photosynthesis.

In photoperiodism the important solar rays are those between 0.5 and 0.7 micrometres. Some plants are indifferent to day length while others are very sensitive to variations in day length. Also, some plants are light loving (e.g. pine, birch and larch trees) while others love shade (e.g. beech and spruce). This is not to say that shade-loving plants do not require solar radiation. Crops may be classified as short-day or long-day types, depending on the period when they achieve their optimum growth or crop maturity lime. Crops which achieve their optimum growth during the period of short days (about 10 hours sunlight are said to be ***short-day crops*** and they include beans, corn, cotton, millet, cucumber and tomatoes. Crops which achieve their optimum growth during the period of long days (about 14 hours sunlight) are ***long-***

day crops and they include barely, clover, mustard, oats, rye, and wheat. As would be expected tropical plants are generally of short-day type while plants that originate in the middle latitudes are long-day types. Vegetables, like cabbage, lettuce, and spinach which all originate in the middle latitudes will have their flowering retarded if grown nearer the equator as the day length will be shorter than what they are accustomed to in the middle latitudes.

● ***Instruments to measure solar radiation***



Pvranometer

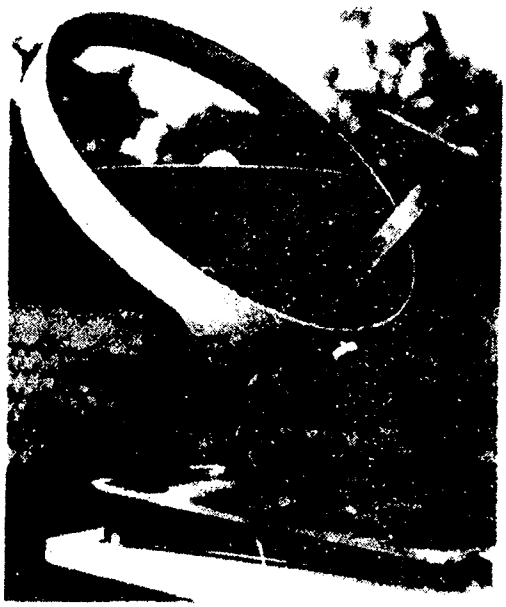
Knowledge of the amount of shortwave radiation at the Earth's surface is vital, from the viewpoint of both the energetics of the climate system and practical applications, notably in agriculture. Surface-based instruments are commonly of three types:

1. *Pyranometers,* which measure solar radiation at all wavelengths coming from an entire hemisphere. They are usually mounted with the receiver surface horizontal, thus observing the total radiation from the Sun and the sky. A pair of pyranometers, one upward facing, one looking down, are usually used to determine surface albedo. With the use of appropriate filters it is possible to measure radiation in particular spectral bands.

2. *Pyrheliomders* measuring direct solar radiation incident on a collector perpendicular to the Sun's rays. Again, these can observe the total spectrum or certain wavelength intervals.

3. *Diffusographs, which* observe radiation from the sky only. This instrument consists of a normal pyranometer surrounded by a 'shade ring' which obscures the direct beam from the Sun.

4. A simpler instrument that records the number of hours of bright sunshine is the *Campbell-Stokes sunshine recorder.* The burn produced on a graduated card is a very useful, but less exact, measure of the extent and nature of sunshine hours.



A shade-ring mounted over a Pyranometer

● ***Temperature:***

The temperature of the air and soil affects all the growth processes of plants. All crops have minimal, optimum, and maximal temperature limits for each of their stages of growth. Tropical crops like cocoa and dates require high temperatures throughout the year. Many crops such as coffee, bananas, and sugar cane are very sensitive to frosts. On the other hand, winter rye has low temperature demands and can withstand freezing temperatures during the long winter period of dormancy. Temperatures below 6° C

are lethal to most plants. The upper lethal temperatures for most plants range from 50° to 60° C depending on the species, stage of growth, and length of exposure to the high temperature. Low temperatures kill or damage plants. Prolonged chilling of plants at temperatures above freezing retards plant growth and may kill those plants adapted only to warm conditions. Although chilling may not directly kill plant cells, it reduces the flow of water from the roots and so interferes with plant transpiration and nourishment. When temperatures are below freezing the living matter of cells may freeze and cell dehydration may occur. This will eventually kill off the plants.

Generally high temperatures are not as destructive to plants as low temperatures provided the moisture supply is adequate to prevent wilting and the plant is adapted to the climatic region. Excessive heat can destroy the plant protoplasm. It has a desiccating effect on plants and the rapid rates of transpiration may lead to wilting.

Most crops cannot be grown successfully unless the temperature exceeds some critical threshold values. For instance, coconuts and pineapples thrive only when temperatures are always above 21° C for at least part of the growing season. Citrus fruit, cotton, sugar cane, and rice will not grow well if temperatures are below 15°C. Many vegetables require temperatures of at least 8°C. The critical temperature for wheat is 3 °C (Hobbs, 1980). The growing season is determined in the temperate region by temperature conditions. In the temperate region, the growing season is usually determined in either of the following two ways. First, the growing season can be defined as the period between the last killing frost of spring and the first killing frost of autumn. Second, the growing season can be defined as the period for which daily mean temperatures exceed some critical value usually taken as 6°C. For most crops soil temperatures are more important than air temperatures because they directly influence seed germination. For potatoes soil temperatures must be between 8° C and 28° C, the optimum soil temperature being 18°C. Cotton seeds require the soil temperature to be at least 10° C but below 18° C for germination.

The intensity of the growing season is represented by the accumulation of temperature units above the growth threshold. The unit used is the degree-day which takes into account the amount by which the daily mean temperature exceeds the stated minimum, usually 6° C. Thus a day of 16° C would count as 10 degree-days. The concept of degree-days can be used to estimate the suitability of a crop for a given climatic region assuming water is available. Once the threshold temperature for a crop is known, the accumulation of temperature units above this threshold can be calculated from available temperature data. This can also provide an index for comparing the thermal needs of plants as well as for indicating the suitability of a location for a particular crop. The concept of degree-days or accumulated temperatures is based on the assumptions that:

1. there is only one significant base temperature operative throughout the life of the plant;

2. day and night temperatures are of equal importance for plant growth;

3. the plant response to temperature is linear over the entire temperature range.

A rather similar index has been computed for Nigeria by Oshodi (1966). The index known as the effective growth energy is based on both temperatures and rainfall. First, a growing month is determined in terms of some critical rainfall amount that must be received. The effective growth energy is then computed as the summation of mean monthly temperatures in excess of 40 °F (4.4° C) during all the

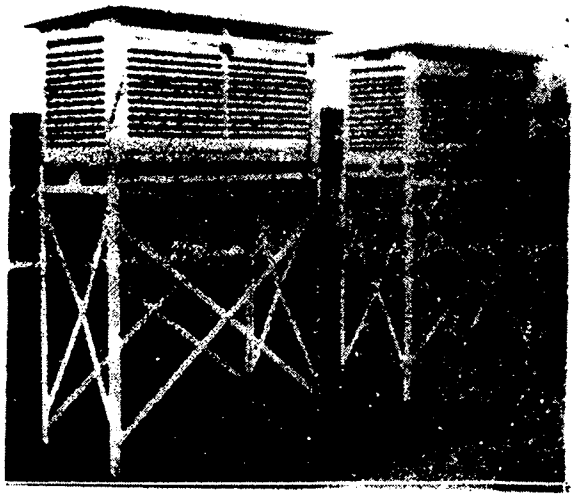
growing months at a given location. Oshodi (1966) has also related this energy index to some crops grown in Nigeria as follows:

Crop	Effective growth energy (EGE)
Swamp rice	greater than 350° F
Oil palm	250-350° F
Rubber, cocoa, coconut	250-300° F
Rice, maize, beniseed	200-250° F
Sorghum	100-250° F
Cotton and groundnut	100-200° F
Millet	75-150° F

● ***Measurement of temperature***

The basic instrument for measuring temperature is the *thermometer.* Although many types are available the most common form is the mercury-in-glass thermometer. Mercury in the bulb expands when heated, the expanding liquid being forced along the tube. The temperature is thus indicated by the length of the mercury column in the tube. The instrument must first be calibrated to provide the relationship between length and temperature. Thereafter the length can be expressed directly in temperature units.

There are numerous variations on this basic design. Two common ones are used in the maximum and minimum thermometers. In the former a constriction is placed in the tube close to the bulb. The expanding mercury is able to force its way past this, but when cooling and contraction takes place the constriction does not allow the mercury to return to the bulb. The mercury is thus left in the tube to record the maximum temperature. A rapid shaking of the lube can restore a continuous thread of mercury across the constriction, thus resetting the instrument for use again. In the minimum thermometer the mercury is usually replaced by alcohol. A small rod called; an index and usually barbell shaped, is placed within the alcohol in the tube. As temperatures fall and the liquid contracts this index is drawn towards the bulb by the surface tension of the alcohol surface.



A Stevenson Screen houses meteorological instruments, particularly thermometers, so that they are well ventilated but protected from direct sun light.

Stevenson Screen:

These instruments are generally housed in a shelter of some form often, Stevenson screen. This serves to shield the instrument from direct radiation, yet provides ventilation so that there is a free flow of air past the thermometers. The instruments thus measure air temperatures above the surface. This type of observation is frequently, and loosely, called 'surface temperature', although it is certainly not the temperature which

would be recorded by an instrument in contact with the ground. The standard usually requires the screen to be of the order of 1 m above a grass surface.

True surface temperatures can be obtained from satellite observations of upwelling radiation in selected channels in the atmospheric window. The results, after corrections for atmospheric transmission losses and surface emissivity, are true surface temperatures integrated over the field of view of the sensor. Hence they are not strictly comparable with the more traditional surface-based observations. Nevertheless, they are an invaluable accessory to these surface observations, especially over the oceans where surface observations are sparse.

● ***Moisture***:

Water in all its forms plays a vital role in the growth of plants and the production of all crops. It provides the medium by which chemicals and nutrients are carried through the plant. Water is also the main constituent of the plant tissue and a reagent in photosynthesis. Soil moisture is the source of water of importance to crop and the state of soil moisture is controlled by rainfall, the evaporation rate, and soil characteristics. The supply of soil moisture may range from *wilting point* when no water is available for plant use to *field capacity* when the soil is fully saturated with moisture but is still well drained. When soil moisture is excessive all the soil pores are completely filled with water and a *water logged* condition prevails. In such a situation free movement of air within the soil is impeded and compounds toxic to the roots of plants may be formed. At the other extreme is the condition of drought in which the amount of water required for evapotranspiration exceeds the amount available in the soil. Unless this water deficit is made good by rainfall or irrigation the plant will begin to wilt and die. Thus, like extremely low and high temperatures, too much or too little water is not good for agriculture.

Table: Rainfall requirements of selected food and commercial crops grown in West Africa

Crops	Mean annual rainfall
Yams	At least 1250mm
Kola nut	At least 1250mm
Groundnut	500-1000 mm
Beniseed and Soya beans	1250- 1500 mm
Oil palm	1500-3000 mm
Cocoa	1250-2000 mm
Rubber	2000-2500 mm
Cotton	625- 1250 mm

The role of moisture in agriculture is even more spectacular in the tropics where because of relatively high temperatures throughout the year, the rates of evapotranspiration are constantly high. On the other hand, rainfall is highly seasonal over most parts of the tropics. Because temperatures are high enough throughout the year to ensure the growth of crops over most parts of the tropics with the exception of a few mountainous areas, the growing season, unlike in the temperate region, is determined by the availability of rainfall. Some have used critical threshold values of rainfall to delimit the length of the growing season. For instance, the number of months having at least 100 mm rainfall has been regarded as constituting the growing season. A more useful parameter is the number of months when rainfall is enough to satisfy the evapotranspiration needs of plants. It has been shown in Nigeria by Kassam et al (1976) that crop water requirements are usually fully met when rainfall is only half the value of potential

evapotranspiration. The growing season in northern Nigeria has therefore, been defined by them as the period during which rainfall is at least half the amount of potential evapotranspiration. But as the amount of rainfall is highly variable, it is important to determine the rainfall requirement for the crops to be cultivated.

- ***Precipitation Measurement***

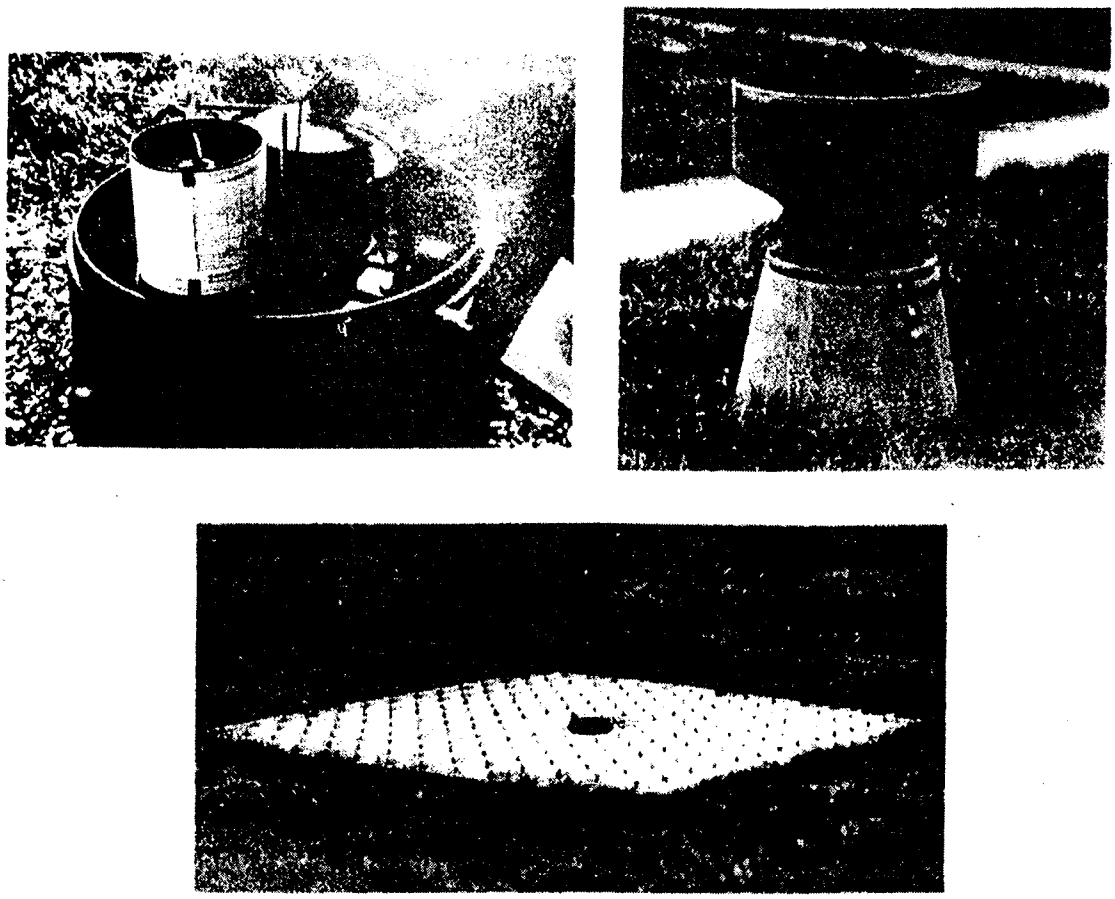
Rainfall can be directly measured using *Rain Gauge* is essentially a bucket with a horizontal orifice of known size exposed just above the surface of the Earth. The water is caught in the bucket and funneled into a measuring cylinder and the depth of water collected at the end of a period of interest is then noted. In order to maintain uniformity, most nations have established standards for the size, exposure and measurement times. There are several problems inherent in this simple measurement technique. In windy conditions turbulence in the airflow is created by the gauge itself. In particular this increases the speed of the flow across the top of the orifice, decreasing the catch and leading to unrepresentative results. This underestimate in measured precipitation is much greater for snow than for rain because the fall velocities and momenta of snowflakes are much less than those of raindrops. The decrease varies with wind speed and, in sloping terrain, with wind direction. Some gauges are equipped with wind shields, but this only partially corrects the problem. Since wind speed decreases rapidly as the ground is approached, a gauge close to the ground is desirable. However, the closer to the ground it is, the more likely it is to receive precipitation which is splashed into it in addition to the falling rain. Hence it is difficult to measure with great accuracy the amount of rainfall that actually arrives at the Earth's surface.

Rain gauges can be constructed so that a continuous record of receipt is made. A mechanism is inserted within the bucket which senses the change in water level as precipitation occurs and translates this into a trace on a chart located on a revolving drum. Such instruments allow not only the determination of total precipitation but also its intensity and duration.

Although these measurements give a good idea of the distribution of precipitation, especially when long-term averages are needed, they are spot measurements. Rainfall amounts, especially from a single storm, can have a very great spatial variation. Unless there is a very dense network of rain gauges these variations will not be identified. This can be a very serious consideration when intense storms that may cause flooding are common.

The lack of spatial coverage by rain gauges can be overcome to some extent by using information obtained by *radar.* Radar emits a pulse of electromagnetic radiation which is reflected of any obstacle in the emission path and returned to the source. By measuring the time between emission and receipt, the distance of the obstacle from the source can be deduced. By choosing an appropriate wavelength for the emission, raindrops can become the obstacles. In sophisticated systems the direction and the speed of raindrops can also be measured.

Another feature of precipitation which is routinely measured is snow depth. To do so, a site representative for the area is selected and the depth is measured simply by a measuring stick.

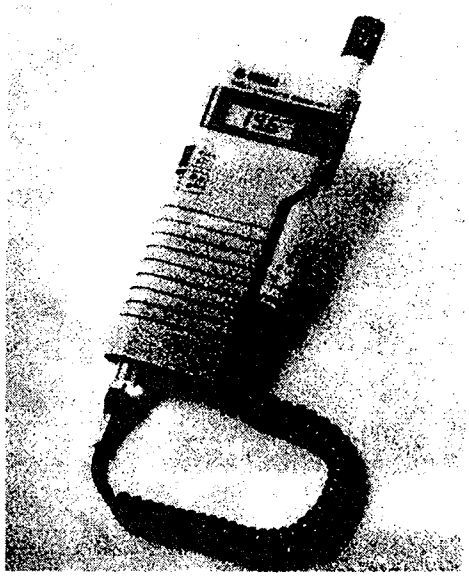


Different Types of Rain Gauge

● ***Measurement of atmospheric moisture content***

Several types of instruments have been devised to measure humidity. Only those commonly used currently are discussed here. The first is the *dew point hygrometer* (dew cell), which measures *Dew Point* directly. A mirrored surface is cooled electrically until dew forms. As soon as this occurs a photoelectric detector senses a change in surface reflectance and switches the cooling circuit to a heating one. The heater remains operative until the dew is evaporated, at which point the cooling cycle is again initiated. The cycling is repeated until a stable temperature is reached, representing the dew point of the air above the mirror surface.

A less sophisticated instrument is the *psychrometer*. This consists of two thermometers. One called the *dry bulb* is unmodified. The bulb of the second, the *wet bulb,* is kept moist by being encased in a wick connected to a water reservoir. Water is evaporated from around the wet bulb. The energy required for this evaporation is extracted from the bulb itself and thus its temperature is lowered. The amount of cooling depends on the evaporation rate, and thus on the humidity of the air. Provided an even flow of water comes from the reservoir, allowing neither flooding nor drying of the bulb, the temperature will become stable. The amount of moisture can then be calculated from the dry bulb or 'air' temperature together with the difference between the dry and wet bulb temperatures (T_a and T_w) the latter being known as the wet bulb depression. Note that the wet bulb temperature is not the same as the dew point but that $T_d \leq T_W \leq T_a$, the equalities holding only when the air is saturated. To obtain reliable estimates of humidity



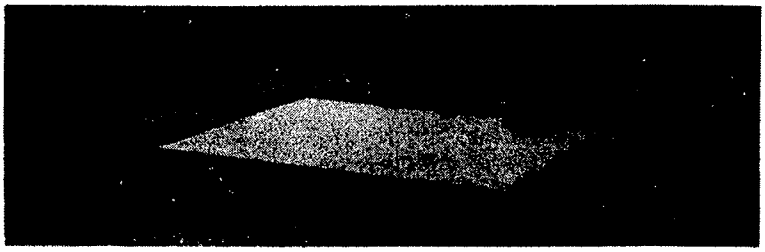
A humidity sensing instrument used in

with a psychrometer it is necessary to ensure some airflow over the two thermometers, which are usually held so that they lie parallel to each other a few centimetres apart. This airflow is created either by placing the instrument in a tube and drawing air across it, forming an aspirated psychrometer, or by *whirling* it through the air manually, as in a sling psychrometer.

Humidity in the free atmosphere is measured by both Radiosonde and satellites. Radiosondes utilize *resistance hygrometers.* These use the property of some materials, such as carbon black, *of* having an electrical resistance that varies with relative humidity. All though relative humidity is thus measured directly, raidiosonde measures temperature, so that other expressions for humidity can be calculated.

● ***Measurement of evapotranspiration***

The measurement of evapotranspiration, potential or actual, is difficult. Many techniques have been devised. The most common method of measuring PET directly is using *evaporation pans*. These are simply containers of a standard size containing water freely exposed to the atmosphere. The water depth is measured at the beginning of the time period of interest and again at the end. The difference, after correction for any precipitation received, is the evaporation. Energy transfer through the sides of the pan, together with turbulence created by the pan itself, make it difficult to relate the results to evaporation from natural open water surfaces. Usually a correction factor, a 'pan coefficient', is employed before the results are used. Rather more sophisticated instruments, *lysimeters*, are available. Usually the pan is placed on a weighing mechanism which is used to record the change in weight and thus the amount of evaporation.



Evaporation Pan

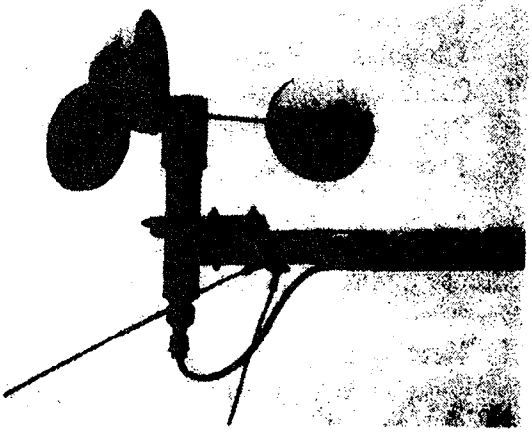
As it is difficult to measure evapotranspiration directly, it is usual to estimate it from more commonly measured parameters. Numerous methods are available. Almost all start by estimating PET from atmospheric measurements. Some simple ones, requiring only air temperature as input, can be used for the determination of monthly average values. Others are much more complex and incorporate solar radiation, wind speed, air temperature and humidity measurements, and can be used to estimate daily values. Once PET is determined, some form of book-keeping



Lysimeter

method is used to track the amount of moisture in the soil and to relate this to the amount that will be available for actual evapotranspiration.

Maximum rates of actual evaporation occur over the subtropical oceans with a general decrease in amounts poleward. Land values are lower than oceanic ones, the isopleths making a sharp break at the coasts.



Anemometer

● ***Wind***:

Wind is another climatic parameter that affects agriculture. On the positive side, wind is an effective agent for the dispersal of plants the carbon-di-oxide intake of plants and rates of transpiration tend to increase with increasing wind speed up to a certain level. On the negative side, wind may cause physical damage to crops. By encouraging a high rate of transpiration high winds can also result in plant desiccation. Winds help in the transport of pollen and seeds of undesirable plants such as weeds. Wind erosion can damage good agricultural land by removing the top soil. Also high velocity winds in relatively dry areas or during the dry season in sub-humid regions can increase the risk of forest fires that can damage farm crops.

Measurement of Wind: Anemometers are used to measure the speed and direction of wind. Anemometers are installed at a number of heights lower atmosphere if the effect of surface friction on wind speed is to be measured. In complex terrain, such as an urban centre, a large array of anemometers may be required as wind speeds can vary considerably over short distance.

● ***Weather hazards in agriculture***:

The growth of crops is not only dependent on weather conditions but crops are subject to a number of weather hazards until they are harvested. The major weather phenomena that constitute hazards to agriculture are frost, drought, hailstones, and high winds.

Frost:

Frost is said to occur if the temperature of the air in contact with the ground (ground frost) or at screen level (air frost) is below 0° C. It is ground frost that is particularly important in agriculture. In weather forecasts, the term *'ground frost'* signifies a grass minimum temperature below 0° C. There are two main genetic types of frost: radiation frost and advection or air mass frost. Radiation frost results from the rapid cooling of the air layer close to the ground following large terrestrial radiation losses on clear, calm nights. Advection or air mass frost occurs when an area is invaded by a cold air mass. Consequently, advection frost affects a large area when it occurs, whereas radiation frost tends to be spotty in occurrence.

Frosts are largely unknown in the tropics except in isolated mountainous areas. Frosts are, on the other hand, common in the temperate region and in the subtropical areas which suffer occasional

incursions of cold air masses. Because the temperature of air masses cannot be controlled on a large scale, not much can be done to control or forest the entire hazard posed by advection frost. Prevention of crop damage by radiation frost is, however, more feasible. Preventive measures are based upon knowledge of the conditions which favour the occurrence of radiation frost. The conditions are:

1. Cool, stable air mass;
2. Cloudless sky to allow loss of heat radiation from the earth's surface;
3. Calm conditions to prevent mixing of air near the ground with warmer air above
4 Relatively high dew point temperature;
5 Topographic features that encourage the drainage of cold air into depressions.

The purpose of frost prevention measures is essentially to break up the inversion that accompanies intense nighttime radiation. This may be achieved in either of the following ways:

1. Heating the air by the use of the oil burners throughout the farm. The pall of smoke formed also reduces loss of heat by terrestrial radiation just like cloud cover does. The heat from the burners also creates convection currents and brings about mixing of air in the inversion layer. The problem with oil burners is that the soot settles on crops and other things around. Also by daytime the smoke retards the warming of the ground surface. Heaters which give less smoke are now more commonly used.

2. Mixing or stirring the air by the use of giant fans operated by electric or gas driven motors. Light planes and helicopters are also used for the same purpose.

3. Other methods of frost protection include sprinkling the crops with water, brushing, and the use of shelter belts (windbreaks). The object of sprinkling crops with water for frost protection is to reduce excessive cooling and increase the thermal conductivity of the ground. The latent heat released when water freezes ensures that the temperature of the plants does not fall below the freezing level as long as the change of state occurs. This method of frost protection, however, has some limitations. Heat gain during the day is limited just as heat loss during the night is retarded. Also, successive applications of water become progressively less effective and there are difficulties in determining when and how much water should be sprinkled on the crops.

4. The method of brushing involves putting a protective covering of Kraft paper over plants to reduce nighttime radiation loss. It is obviously a slow process that is labour demanding. Mulching can also inhibit frost. Windbreaks may also be used to minimize the effects of frost, particularly advective frost.

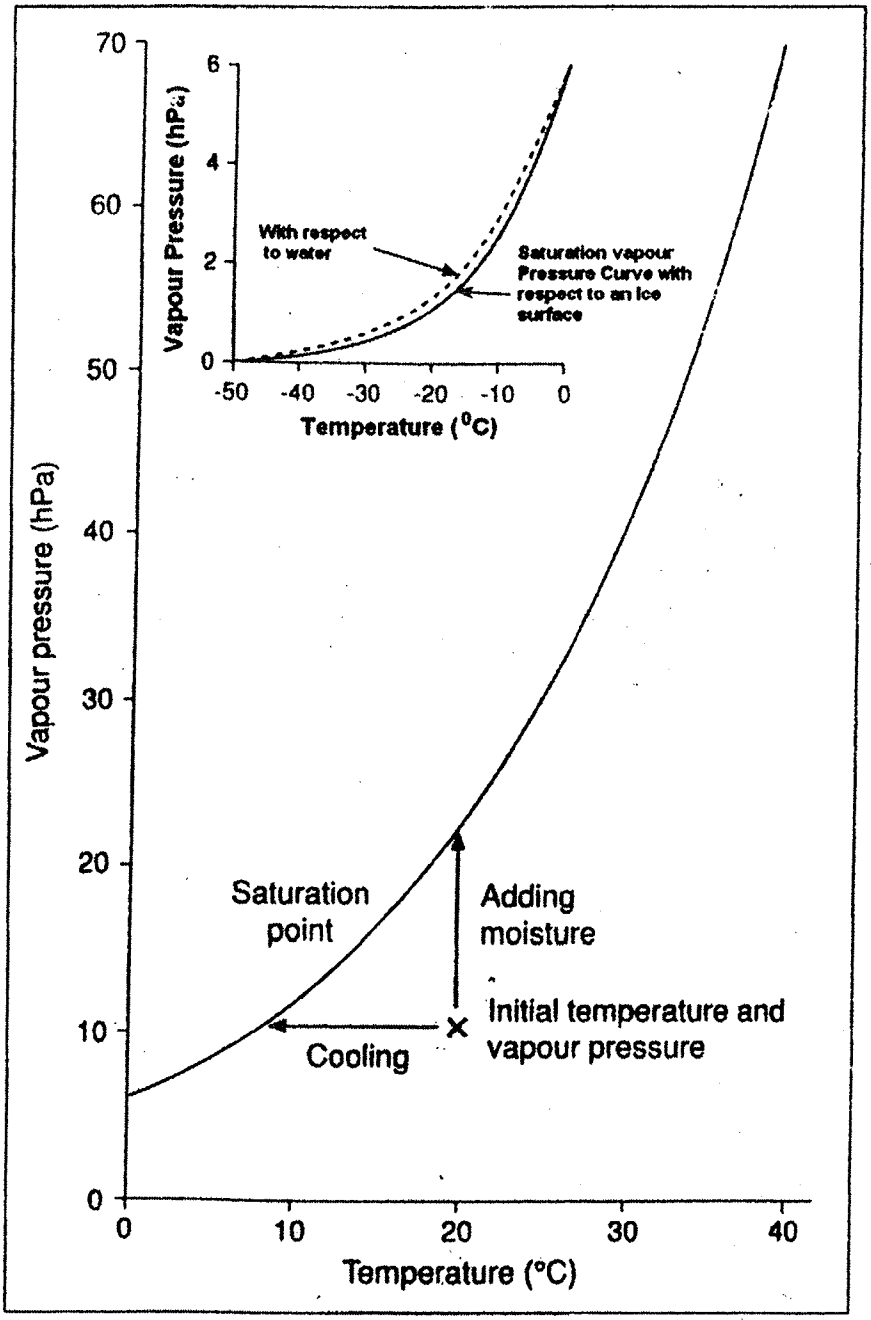
Other crop enemies like mildew, rusts, scabs, and blights reproduce and spread most rapidly when the weather is warm and very humid. Although the control of crop pests and diseases is the work of the plant pathologists, climate is an important factor in such control and must, therefore, be considered by the plant pathologist. Bioclimatology is of fundamental importance in the control of crop diseases and pests.

■ 3.3.5 MECHANISM OF PRECIPITATION

Water that falls from clouds to the ground in either solid or liquid form is referred to as precipitation. Therefore the process starts with uprising of moisture laden air mass, and passes through the intermediate stages involving- saturation of the said air mass, condensation, creation of embryonic water droplets, their growth to form cloud droplets and ultimately the raindrops.

●*Condensation:*

The ability of the air to hold moisture is dependent upon its temperature. Water molecules are continuously changing from one state to another. If more molecules are leaving a liquid surface than arriving, net *evaporation* is experienced; if more arrive than leave there is net *condensation*. As the temperature of the air increases so its moisture-holding capacity also rises; or, to put it another way, more moisture must be added to reach saturation at a higher temperature. If air is cooled, the evaporation rate will decrease more rapidly than does the condensation rate. At a certain temperature, evaporation becomes less than condensation and the water droplet grows. This temperature is known as the *dew point* and varies with moisture content. The amount of moisture which air can hold may be assessed in a number of ways. *Relative humidity* is the most frequently used term.



●*Causes of Condensation:*

Clouds are one of the most interesting aspects of the sky. Their shape and form change constantly to reflect the processes of formation and the environment in which they are developing. To produce clouds, the air is needed to reach saturation point. It is clear that saturation can be reached either by cooling the air or by adding water to air. It is by cooling of the air that the majority of clouds are formed. Orographic lifting, convergent uplift near depressions or within air

streams, and convection will all produce vertical motion which may be sufficient to produce clouds. The second process of adding water occurs over warm-water surfaces such as the Great Lakes in the autumn, or over the Arctic Ocean, where water will evaporate from the relatively warm sea surface and rapidly condense into the cold air. Almost calm conditions are needed to avoid the saturated air being mixed with drier air above.

Radiational or contact cooling at a cold ground surface may also be sufficient to produce saturation, but as these are ground-based processes the resulting condensation is known as fog. It is like cloud in being composed of myriads of water droplets.

●*Precipitation Formation*:

When a cooling air parcel reaches saturation, condensation does not occur immediately. Indeed if the parcel were rising in pure, particle free air, relative humidity could reach several hundred percent before spontaneous condensation occurred. However, even clean air is rarely entirely free of particles, and certain particles act as *Cloud Condensation Nuclei* (CCN), promoting condensation at relative humidity at or close to 100%. Common CCN include dust, day and organic particles derived from land surfaces, salt crystals derived from sea spray and particles created in the atmosphere by chemical actions usually called gas-to-particle conversions.

● Growth of cloud droplets

The size of the panicle has a great influence on its propensity for growth. Recalling that saturation is defined with respect to a plane pure water surface, water that condenses on a CCN is neither plane nor pure. Two effects come into play. The first is the solute effect. If a CCN is dissolved by the water, the air surrounding it may be saturated with respect to the resulting droplet at relative humidity <100% and further condensation is possible. Also, because of a spherical droplet, the surface is not planar and surface tension creates *curvature effect*. This second effect requires that the air be supersaturated before further growth can occur. In practice, these two effects occur simultaneously, so that droplet growth follows. If there are a large number of small CCN competing for water vapour, the supersaturation may not achieve a high enough value to allow the droplets to grow. The droplets remain small and precipitation unlikely. If this happens at low levels, haze is formed. With a variety of CCN sizes, as found in marine clouds, some droplets will be able to attain a critical size and continue to grow. They are then said to be activated and may continue to grow into raindrops.

● Growth of raindrops

Growth of activated droplets will continue by direct condensation. However, this process is very slow, much slower than the observed times needed for precipitation formation. Hence other mechanisms must be involved. The droplets suspended in the atmosphere fall under their own weight. The velocity a water droplet attains in free fall through still air, being the result of the balance between the gravitational attraction downwards and the frictional drag of the air itself, is called *terminal velocity*. This velocity increases rapidly with particle size. When clouds are formed, the air is rarely motionless, and in particular, there is likely to be an updraught in the cloud. This will mitigate against the downward movement so that the speed of the final movement towards the Earth's surface, the *fall velocity*, is given by

Fall velocity = terminal velocity — updraught velocity

Only if the terminal velocity is greater than the updraught velocity will the drop fall. In practice the small cloud condensation droplets will have a terminal velocity that is smaller than the updraught velocity and will remain suspended in the cloud. Indeed, they may never grow to sufficient size to have a positive fall velocity and thus may never leave the cloud. In order for precipitation to occur, therefore, some mechanism is needed to increase the size of a cloud droplet to that of a raindrop. The mechanism which becomes active depends greatly on the temperature of the cloud.

● ***Collision and coalescence***:

In warm clouds, where the ambient cloud temperature is above 0° C, all the condensation products are liquid water. The larger droplets will have a higher terminal velocity than smaller ones and will fall through them, collecting them and increasing in size through the collision and coalescence processes. For collision to occur the smaller droplet must be close to the axis of fall of the larger drop, otherwise it will follow the air currents around the falling drop and there will be no impact. Generally the larger the falling drop, the more efficient is the collection, drops with a radius greater than 40 μm collecting most of the droplets they encounter. Even with a collision, growth will only occur if the two drops coalesce. This will occur most readily if the drops are of considerably different sizes. These factors thus reemphasize the importance of a wide range of sizes for the original CCN for precipitation production.

● **Bergeron-Findeisen mechanism**

In cold clouds, where the ambient temperature is below freezing, the condensation products can be both liquid water and ice crystals. At temperatures below about —40 °C all the products are ice crystals and the cloud is said to be glaciated. Between 0 °C and —40 °C ice and water coexist, giving a mixed cloud. In glaciated clouds there is some crystal growth by processes analogous to the direct condensation and the collision/coalescence processes of warm clouds, but rarely do these high, cirrus type clouds yield precipitation that reaches the surface. In mixed clouds the initial growth phase depends on the coexistence of ice and water. The process is known as the *Bergeron-Findeisen process*. At temperatures below 0°C the saturation vapour pressure with respect to water is greater than that with respect to ice. Thus, in a mixed cloud, the air which is close to saturation with respect to water is supersaturated with respect to ice. Consequently ice crystals can grow much more rapidly than, and at the expense of, water droplets.

The individual ice crystals will grow and collect together to form snowflakes. The shape of snowflakes that are created depends on the temperature at which the condensation occurs. Since a crystal may move about in a cloud and experience a variety of temperatures, the shape of the snowflake which grows as a result of the accumulation of crystals can be very complex. In addition, the growing ice crystals may come into contact with super-cooled liquid water droplets which will freeze onto or around the crystal immediately on contact, a growth process known as riming. Riming is a primary mechanism of hail formation. Crystals may also grow by aggregation, a process similar to collision/coalescence. Aggregation is most marked at ambient temperatures above -5°C, when crystal surfaces become moist and sticky.

■ 3.3.6 SUMMARY

In this module three climatological issues of geographical interests have been dealt. Key points in regard to those are as follows.

1. The general circulation of the atmosphere is the outcome of the unequal receipt of insolation between equatorial and the polar regions. From knowledge of zonal net imbalance of energy and water vapour, and incorporating the impacts of the rotation of

earth, the theoretical picture of the general circulation has been explained. The general circulation serves to redistribute the energy and moisture, modifying their latitudinal imbalances and thus establishing the climate.

2. Understanding of the climatic variables is essential for agricultural planning, crop selection, optimization of agricultural productivity etc. Because, climatic conditions control every stages of crop growth.

3. Precipitation is a process that plays significant roles in maintaining the Global Hydrological Cycle. It is the most important process by which atmospheric moisture returns to the Earth's surface. Global hydrological balance and the local hydrological budget largely depend on precipitation. Therefore, the mechanism of precipitation and the conditions required for this process to take place are to be understood in the light of physical processes operative within the cloud.

7.7 SELF ASSESSMENT QUESTIONS

1. **What do you mean by Pressure Gradient Force? Elucidate its roles in Geostrophic and Gradient winds.**

2. **Bring out the concept of Coriolis Effect. How does it modify the global scale atmospheric circulation?**

3. **Describe the three cellular model of atmospheric circulation? On which points, has it been criticized?**

4. **Why the the Rhossby waves follow meandering paths? Analyze their roles in maintaining [illegible]**

5. **Why the Ferrel Cell is called thermally indirect? How does this cell operate?**

6. **How the eastward angular momentum and energy are transferred poleward through atmospheric circulation?**

7. **What are the types and characteristics of Jet Streams? How do they influence surface weather phenomena?**

8. **How do the climatic elements influence agricultural practices?**

9. **Describe the methods of measuring the agro-meteorological variables.**

10. **Briefly describe the processes involved in rain making.**

■ 3.3.8 REFERENCES

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PART - I
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Paper-II : Module-III

Unit – 04

1. Dynamics of air masses- source areas and modifications
2. Tropical cyclones and related hazards; Fronts and Extra-tropical cyclones
3. Thunderstorms and tornadoes

■ 3.4.0 Introduction

Atmospheric circulation is very important to produce weather systems as well as to modify them in an area. The role of contrasting air with their change in character due to movement is significant not only in the tropical areas, but also in the extra-tropical or mid-latitude areas. Study of weather and climate in relation to this atmospheric motion is called *synoptic climatology*, as it is done with the help of a synoptic chart showing atmospheric circulation pattern in a regional scale.

The main objectives of studying this unit are as follows:

1. To define and classify air masses, and discuss about their modifications in relation to associated weather characteristics
2. To describe tropical and extra-tropical disturbances with special reference to tropical and mid-latitude (extra-tropical) cyclones, thunderstorms and tornadoes in relation to weather characteristics
3. To understand the importance of these weather hazards in terms of their damaging impacts on man

■ 3.4.1 Air mass

● Definition

Meteorologically air mass can be defined as an extensive body of the atmosphere that is relatively homogeneous horizontally. On the weather map it is an entity that moves with the day-to-day movement in the general circulation of the atmosphere. A boundary of contrasting air masses is called *front*. The nature and degree of uniformity of air mass are determined by the following factors: (i) the nature of the source- sufficiently uniform earth's surface underlying the concerned atmosphere, (ii) the direction and speed of movement, and (iii) the age of the air mass. Although temperature and humidity near the earth's surface are usually considered two identifying criteria for air mass; specific humidity and changes in Dry Adiabatic Lapse Rate (DALR) and Saturated Adiabatic Lapse Rate (SALR), along with cloud types, wind structure and types of hydrometeors are said to be better indicators of air mass. Some of the important features associated with air masses can be outlined as follows:

(a) Surface low pressure and fronts are most often found within the transition zone of air masses.

(b) Cold dry air masses are stable due to having a higher density and higher average molecular weight (as dry air is more dense than moist air)

(c) Warm moist air masses are unstable due to a lower density due to thermal expansion and a lower molecular weight.

(d) Air masses are three-dimensional entities.

(e) The mid-latitudes are uniquely experience several different types of air masses over in a year.

(f) Low pressure forces movement of air masses. With a strong low pressure, abnormally warm air will be to the south east of the low and abnormally cool conditions to the west of the low.

(g) Air masses and air mass modification are determined by latitude, altitude, ocean currents, hours of sunshine, angle of sunshine, vegetation, soil temperatures, snow cover, prevailing wind, etc.

● Classification of major air masses and their modifications

Swedish meteorologist T. Bergeron first proposed a comprehensive classification of major air masses in 1928. His classification was originally based on air mass source or donor regions, but later on he modified the classification system by incorporating the character of airflow in the receptor region. Thus there is four-fold classification based on two major source regions (Polar and Tropical) along with their moisture regime and thermal homogeneity, as presented (Thompson, 1997) in the following table.

Major group	**Sub-group**	**Source region**	**Source properties** (***With mean temperature and absolute humidity***)	**Air mass modifications**
Polar (P)	Maritime (Pm)	Oceans north and south of 50° latitude	Cold, moist and unstable (***5 ℃ and 4.4 g/Kg***)	Moving eastwards increasingly unstable with ELR steepening (Ku) and thunderstorms
	Continental (Pc)	Arctic regions, Antarctica, north America and Eurasia	Very cold, dry and stable (surface inversions) (***-10 ℃ and 1.4 g/Kg***)	Moving equatorwards over the sea, increasingly unstable with ELR steepening (Ku) and thunderstorms
Tropical (T)	Maritime (Tm)	Sub-tropical oceans	Very warm, moist and unstable in the west; cooler and stable in the east with surface inversion (***20 ℃ and 17 g/Kg***)	Moving polewards increasingly stable with advection fog (Ws)
	Continental (Tc)	Low-latitude sub-tropical deserts	Very hot, dry and unstable in summer with dust storms; cooler, dry and more stable in winter (***25 ℃ and 11 g/Kg***)	Moving over the sea acquires moisture and prevailing instability favours thunderstorms

Cold air mass (suffix 'K'= *Kalt* means cold) moving over warm surface i.e. towards equator receives heat from below with ELR (Environmental Lapse Rate) steepening and it becomes increasingly unstable (suffix 'u'). Conversely, warm air mass (suffix 'W'= warm) moving over cold surface i.e. towards poles cools from below with surface inversions and it becomes increasingly stable (suffix's'). Thus when applied on a regional scale the complete classification takes into account the process of air mass modification too. For example, polar maritime (Pm) air mass moving equatorwards is classified as 'PmKu', where as tropical maritime air moving polewards is classified as 'TmWs'

Airmass modifications take place when an air mass moves away from its source region and are therefore affected by different heat and moisture regimes. There are types of factors, either acting separately or in combination, for such modifications. These are: (1) *Mechanical* (or Dynamic) factors, involving- (i) prolonged turbulent mixing especially at low level, and (ii) large-scale lifting by mountain barrier or by air stream convergence; and (2) Thermodynamic factors, involving- (i) radiative heat loss by the air while moving over a cold surface or *vice versa*, and (ii) addition or loss of latent heat due to condensation of overlying air mass or evaporation of underlying air mass. The processes involved in air mass modification are gradual, but in general, the lower air is changed more rapidly than that at higher levels.

● **Air masses of India**

Indian sub-continent experiences a number of air masses having their dominant characteristics in different seasons, and over different areas. A summary of these air masses may be presented in the following table.

Air mass		*Source region*	*Entry into India*	*Character*	*Dominant season in India*
Western Himalayan	*Extra-tropical*	Central Asia and Europe	Western Himalayan passes	Pc	Winter
Eastern Himalayan		Central Asia, Tibet, China	Across Tibet, Assam, Myanmar (by subsidence)	Pc	Pre-monsoon and Monsoon
Dry Transitional		North Arabian Sea, Indian deserts	West coast	Tc (hot)	Pre-monsoon summer and Post-monsoon
Westerly	*Tropical*	North Africa, Arabia, Iran	Gujarat and adjoining coasts	Tc (hot)	Summer and Post-monsoon
Moist Transitional		North of the Equator	South Arabian sea	Tm (hot)	Summer and Monsoon
South-easterlies	*Equatorial*	Equatorial region	Across Myanmar	Tm (hot)	Winter and summer
South West Monsoon		Southern Hemisphere	Across south Indian Ocean	Em	Monsoon

Note: Em= Equatorial (i.e. equator as the source region) maritime is a variant of Tm

■ 3.4.2 Tropical Cyclones and related hazards

● Definitions and characteristics

Henry Piddington, a former sea captain serving as President of the Marine Court of Calcutta, first used the term '*cyclone*,' in a presentation to the Asiatic Society of Bengal around 1840, as a derivation from the Greek word '*kyklon*' which means moving in a circle, like the 'coil of the snake'. Tropical cyclones are intense, circular low-pressure systems with strong cyclonic circulations and vigorous airflows. These weather disturbances have a variety of different regional names and period of occurrence: e.g. in the Bay of Bengal (Indian Ocean) they are called cyclones (April-July and September-November) and also in South Indian Ocean –near Malagasy (November-April), typhoons in north-west Pacific (July-October), hurricane in the north Atlantic and in south-west Pacific (June-October); and willy-willies (in loose sense, actually it is a dust storm occurred in December-April) in northern Australia. On the basis of wind speed the World Meteorological Organization (WMO) in Geneva has classified the tropical cyclones of all intensities under the following four categories:

Category	Wind speed			
	Knots (nautical mile* per hour)	Metre per second (mps)	km per hour (kmph)	Beaufort Scale Force
Tropical depression	up to 33	up to 17.1	up to 60	7
Tropical storm (moderate)	34 to 47	17.2 to 24.4	60 to 90	8 or 9
Tropical storm (severe)	48 to 63	24.5 to 32.6	91 to 120	10 or 11
Hurricane/ cyclone/ typhoon	More than 63	More than 32.6	More than 120	12

Note: * 1 nautical mile= 1' (minute) arc distance on a Great Circle, e.g. the equator.

The general characteristics of tropical cyclones can be outlined below:

(i) Their diameter is usually small, within 50 km; but may extend up to 600 km.

(ii) The storms themselves travel slowly (about 20 kmph) but erratically.

(iii) The average low pressure at the center is quite low about 950 millibar (mb), but may attain as low as 882 mb (Hurricane Gilbert in the Caribbean in September 1988).

(iv) Due to intense low pressure at the center, the pressure gradient is also very high (around 1 mb per km) producing a wind speed of more than 350 kmph.

(v) The center, with an average diameter of 15 km, of the cyclone is remarkably calm, and is called 'eye'.

(vi) Tropical cyclones mainly occur in the summer months, when their frequencies as well as rain bearing capacity are quite high.

(vii) Their frequency has progressively increased during the last few centuries, probably as a reflection of global warming.

● Origin and structure of tropical cyclones

The exact mechanism for the origin of tropical cyclones is still poorly understood. Sometimes it is said to origin due to development of a front-like situation between land and sea winds. But more acceptable concept in this regard is its thermal origin over warm tropical seas (or oceans), development of which is related to the release of latent heat of condensation. The general conditions necessary for the origin and development of tropical cyclones can be summarized (Ayoade, 1983; Singh, 2007) as follows: (a) a continuous supply of abundant heat and moisture; (b) a suitable heat source, usually a large tropical water surface; (c) low level convergence, turbulent vertical motion of air, and strong anticyclonic (diverging) circulation in upper troposphere; (d) high Coriolis deflection to generate a cyclonic movement; (e) weak vertical wind shear; (f) existence of weak tropical disturbances favouring intensification the storm; etc.

A tropical cyclone structurally looks like a cylinder extending from a low base up to the top of the troposphere. The cylinder consisting mainly of cumulus clouds widens out in its upper reaches. The cylindrical form is also associated with spiraling bands of stratocumulus and cumulus at lower levels, and cirrus or cirrostratus at higher levels. The central calm area, called 'eye' is a funnel of about 10-20 km diameters, through which adiabatic warming takes place due to subsidence of high-level air in it. This entire air column is almost cloud-free, except very thin cloud within 1.5 km from the base of the cyclonic vortex. The central calm area is surrounded by a spiral band of very strong winds associated with dense cumulonimbus clouds. Beyond this spiral band an annular belt with relatively low humidity and less cloud density occurs, in which the wind speed is also progressively lesser.

● Distribution of tropical cyclones and weather characterizes

Warm seas and oceans between 5°-20° latitudes are the favaoured areas of origin of tropical cyclones. There are six such major regions (Singh, 2007), namely (1) West Indies, Gulf of Mexico and Caribbean Sea; (2) Western North Pacific Ocean including Philippines Islands, China Sea and

Japanese Islands; (3) Arabian sea and bay of Bengal; (40 Eastern pacific coastal region off Mexico and Central America; (5) Southern Indian Ocean off Madagascar; and (6) Western South Pacific Ocean, in the region of Samoa and Fiji Island and the east-north coast of Australia.

Tropical cyclones are associated with severe decrease of pressure due to increase in air temperature, leading to high velocity wind. In the initial stage cirrus and cirrostratus clouds appear, but soon cumulus clouds overtake it with heavy rains particularly in the zone of high velocity winds. Thunders and lightning are very common phenomena especially when the cloud character changes to cumulonimbus. This type of rough weather persists for few hours, and with the passage of the cyclone the over all weather becomes clear.

● Hazards related to tropical cyclones

High velocity winds and intense rainfall are coupled with storm surges creating havoc in the low-lying coastal areas where a cyclone hit. According to Saffir and Simpson hurricane damage scale, the damages and associated storm surge (in metre, m) can be summarized (on the basis of Oliver and Hidore, 2003) as follows: (i) *minimum damage* (1.5 m surge)- causing damage to vegetation and mobile houses, (ii) *moderate damage* (1.6-2.5 m)-uprooting and blowing trees, damage to roof tops, (iii) *extensive damage* (2.6-4.0 m)- to structures, buildings, trees etc. (iv) *extreme damage* (4.1-5.5 m)- major damages to buildings and structures, severe inundation, and (v) *catastrophe* (>5.5 m)- severe damages to heavy structures, huge loss of property and life.

Storm surges are very destructive in low-lying coasts, and the potentiality of destruction increases in estuaries when incursion of sea water is blocked by river flood water leading to piling up of huge water to spread over the low-lying areas. In the USA the states of Florida, Texas, Louisiana and North Carolina are frequently hit by tropical cyclones (hurricanes) and severe damages occur. Damage to property and loss of life occur mostly due to inundation and flying planks and timbers by strong gale winds.

Adjoining areas of the Bay of Bengal are frequently worst hit by tropical cyclones. Bangladesh is a traditional victim of the storm and associated hazards. In India, Tamil Nadu, Andhra Pradesh and Orissa, and parts of West Bengal are affected by cyclones. The Super Cyclone (29th October, 1999) of Orissa is probably the strongest cyclone in India that severely affected almost one-third area of the state. The cyclone generated a storm surge of about 9 m high inundating up to 20 km inside the landmass, which remained marooned for more than a week.

Cyclonic storms and depressions occurring in the Bay of Bengal and the Arabian Sea area have three distinct periods, as follows: (1) April and May- the pre-monsoon summer months, (2) June to September- the four monsoon months, and (3) October to December- the post-monsoon period. January, February and March- these three months experience only very few and relatively weak storms. Average frequency of cyclones and the high intensity storms (within brackets) in the Bay of Bengal and the Arabian Sea area are given in the following table, from which it is evident that cyclonic activities are more frequent in the Bay of Bengal.

Months	The Bay of Bengal	The Arabian Sea
January	4 (1)	2 (0)
February	1(1)	0 (0)
March	4 (2)	0 (0)
April	18 (7)	5 (4)
May	28 (18)	13 (11)
June	34 (4)	13 (8)
July	38 (7)	3 (0)
August	25 (1)	1 (0)
September	27 (8)	4 (1)
October	53 (19)	17 (7)
November	56 (23)	21 (16)
December	26 (9)	3 (1)

Source: P. K. Das (1995) - *The Monsoons*, NBT

■ 3.4.3 Fronts and Extra-tropical Cyclones

● Definition and types

V. and j. Bjerkness, H. Solberg and T. Bergeron coined the term 'front' during the First World War to denote a surface of air mass conflict or separation, as analogous to the military dispositions and activities in the war zone. A front can be defined as a narrow zone of thermal discontinuity (called *baroclinic zone*) in air mass properties. This is transitional layers of about one kilometers thickness, and slopes very gently up towards the cold air mass. Within this layer there is turbulent mixing between the two air masses. In the zone of separation, where warm air replaces cold air a *warm front* is developed, similarly where cold air replaces warm air a *cold front* is originated. Sometimes existence of two more types of fronts is recognized. These are- *occluded front*, a situation when cold front overtakes warm front and warm air is completely displaced from the ground surface; and *stationary front*, when two contrasting air mass converge but remain parallel and stand still. The occlusion of fronts can occur in two ways: (a) when the cold air behind the cold front is colder than

the advancing cold air that is ahead of warm front, the cold front overtakes warm front, the *cold front occlusion* occurs; and (b) when the air behind the cold front is warmer than the advancing air that is ahead of warm front, the retreating air overtakes the advancing air, the *warm front occlusion* occurs. The process, through which fronts are created or are intensified, is called '*frontogenesis*' the initial process of cyclonic development (called *cyclogenesis*). This is common in low-pressure regions where two contrasting air mass- warm and cold, converge. If airflow pattern diverges the existing fronts weakens. This occurs due to subsidence of air from higher level, leading to development of anti-cyclones and disappearance of fronts, called '*frontolysis*'.

● ***Fronts and weather***

Vertical motion in the air masses is responsible for the associated weather conditions. If the air in the warm sector rises relative to the frontal zone the front is usually very active, and is called '*ana-fronts*' (*ana* means up). When warm air sinks relative to the cold air mass, it becomes less intense and it is called '*kata-fronts*' (*kata* means down). Since a warm front moves at about 50 kilometer per hour, the entire warm front cloud sequence takes about 18 hours to pass by a given location, giving rain and drizzle for some 6 hours at a stretch. In a very active cold front thunderstorms and tornadoes are quite common features of cumulus clouds, and precipitation takes the form of torrential rain showers along with hailstorms.

● ***Major frontal zones***

The two low-pressure belts, namely- equatorial and sub-polar, are principal converging zones of air masses, but there are other potential areas where contrasting air masses create fronts. The most prominent frontal zones in the Northern Hemisphere conspicuously found both in summer and winter are- the Polar and the Arctic fronts. The other major front, called the Mediterranean Front, occurs only in winter season.

The *polar front* is found in both of the hemispheres, and it is more prominent over the Atlantic and the Pacific Oceans. In northern winter it shifts towards the equator. The *Arctic Front* lies roughly parallel to the shores of the Arctic Ocean both in summer and winter. The *Mediterranean Front* is created in winter, when European (Pm or Pc) air mass converges with North African (Tc) air mass. In summer the Mediterranean region comes under the influence of sub-tropical anti-cyclone with hot and dry air. Two trade winds (*not air masses in true sense, as there is no temperature contrast between the two*)

converge in the equatorial low-pressure area, forming a front-like zone that shifts with the apparent movement of the sun.

▲ Extra-tropical cyclones

Fronts, together with traveling high and low pressure systems, are responsible for the development of mid-latitude or temperate or extra-tropical cyclones. These are also called wave cyclones or depressions due to occurrence of low pressure in the center and increasing pressure outward. On the basis of their shape, may be roughly circular or elongated/ elliptical (like wedge) or oval, they are variously called *lows*, or *troughs*. General characteristics of extra-tropical cyclones can be outlined as follows:

(i) They are usually found in the temperate region between 35° to 65° latitudes of both the hemispheres.

(ii) They are originated due to convergence of contrasting air masses- i.e. warm moist tropical and cold dry polar.

(iii) They move in a easterly direction due to the influence of westerly winds (as effect of Coriolis force is high in these high latitudes)

(iv) Their diameter ranges between 200 and 3000 km, but mostly within 800 to 1500 km. The vertical extent of them is usually within 10 to 12 km from the earth's surface.

(v) The speed of extra-tropical cyclones also vary, the average is about 30 to 50 km per hour. The wind speed increases with height and decrease of temperature.

(vi) The weather pattern is more complex, particularly in winter. Within a period of 2 days as many as four depressions may pass over an area experiencing varied changes of weather within a short period of time.

● Origin of extra-tropical cyclones

Frontogenesis in extra-tropical cyclones or depressions must fulfill three conditions, namely (i) existence of two adjacent air masses of contrasting temperature, (ii) a strong converging atmospheric circulation to bring the air masses close to each other, and (iii) sufficient Coriolis force to ensure warm air does not just lie on the cold air (Ayoade, 1983). A number of postulations and theories have been developed by different meteorologists since the second half of nineteenth century; among them *polar front theory* and *baroclinic theory* are front-runners.

● **Polar front theory:** This is also known as wave theory, which was propounded by Norwegian meteorologist Vilhelm Bjerknes and his son Jakob Bjerknes in 1918. This theory is primarily based on formation of fronts. According to theory the life-cycle of an extra-tropical cyclone undergo six successive stages as follows: (1) *Initial stage*- during this two contrasting air masses lie parallel to each other, a stationary front is created; (2) *Incipient stage*- a wave-like unstable front is created due to penetration of warm and cold air masses into one another's territory; (3) *Mature stage*- warm and cold fronts are fully developed and isobars become almost circular, warm air ascends over cold air; (4) *Narrowing stage*- fast advancement of cold front narrows down warm sector- the two fronts come very close; (5) *Occlusion stage*- advancing cold front overtakes the warm front leading to occlusion; and (6) Final stage- warm sector completely disappears along with the occlusion, resulting in dying of the cyclone.

● **Baroclinic wave theory**: This is actually an assemblage of conceptual developments based on information of upper air circulation to provide a satisfactory explanation of *cyclogenesis*- the formation of cyclones. Although polar front theory is still accepted as a valid theory to explain origin and development of extra-tropical cyclones, its inadequacy is felt in regard to its consideration of surface data only. In comparison baroclinic wave theory relies mostly on upper air knowledge in addition to surface data. Some of the important postulations of baroclinic wave theory are: (1) the cyclones and anticyclones are part and parcel of general circulation; (2) observations of upper winds show that the circulation is wave-like and within the waves there are troughs and ridges; (3) the waves of variable lengths and magnitudes migrate eastwards (as observed across the USA); (4) occurrence of the westerly jet stream can be attributed to the fact that winds aloft move from warmer to cooler areas due to strong Coriolis deflection; (5) exchange of heat and moisture between the tropics and polar region is possible through these weather process, etc.

● **Weathers associated with extra-tropical cyclones**

Weather characteristics associated with extra-tropical cyclones vary greatly over an area due to its moving nature and also different stages of its development over time. However, on the average, the following sequence of weather can be observed over a given location associated with the passage of a depression: (a) *Ahead of the warm front*- with the slow but steady rise in temperature there is fall of atmospheric pressure and increase in wind speed and occurrence of precipitation; (b) *At the warm front*- rise of temperature, decrease of wind speed, almost no precipitation; (c) *In the rear of the warm front*- little or no change in temperature, steady wind, intermittent rain and drizzle; (d) *Ahead of the cold front*- pressure falls and wind speed increases, some rain; (e) *At the cold front*-pressure rises suddenly followed

by increase in wind speed, fall of temperature and humidity, occurrence of heavy rain accompanied by hail and thunder; (f) *In the rear of the cold front-* fine spells of rain followed by low humidity and continuous rise in atmospheric pressure. Therefore, it is obvious that the people residing in a frequently occurring extra-tropical cyclonic region are in great difficulties to adjust with the rapidly changing weather conditions.

● 3.4.4 Thunderstorms and Tornadoes

Among the tropical weather systems thunderstorms and tornadoes are very important in terms of their destructive presence. Both are considered as tertiary type of atmospheric phenomena as they use to be short in duration and highly localized in their operation. But both thunderstorm and tornado are quite quick in their movement so that very difficult to cope with the damages associated with them.

● 3.4.4.1 Thunderstorms

Thunderstorms are intense local storms associated with dense cumulonimbus clouds produced due to rapid updraft (convection) of moist air; and include torrential rain, hail, lightning and thunder, and gusty squall winds near the earth's surface. Sudden heavy downpour from cumulonimbus clouds is often called *cloudbursts*. Thunderstorms usually occur in the tropics but they are not uncommon in the mid-latitude regions.

Injuries and fatalities are common hazards associated with thunderstorms. Lighting when struck on buildings may damage it substantially and it also causes loss of life. Hailstones are quite dangerous for grazing animals and also for standing crops. Localized downdrafts with strong wind (called downbursts) can cause much damage on the ground surface. bn

● Conditions of origin and stages of development

The preconditions for origin of thunderstorms are the presence of rising unstable (warm and moist) air with a vertical extent of about 8 km, throughout which ELR is usually greater than both DALR and SALR, called absolute instability. Latent heat energy released through condensation of rising air is quite responsible for the development of thunder clouds. The common processes for initiation of thunderstorms are (Critchfield, 2004): (a) heating and convection in moist air over warm and surface, (b) passage of cold and moist air over warm water, (c) forced ascent of conditionally unstable [*Note*: in such situation Dry Adiabatic Lapse Rate (DALR) is greater than Environmental Lapse Rate (ELR) or normal lapse rate up to Lifting Condensation Level (LCL), and above LCL due to release of latent heat ELR is greater than Saturated Adiabatic Lapse Rate (SALR)] air along zones of convergence or at mountain barriers, (d) radiation cooling at upper levels, or (e) advection of cold air aloft.

The life-cycle of a thunderstorm is usually very short, about 1 to 2 hours and has a very small size, diameter normally does not exceed 25 km. Three stages of development of a thunderstorm can be recognized: (1) *the developing stage*- characterized by strong updrafts, development of cumulus (thunder) clouds and almost no precipitation; (2) *the mature stage*- the intensity of the thunderstorm is the highest, some downdrafts occur although updrafts are still very strong, development of an anvil-head cumulonimbus cloud at the top of the troposphere (at about 18 km above the ground surface), and intense but localized precipitation along with thunder and lightning; (3) *the dissipating stage*- down drafts prevail over updrafts, moisture in the cloud is exhausted resulting in decrease of rainfall intensity, and the clouds disintegrate into stratiform (altostratus and cirrostratus).

● **Types of thunderstorms**

Conventionally thunderstorms can be classified into three types, as follows:

(1) ***Air mass thunderstorms***- they are found locally where lapse rate is steeped due to intense solar heating. They occur usually in the afternoon, e.g. *Kalbaishakhi* in West Bengal

(2) ***Line thunderstorms***- they are organized in bands, called ***squall lines***, in the direction of winds at lower level. These are originated and powered by mechanical lifting of conditionally or convectively unstable air mass by highland barriers, as in North Bengal and in the states of Meghalaya and Assam. These also occur in the afternoon.

(3) ***Frontal thunderstorms***- they occur at day or night time, but in the mid-latitude only, usually along the cold fronts, where unstable air is forced to ascend.

● **Lightning in thunderstorms**

The flash of light accompanied by discharge of atmospheric electricity is called lightning, and thunder is the noise created by sudden heating and expansion of air along the path of lightning. Origin of lighting in thunderclouds is still poorly understood. But is seems that this is due to difference in electric potential between the earth's surface (negatively charged) and the atmosphere (positively charged). In a thunder cloud there is accumulation of both positive and negative charges produced during break of raindrops and/ or ice crystals. Sparks occur between the centers of charges when the potential difference is over 100 million volts or so. The discharge of potential through lightning may occur within the cloud or between cloud and ground.

■ **3.4.4.2 Tornadoes :**

The tornado has its origin in Spanish word '*tornada*' meaning twisting (earlier '*tronada*' meaning *turning*). It is an extremely intense vortex (i.e. a twisting funnel of converging spiraling air) of small

horizontal extent that comes down from the base of a cumuliform cloud. The exact mechanisms and characteristics of tornadoes are not yet fully known due to the facts that: (a) tornadoes are short lived, having erratic path of movement and are highly localized, usually within a very small area, and (b) no meteorological recording instrument can withstand against the violent winds of tornadoes. Thus, the characters of the storm are largely an estimation based on the damages created along the passage of a tornado. However, following characteristics of tornadoes can be generally accepted:

(i) These are probably the most violent storms on the earth's surface. The estimated wind speed of rotation is about 3 to 4 hundred kilometers (km) per hour, against which no anemometer can survive.

(ii) There is a sudden drop of atmospheric pressure, the average being more than 25 millibars along the passage of a tornado. This intense pressure difference between inside and outside of closed buildings cause 'explosion' of such structures, instead of being blown over.

(iii) The surface path of most of the tornadoes is quite narrow varying few meters to less than two kilometers; and the average length of passage is about 40 kilometers.

(iv) Tornadoes are very short lived, on the average they stay about 15 to 20 minutes, but sometimes the duration may be longer.

(v) Usually they rotate in a cyclonic (counter-clockwise) direction. But the movement of a tornado on the ground surface is very erratic. Speed of movement of the tornadoes on the surface varies from near stationary to about 100 km per hour.

● Origin of tornadoes

The essential preconditions for formation of tornadoes are: (a) presence of a warm and very moist air mass, (b) existence of unstable vertical temperature profile, and (c) presence of a mechanism to start rotation. For this reasons they usually occur in conjunction with severe thunderstorms, squall lines or severe cold fronts. Tornadoes mostly occur in the tropical air, as supply of energy through moisture is abundant in this region. However, they may also occur elsewhere having favourable conditions to form.

It may be noted that tornadoes occurring in conjunction with scattered storms usually have less duration and they have erratic path of movement, but those associated with squall lines or severe cold fronts live longer, with more regular and longer path of movement.

● **Global distribution tornadoes and associated hazards**

The Great Plains of the USA, having farourable cold air of the Rocky Mountains and warm moist air of the Gulf of Mexico, is the foremost tornado region of the world. Spring and early summer are the most likely seasons of their occurrence in this region, and here they appear mostly in the late afternoon in coincidence with diurnal heat maxima. Other regions of the world experiencing tornado menace are the coastal or near coastal regions of Europe, Australia, Japan, Argentina, South Africa, and the Gangetic Plains of India and Bangladesh.

Tornadoes in the sea are known as water spouts, having a relatively small diameter column of condensed water vapour in the low-pressure vortex. These are found in the offshore region of China, Japan and the USA, where cold continental air pushes over warm water. They constitute serious hazards for smooth movement of sea vessels. In hot deserts, tornadoes do not give any precipitation but raise enormous dust, and hence they are aptly called *the dust devils.*

A large, well-developed tornado funnel when touches the ground surface destroys most of the things on its passage. Sometimes a number of tornadoes may occur in groups, called *tornado outbreak* to create severe damages. The deadliest component of tornadoes is the uprooted trees, their branches, torn roofs of buildings and structures- together called *tornado missiles.* The severity of tornadoes is assesses on the basis of its destructive activities, on the basis of which T. Theodore Fujita of Chicago University has developed a relative severity scale, popularly known as the *Fujita Scale*, in the late 1960s (Oliver and Hidore, 2003). Forecasting of tornadoes is very difficult due to unpredictable nature of the storm. However, recently developed *Doppler Radars* can be successfully used to predict the likeliness of occurrence and path of a tornado, at least 20 minutes earlier, so that some protective measures can be taken beforehand.

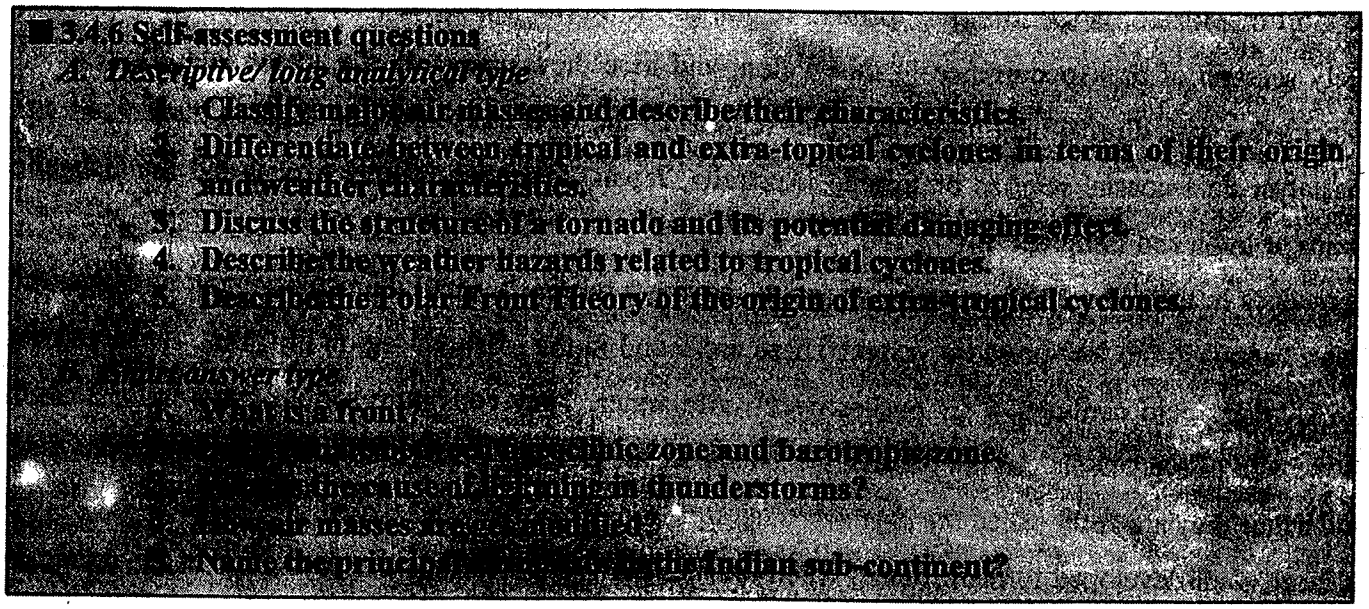
■ **3.4.5 Key words and study guides :**

The discussion as above has tried to incorporate the following key words with their relevance and meaningful understanding in climatological studies among the advanced learners in geography:

Air mass, Air mass modifications, Tropical cyclones, Cyclonic hazards, Fronts- ana fronts and kata fronts, Baroclinic zone, Frontogenesis and frontolysis, Extra-tropical cyclones, Polar Front Theory, Baroclinic Wave Theory, Thunderstorms, Lightning and Tornadoes.

The points discussed here are only illustrative, but concise and to the point. Readers are advised to follow some of the basic literatures of climatology as given in the reference. Advanced readers may consult other

books and journals available in various libraries and take note of more theoretical aspects related to some weather systems, and also the latest reports on weather hazards from different parts of the globe.



■ 3.4.6 Self-assessment questions

A. Descriptive/ long answer type

1. Classify mid-latitude cyclones and describe their characteristics.
2. Differentiate between tropical and extra-tropical cyclones in terms of their origin and weather characteristics.
3. Discuss the structure of a tornado and its potential damaging effects.
4. Describe the weather hazards related to tropical cyclones.
5. Describe the polar front theory of the origin of extra-tropical cyclones.

B. Short answer type

1. What is a front?
2. Distinguish between the cyclonic zone and baro-tropic zone.
3. What are the causes of lightning in thunderstorms?
4. How air masses are classified?
5. Name the principal [illegible] in the Indian sub-continent?

■ **3.4.7 References :**

Ayoade, J. O. (1983) - Introduction to Climatology for the Tropics; John Wiley & Sons, New York

Critchfield, H. J. (2004) - General Climatology; Prentice-Hall of India Private Limited, New Delhi, Fourth Edition

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M.A./M.Sc. PART – I
Paper - II : Module - III
Unit – 05

Module Structure

- 3.5.1 Introduction
- 3.5.2 Objectives
- 3.5.3 Climatic Classification By L.D. Stamp
- 3.5.4 Trewartha's Scheme of Climatic Classification
  - ▲ 3.5.4.1. Deviations of Trewartha's Classification from the Koppen's System.
  - ▲ 3.5.4.1. Distribution of Climates on a Hypothetical Continent
- 3.5.5 Global Climatic Changes and Global Warming
  - ▲ 3.5.5.1 What Is Climatic Change
  - ▲ 3.5.5.2 The Present Climate
  - ▲ 3.5.5.3 Evidence for Climate Changes
  - ▲ 3.5.5.4. Causes of Climate Change
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- 3.5.6 ENSO Phenomena
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  - ▲ 3.5.6.4. El Nino characteristics
  - ▲ 3.5.6.5 La Nina Characteristics
  - ▲ 3.5.6.6 Global Effect
  - ▲ 3.5.6.6 Southern Oscillation Index (SOI)
  - ▲ 3.5.6.7 El Nino and Climate Change
- 3.5.7 Summary
- 3.5.8 Self Assessment Questions
- 3.5.9 References

M.A./M.Sc. Part - I
Paper-II,
Module-3, Unit-V
Marks- 10

■ 3.5.1 INTRODUCTION:

The climate of any place depends chiefly on six factors- *the hemisphere* that determines the warm season outside the tropics, or the wet season between them; the *latitude* that controls the day length, annual mean temperature, seasonal range, rainfall and prevailing winds; the *elevation*, which influences the amount of net radiation, mean temperature and its annual and diurnal range, precipitation; the *ocean circulation* which affects conditions at the coast; the *distance from the ocean* front that determines the range of temperature; and lastly, the *topography* that determines the local airflow and temperature. Being influenced by these factors, climate of a place exhibits particular characteristics defined by temperature, pressure, moisture content of air, winds, precipitation, sky condition, sun shine etc. which exhibit variability over time and space. But when the time series data on the above parameters from all the meteorological stations reaches our hand, it becomes a flood of numbers from which it is impossible to derive any information about the spatial distribution of climatic types. So, it is needed to summarize them. Climate classification is an exercise of averaging climatic information over space and time that allows to understand the characteristics of climatic regions and the differences between two such regions.

Any change in the climate factors does introduce changes in the climate of a region. Evidences have shown that the climate of the Earth have undergone changes at regional as well as global scale through out the geologic history. Biological world had been influenced and the abiotic components of the earth have also responded to the events of climatic change. Therefore, goal of recording climate is not only to understand its variability over space but also to recognize the changes over time.

■ 3.5.2 OBJECTIVES:

The purpose of this module is to elaborate the schemes of climatic classification advocated by L. D. stamp and G. T. Trewartha. They are required to be understood as climatological exercises to broadly describe the climatic types of the world. Students are also to learn the bases and approaches followed in these schemes and how they differ from those of Koppen, Thornthwaite. The second part of this module deals with climate change during geological past and twentieth century global warming. The evidences and information gathered so far regarding the nature of climate changes during geological periods have been briefly presented along with the probable causes of climate change. The phenomena of global warming have been discussed covering all the relevant issues like- anthropogenic cause, observed and predicted effects etc. The El Nino and Southern Oscillation phenomena have been treated here as the regional climatic variability of short duration.

■ 3.5.3 CLIMATIC CLASSIFICATION BY L. D. STAMP

L. D. Stamp presented a scheme of climatic classification for the Asian continent. He identified three essential elements in the climate of Asia- the dry out blowing winds of winter, the wet in-blowing winds of summer and the controlling influence of the relief. Due to vastness of the continent and higher degree of variations in its topography, the continent of Asia exhibits a wide diversity in climatic types which have been described below.

(1) The Equatorial Climate: The equatorial climate occurs as a belt on either side of the Equator, normally extending roughly between 5° North and 5° South. It therefore occurs almost throughout the East Indies, in Malaysia and, in a modified degree, in Sri Lanka.

The temperature is high all the year round, and is characterized by its very small variation. In typical localities the average for the year is between 78° and 80° F.; the range between the hottest and coldest months is normally less than 5°. Similarly, the differences between day and night temperatures are small, and may be taken as usually less than 20°F. The average temperature is uniformly high. The absence of really high temperatures—the thermometer rarely rises above 100° F.—and the pleasantly cool rains accompanied by the afternoon thunderstorms, make the climate quite pleasant. This is particularly the case in maritime situations such as the island of Singapore, where land and sea breezes impart a welcome movement to the air. The climate is found at its worst in the interior of the great Equatorial forests where the air is absolutely still. The effect of elevation is to lower the average temperature and, sometimes, to result in a slightly greater range.

In Equatorial regions the rain falls at all seasons of the year and there is, typically, no 'dry season', except in a relative sense. As the Equatorial lands are lying in the Belt of Calms or Doldrums, and the rains are mainly, sometimes entirely, convectional rains. During the early part of the day bright sunshine induces rapid evaporation and an upward current in the atmosphere. The ascending moisture-laden air becomes cooled and clouds form. The formation of clouds in the afternoon and the subsequent precipitation is frequently accompanied by thunder. The rain falls in torrential downpours, usually of short duration. The average of cloud lies between $\frac{3}{8}$ and $\frac{7}{8}$ throughout the year. The relative humidity in regions of Equatorial climate is uniformly high, being on an average over 80 per cent, the year through. Although rain falls throughout the year, stations near the Equator usually have two periods of maximum rainfall; stations towards the northern or southern fringes of the belt have usually one. In most cases the rainfall maximum or maxima occur shortly after the period when the sun is vertical. The farther one goes away from the Equator the longer will be the duration of the dry or relatively dry period; hence the gradual passage into the Tropical Monsoon climate.

(2) The Tropical Monsoon Climate: This type of climate occurs mainly within the Tropics. The typical monsoon lands are India, Indo-China and southern China. Central and northern China and Japan are often called 'monsoon lands'; their rainfall is due to similar causes, but they lie outside the Tropics, and have distinctly cold winters, thus necessitating their separation from the tropical monsoon lands. In winter the monsoon lands are under the influence of the normal Trade winds—the 'winter monsoon'; in summer these winds are completely reversed. The three major seasons are:

(a) The cool season, with little rain, from November to about the end of February.
(b) The hot season, also rainless, from February to the middle of June.
(c) The rainy season, when the rain cools the atmosphere and temperature is generally lower, from the middle of June to about the end of October.

Generally speaking, the drier the place the less the cooling influence of the rain is felt and the greater the range of temperature. There is thus a very large range in the Punjab (plains of North-west India). The wetter places, on the other hand, and those under the influence of the sea, have a much smaller range of temperature. Bombay is a good example. It should be noted that in October, when the rains are drying up, there is a slight rise in temperature.

The rainfall in monsoon lands depends largely on relief. Where the monsoon comes in contact with high mountains near the coast, and is forced to rise, the resulting rainfall is very great. Average annual rainfalls of over 500 inches are known, and such exposed situations have been found to be the rainiest in the world. On the other hand, near the low-pressure centre in India, towards which the winds blow for great distances overland, they- arrive practically dry, and certain stations have less than 5 inches of rain per year.

(3) The China Type of Climate: The China type of climate or the Warm Temperate East Coast Climate is found in central and northern China. Central and northern China form part of the great monsoon region of Asia, but the climate differs from the Tropical Monsoon climate of India and southern China in the coldness of the winters. The rainfall, like that of India, is due to the development of low-pressure centres in the interior of Asia in summer, towards which rain-bearing winds from the ocean blow. Whilst India is protected in winter from the cold out blowing winds from the heart of Asia by the mountain barrier of the Himalayas, China is not so fortunate. The January isotherm of 32°F almost reaches the Tropic of Cancer; snow is common in winter, even on the plains. The essentially summer rainfall is greatest near the coast.
Three sub-types may be distinguished:
(a) Central China (examples Shanghai and Hankow).
(b) Northern China (example Peking).
(c) Japan type, modified by Japan's insular position.



(4) The Manchurian Type of Climate: The Manchurian or Cold Temperate East Coast Climate may be assimilated with the climate which is found around the mouth of the St. Lawrence in North America in the large temperature range but not in the rainfall regime. The climate is found in Manchuria and Amuria, and one might, indeed, include the north China region mentioned above. The range of temperature is very large; the winters are long and severe. The monsoonal influence is still seen in the rainfall regime.

(5) The Hot Desert Climate: This type of climate is found over wide areas in south-western Asia about the latitude of the Tropic of Cancer. These regions lie along the sub-tropical high-pressure belts, and they are situated practically outside the influence of either the true monsoon or the true Mediterranean belts.

The hot deserts of south-western Asia can be resolved into two types —those which have a very dry type of monsoon climate (Lower Indus Valley and the Thar Desert of India) and those which have a very dry type of Mediterranean climate (Syria, Iraq and part of Iran).

The absence of clouds allows the sun's rays to shine down with unmitigated force on the unprotected soil during the day, whilst the absence of cloud at night permits rapid radiation of heat, so that the nights are often very cold. Similarly there is a big contrast between the hot season, when the sun is almost vertically overhead, and the cold season. There is little or no rain to exercise a cooling influence on the summer temperatures; most of the hot deserts are low lying, so that there is not even altitude to temper the heat. As a result some of the highest temperatures of the world are recorded in these regions. Jacobabad, in the driest part of the Indus Valley of India (a very dry monsoon type), has an average temperature of nearly 98°F in June.

(6) The Mid-Latitude Desert Climate: This type of climate is the climate of the high plateaus of Asia. These deserts like areas are cut off from the oceans by distance and mountain barriers. They are characterized by having wide ranges of temperature and a very low rainfall. Generally they are huge areas of high pressure –great masses of cold air—in winter, and areas of low pressure with in blowing winds in summer. The scanty rainfall is therefore mainly in summer, except in those regions which border the Mediterranean countries. Indeed, it is observed that the climate of the mid-latitude deserts is obviously related to the climates of the surrounding regions. The deserts of the heart of Asia are bordered on the south-west by Mediterranean lands, on the south and south-east by monsoon lands, on the east by regions with the China and Manchurian types of climate, on the north by the cold forest lands, on the west by the mid-latitude grasslands. The desert may thus be a very dry grassland region, a very dry Mediterranean region, and so on.
At least four sub-types may be distinguished:

(a) *The Tibet type*—found on the highest plateaus (Leh in Kashmir).

(b) *The Iran type*—found on the enclosed plateaus of Iran and Afghanistan, with a winter rainfall regime (example, Tehran in Iran).

(c) *The Gobi type*- found on the plateaus of lower elevation and in the basins north of Tibet (examples, Kamgar, Urga in the Gobi Desert, Lukchun in the Tarim Basin).

(d) *The Turkistan or Turan type*- found on the lowlands to the south-west of Siberia, the Turanian Basin—a very dry type of steppe (example, Tashkent).

The rarity of the atmosphere may result in some extraordinary phenomena of temperature. In Tibet the ground temperature in the sun may be over 130°F whilst it is still freezing in the shade. There are similarly enormous differences between day and night temperatures. Some of the greatest known annual ranges are in the climates of the mid-latitude deserts. The rainfall varies from 15 inches downwards. Semi-desert conditions may even prevail where the rainfall is rather more. In the higher regions some of the precipitation is in the form of snow.

(7) The Mediterranean Climate: Like the monsoon climate, the Mediterranean climate is a very distinctive type. It is found in Asia round the coasts of Asia Minor and Syria and in a modified form along the Kurdistan Mountains. The Mediterranean climate is a 'west coast' climate, occurring on the western sides of the land masses in roughly the same latitudes as the China type on the east. On the west the great

land masses roughly between latitudes 30° and 45° are under the influence of the sub-tropical high-pressure belt in summer when the regions are hot and dry, with out blowing winds. In winter, however, the regions come under the influence of the Westerly wind belt and so enjoy moist, mild winters. In other words this is, par excellence, the 'Winter Rain Climate'. Another characteristic of the Mediterranean climate is the large amount of sunshine. Almost cloudless skies are the rule in summer, and even in winter clouds are less numerous than would be expected. The Mediterranean lands of south-western Asia belong to what is called the 'Eastern Mediterranean type', and suffer from colder winters than are usual farther west.

(8) The Mid-Latitude Continental: The Mid-Latitude Continental or mid-latitude grassland climate, is found in the wide open grasslands or steppe lands of western Siberia and, in a rather modified form, in such areas as the grasslands of Mongolia. This type of climate is characteristic of the interiors of the great land masses, removed from the influence of the sea and hence suffering considerable extremes of temperature. The light spring and summer rains encourage the growth of grass, but are insufficient for trees. The winters are long and severe; the summers are short but warm. The rainfall in typical regions ranges between 10 and 30 inches, coming almost entirely in spring and summer. The great heat of late summer and the intense cold of winter are alike immaterial to the growth of grass: it seeds and withers. The winter precipitation where present is in the form of snow, and it should be noted that the snow covering keeps the ground warm in winter, whilst the melting of the winter snows in spring enhances the supply of moisture for the germinating grass.

(9) The Cold Temperate Climate: The Cold Temperate Climate or climate of the northern coniferous forests is found over a broad belt across the northern lowlands of Asia. The average temperature is low, and the greater part of the somewhat scanty precipitation is in the form of snow. The natural vegetation is everywhere of the evergreen coniferous forest type; the warmth of the summer sun is normally insufficient for the ripening of cereals. A feature of very great significance is the difference between the length of the very short winter days and the very long summer days. In the heart of northern Asia there are tracts with a temperature range of over 100°F in the year—the greatest in the world. Nearly all stations have an average temperature for the year below 40°F and over very large areas the average is below freezing. There is usually a short but surprisingly' warm summer, with the average for the hottest month sometimes approaching 70°F. Three months with a temperature of over 60°F are needed for the ripening of wheat; in this climatic belt only the extreme southern margins are sufficiently warm, though the long summer days permit the hardier grains to ripen with great rapidity rather farther north. Owing to the small evaporation and the fact that much of the precipitation is in the form of snow, which lies on the ground in winter so that when the warmth of spring comes it melts and soaks gently into the ground and little is lost, a rainfall as low as 10 inches is adequate.

■ 3.5.4 TREWARTHA'S SCHEME OF CLIMATIC CLASSIFICATION

The general scheme of climatic classification employed by G. T Trewartha (1937) describes the world pattern of climates. The needs of geographers were made paramount in this scheme of climatic classification. According to Trewartha, such a classification should be kept simple, and consequently it should recognize only a relatively few principal climatic types. Increasing the number tends to obscure the elemental features of the climatic pattern. Where further detail is required than that provided by the major climatic types, this can be readily secured by adding as many second-order and third-order subdivisions within a climatic type. Such a method has the merit of flexibility in that it retains the great

advantage of a relatively few primary climatic types as comprising the principal elements of the world system, while at the same time allowing for any degree of detail desired.

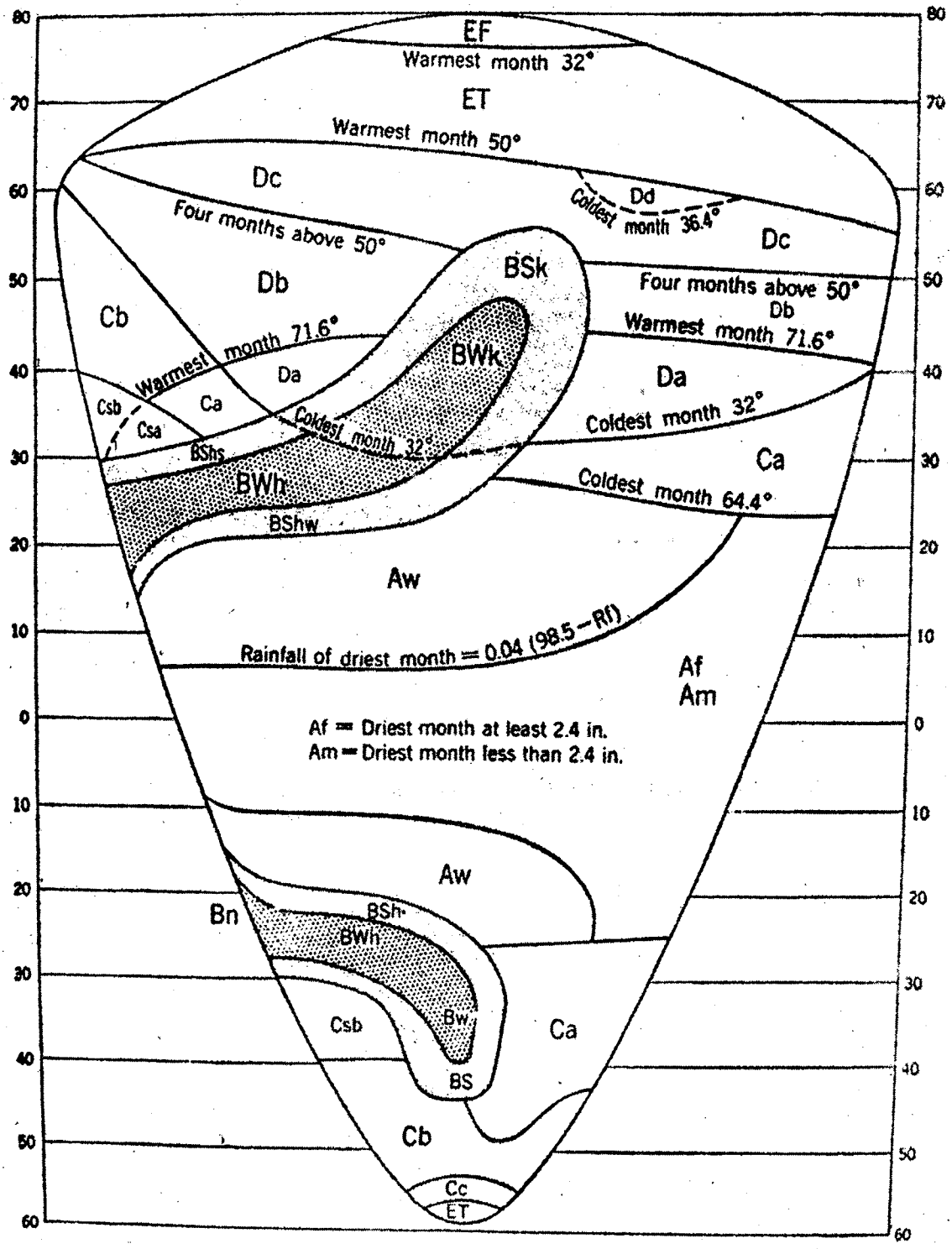
Trewartha also argued that, an empirical type of classification is the most appropriate scheme for presenting the main lineaments of climatic distribution. For those such as geographers, biologists, or agriculturists, who need to understand and use the climatic environment for their own purposes, the facts of climate must be presented realistically and without forcing them into any preconceived genetic structure or any scheme of type location. First and foremost, one must be guided by the observed data.

On the other hand, description without considering genesis or origin, leading to explanation, soon becomes dull and tiresome, features which, unfortunately, characterize much of the regional climatic literature. Recognition of the importance of genesis not only whets interest and adds to the scientific quality of climatic analysis but also gives insight and understanding which increases the quality of the description. One cannot observe the arrangement of world climates as developed under any good empirical classification without being conscious that there is order and system in the distribution. In other words, there is a recognizable world pattern in many of the larger features of climatic distribution. This fact suggests genesis. The empirical classification of climates should be supplemented in every way possible by genetic classification to the end that explanation of the qualities and distribution of climates shall be suggested.

Fundamentally, the classification of climates employed by Trewartha is a modified form of the Koppen system. But he did not want to put much emphasis on boundaries and their definitions. The boundary definitions are useful, but they need not be turned into a feat of memorization. A climatic boundary as it appears on any small-scale map of climates represents only the mean position of numerous climatic-year boundaries which often depart widely in location from the mean position. Too great emphasis in memorizing the exact location of a mean boundary which shifts its position from year to year can be avoided.

Climatic Types:

Tropical Rainy Climates: Following Koppen, five great groups of climate has been recognized by Trewartha. In the low latitudes near the equator, there is a winterless region of constantly high temperatures with adequate rainfall (*A*). This is the humid tropics. Within this group two climatic types, based upon rainfall contrasts, have been identified- the constantly wet type (*Af*) and the tropical wet-and-dry type with its summer, or zenithal rains and its low-sun dry season (*Aw*). The former type (*Af*) reasonably well coincides with the zone of equatorial convergence (ITCZ, doldrums, equatorial westerlies) and is dominated by convergence throughout most of the year. The *Aw* type alternately is under the influence of the ITCZ for a part of the year (high sun) and of the drier trades, characterized by subsidence, for the rest of the year.



Dry Climate: Poleward from the A group and extending beyond the tropics far into the middle latitudes are the dry climates (*B*). The *B* group is subdivided into an arid, or desert, type (*BW*) and a semiarid, or steppe, type (*BS*). Further subdivision separates the hot tropical and subtropical deserts and steppes (*BWh*,

BSh) from the cold middle-latitude deserts and steppes (*BWk*, *BSk*). The h/k boundary separating hot, dry climates from cold, dry climates is the 0°C., or 32°F., isotherm for the coldest month. The hot dry climates reasonably well coincide with the subtropical anticyclones and poleward parts of the trades where atmospheric subsidence and divergence are characteristic. The cold dry climates have locations leeward of high mountains or in the interiors of large continents far from sources of moisture and where cold anticyclones with subsidence prevail in winter.

Humid Mesothermal: The humid middle latitudes, with their seasonal contrasts in temperature, are divided into two climatic groups, the mesothermal in which the winters are mild and short (*C*), and the microthermal in which they are severe and long (*D*). Within the *C* group three types of climate are recognized: subhumid dry-summer subtropical (*Cs*), humid subtropical with hot summers (*Ca*), and middle-latitude marine with cool summers (*Cb*). The *Cs* group with its winter rainfall and summer drought is alternately influenced by middle-latitude westerlies and their cyclonic storms in winter and the subtropical high in summer. The *Ca* type, also in the subtropics, is affected by the unstable western margin of the subtropical anticyclone in summer and the westerlies and their cyclonic storms in winter. *Cb*, poleward of the subtropics and characteristically on the windward side of the continent, is affected by the cyclonic westerlies throughout the entire year.

Humid Microthermal: Within the microthermal group *D*, the principal types are based upon temperature contrasts. This is a further departure from the standard Koppen system. This group of boreal climates is associated with large land masses in relatively high middle latitudes so that they alternately feel the effects of the westerlies in summer and the polar winds in winter. The humid continental types (*Da* and *Db*) are differentiated on the basis of summer temperatures, *Da* having warm summers (warmest month over 22°C., or 71.6°F.) and *Db* cool summers (warm month under 22°C., or 71.6°F.). The sub arctic type (*Dc*, *Dd*) is characterized by very short cool summers and long severe winters (*c* = less than 4 months over 10°C. or 50°F.; *d* = coldest month below -38°C, or -36.4°F).

Polar: Finally, in the higher latitudes are the summerless polar climates (*E*). These are dominated by polar winds throughout the year. Two subdivisions are recognized, *ET*, or tundra, where the warmest month is above 0°C, or 32°F, and *EF*, or ice cap, where all months are below 0°C, or 32°F.

Group of climates	Types of Climates	Present system and wind belt		Precipitation
		Summer	*Winter*	
A. Tropical rainy	*Af* (*Am*), tropical wet	ICT, doldrums, equatorial westerlies	ICT, doldrums, equatorial westerlies	No dry season
	Aw, tropical wet and dry	ICT, doldrums, equatorial westerlies	Trades	High-sun wet (zenithal rains) low-sun dry
B. Dry	*BS*, semiarid (steppe)			
	BSh, tropical and sub-tropical	Subtropical high and dry trades	Subtropical high and dry trades	Short moist season
	BSk, Middle latitude		Continental winter anticyclone	Meager rainfall, moist in summer
	BW, arid (desert)			
	BWh, tropical and sub-tropical	Subtropical high and dry trades	Subtropical high and dry trades	Constantly dry
	BWk, Middle latitude		Continental winter anticyclone	Constantly dry
C. Humid mesothermal	*Cs*, dry summer mesothermal	Subtropical high (Stable eastside)	Westerlies	Summer drought, winter rain
	Ca, humid subtropical	Subtropical high (Unstable westside)	Westerlies	Rain in all season
	Cb, *Cc*, marine climate	Westerlies	Westerlies	Rain in all season, ascent on winter
D. Humid microthermal	*Da*, humid continental, warm summer	Westerlies	Westerlies and winter anticyclone	Rain in all seasons, ascent on summer; winter snow cover
	Db, humid continental, cool summer	Westerlies	Westerlies and winter anticyclone	Rain in all seasons, ascent on summer; long winter snow cover
	Dc (*Dd*), Sub arctic	Westerlies	Winter anticyclone and polar winds	Meager precipitation throughout the year
E, Polar	*ET*, Tundra	Polar winds	Polar winds	Meager precipitation throughout the year
	EF, ice cap	Polar winds	Polar winds	Meager precipitation throughout the year
H, Undifferentiated highlands				

The outline of principal climatic groups and their subdivisions into types, together with their appropriate letter symbols, is given in the table. Also an attempt has been made to suggest significant relationships of the individual climatic groups and types to features of the atmospheric circulation and to characterize their seasonal rainfall regimes.

A = temperature of coolest month over 18°C (64.4°F)
B = evaporation exceeds precipitation
C = coldest month between 18°C (64.4°F.) and 0°C (32°F)
D = temperature of coldest month under 32°F (0° C.); warmest month over 10°C (50°F) E = temperature of warmest month under 10°C (50°F)
a = warmest month over 22°C (71.6°F)
b = warmest month below 22°C (71.6°F)
c = warmest month below 22°C (71.6°F.); less than four months above 10°C (50°F.)
d = coldest month below -38°C. (-36.4°F)

With A climates:
f = no dry season; driest month over 6 cm. (2.4 in.)
s = dry period at high sun or summer; rare in A climates
w = dry period at low sun or winter; driest month under 6 cm. (2.4 in.)
With C and D climates:
f = no dry season; difference between rainiest and driest months less than in *s* and *w*; driest month of summer over 3 cm. (1.2 in.)
s = summer dry; at least 3 times as much rain in wettest month of winter as in driest month of summer; driest month less than 3 cm. (1.2 in.)
w = winter dry; at least 10 times as much rain in wettest month of summer as in driest month of winter

▲ 3.5.4.1 Deviations of Trewartha's Classification from the Koppen's System:

1. In the B climates Koppen has used the mean annual isotherm of 64.4°F. (18°C) as the boundary separating *Bh* from *Bk*, i.e., the hot dry from the cold dry. In the modified system here employed the 32° F isotherm for the coldest month has been accepted as the h/k boundary. For the United States at least, the 32°F January isotherm is more significant than the 64.4°F mean annual.

2. Koppen used the coldest month isotherm of 26.6°F (- 3°C) as the boundary between *C* and *D* climates. In the present modified system 32°F (0°C) for the coldest month is substituted for the above. This is identical with the h/k boundary in the dry (*B*) climates. In North America, Europe, and Asia the 32°F January mean temperature is much more significant than 26.6°F for January.

3. In the humid mesothermal group of climates (*C*) Koppen distinguished three principal climatic types, the basis for the differentiation being seasonal distribution of rainfall: *Cs*, summer dry; *Cw*, winter dry; and *Cf*, no dry season. From the standpoint of logic, this method of differentiation is sound, but Trewartha believed that it does not differentiate the three principal climatic types in so far as their effects upon soils, vegetation, and culture are concerned. Koppen's *Cw* type is found not only in lower middle latitudes where there is a strong monsoon influence, but also in tropical uplands where altitude reduces the temperature of at least one month below 64.4°F, which is the A/C boundary. These two very unlike type locations of *Cw*, plus certain fundamental contrasts in the climates they represent, have led Trewartha to discard the type.

Moreover, most Koppen *Cfa* regions have a summer maximum of precipitation, and whether the wettest summer month has somewhat more or less than ten times the precipitation of the driest winter

month does not seem very consequential. In southern China, where both *Cfa* and *Cwa* are represented, there appear to be no significant differences between them in native vegetation, soils, or culture.

Within the *C* group of climates seasonal rainfall is the critical differentiating factor in only one type, *Cs*. In other *C* regions summer temperatures stand out as of greater consequence than the season of rainfall. Therefore, in the Trewartha's classification the second and third subdivisions of the C group are *Ca(f, w)* and *Cb(f, w)*, one having warm summers such as the cotton belt of the United States, and the other cool summers such as western Europe. Therefore, he differentiated climatically between southern China (*Ca*) and the British Isles (*Cb*) than between *Cw* and *Cf* in southern China.

4. In the humid microthermal group of climates (*D*) Koppen again differentiated the principal types based upon season of rainfall: *Dw*, winter dry; *Df*, no dry season. *Dw* occurs only in eastern Asia where a strong monsoon wind system prevails; yet on the other hand most of the *D* regions of the world have a pronounced summer maximum, even though they cannot qualify as *Dw*. Based upon observations in eastern Asia, Trewartha argued that *Dw* and *Df* climates in that region do not differ so fundamentally in vegetation, soils, and culture as do *Da*, *Db*, and *Dc* climates, where summer temperature is employed as the differentiating element. In the Trewartha's classification, therefore, the subdivisions of the *D* group are based primarily upon summer temperatures.

5. Koppen attempted to differentiate the various climates within highland areas, employing the same boundary criteria used for lowland climates and with somewhat unsatisfactory results. Due to relatively few climatic data that are available for most highland regions, and also because of the great complexity of climates within mountains, this differentiation has usually not been attempted by Trewartha.

▲ 3.5.4.2 Distribution of Climates on a Hypothetical Continent:

Trewartha designed to show the typical positions and arrangements of the climatic types and their boundaries as they would appear on a hypothetical continent of low and uniform elevation, the shape of which corresponds roughly to that of the actual land masses. In other words, on this hypothetical continent one is able to see the climatic types as they probably would be, with the modifications and complications resulting from varying shapes, sizes, positions, and elevations of the land masses eliminated. Here the world pattern of climates is most clearly revealed.

■ 3.5.5 GLOBAL CLIMATIC CHANGES AND GLOBAL WARMING

▲ 3.5.5 WHAT IS CLIMATIC CHANGE?

Climatology not only deals with just the average weather conditions over a long period of time but it considers both the average conditions and variability as well as the extremes, long term trends, and impacts of atmospheric conditions. Generally the greatest impacts occur during periods of extremes and these extremes may provide evidences of climatic changes or variability. Temporal changes and variability may take various forms.

Types of Climatic Variability:

Random variability (Noise): It includes unsystematic fluctuations of an atmospheric variable without repetition of such fluctuation at any distinct interval. They are not important.

Periodic Variability: It takes the form of an abnormality that recurs with some relatively constant regularity.

Variability changes: They may or may not involve a change in mean, but include a temporal shift to larger or smaller variability about the mean.

Types of Climatic Changes:

Temporal Trends: They are represented by slow temporal shift of atmospheric variables toward an increasing and decreasing mean.

Step Changes: They involve a sudden shift to a different mean.

This is required to be understood that any type of climatic variability or change influence the entire climate system because the system undergoes exchanges of energy, moisture, or momentum among the atmosphere, hydrosphere, lithosphere, biosphere, and cryosphere. Climatic changes do not occur in isolation and remain restricted within the atmosphere only. Moreover, temporal changes and variability being experienced may be complicated because trends and cycles can be superimposed on other trends and cycles operating over longer time scales.

Definition and connotation of climatic change has undergone changes over time. In the 1960s, "climatic changes" was largely used to refer to the climatic variability or the climatic anomalies. In the 1970s, climatic change generally connoted very long term changes, perhaps in the order of one thousand years. In the 1980s, climatic changes refer to differences in 30-years averaging periods. Traditionally climatologists have used data sets of 3o years. Therefore, climatic change came to refer to differences in atmospheric variables from one 30-year period to another 30-year period, such as 1951-1980 period versus 1961-1990 period. By the 1990s, climatic change came to imply that humans were having an impact, whether through the combustion of fossil fuels, deforestation, land use change, or deliberate attempt to alter the climate directly. In the 2000s, climatic change continues to imply a human influence, but with the realization that this human influence can occur on much shorter time than was previously believed. So, climatic changes may be seen to occur even within the averaging period (30-year), rather than the differences between them.

In recent years, the difference between the climatic variability and change has been blurred because it is difficult to detect whether we are experiencing variability or change as we live through the phenomena. But variability is experienced as uncharacteristically intense flood, storm frequency, heat waves or other individual extreme events. But change is experienced more dangerously, as the barely noticeable shifting of agricultural and bio-climatic zones, increasingly more extreme events and so forth. But when the policy making to deal with the phenomena is in question, such differences have no meaning.

PAST CLIMATE CHANGES

There is little remaining to tell us the climate changed for most of the first 90% of the Earth's life time. It is difficult to now where the oceans and continents were, or what precisely the constituents of the atmosphere were. The mists begin to clear around 1000Mya.

PRECAMBRIAN:

The late Precambrian period experienced a glacial period, which as best we can tell lasted some 200 Myr, sometimes termed the *Cryogenian* period of the late Precambrian. It appears there were at least two icy epochs between 800 and 590 Mya. These two glacial periods may have been made up of a number of shorter glaciations, which most geologists consider to have been among the coldest in the Earth's history. The older episode, called the *Sturtian* glaciation, occurred about 750 Mya, and the younger one, called the *Varanger* glaciation, took place roughly 590 Mya. Analysis of ancient glacial sediments suggests that continental-scale ice sheets extended to latitudes as low as 10°. Around 700 Mya there was a rapid diversification of higher plants and animals with soft bodies. Then, following the Varanger glacial, during the Cambrian there was a sudden dramatic acceleration in evolution starting around 565 Mya when all the basic designs for animal life, involving shells and hard skeletons, make their first appearance. Those last 600Myr are known as the *Phanerozoic* (the Ago of Visible life).

PHANEROZOIC:

During the first half of the **Phanerozoic** the main continent was Gondwanaland, which was made up of Africa, South America, India, Antarctica, and Australia. Other continental fragments included parts of what are now North America and Eurasia. Mapping the movement of Gondwanaland has enabled the changes in geological record, which might be attributed to climate change, to be put into context.

Paleozoic Era

During the *Cambrian* the climate warmed appreciably and remained relatively warm for most of the following 300 Myr. There was a relatively brief glacial period around the end of the *Ordovician* and beginning of the *Silurian.* The most extensive evidence of this cool period is now to be found in the Sahara, which was close to the South Pole at this time. During the *Carboniferous* the temperature dropped, culminating in the long *Permo-Carboniferous glaciation* from 330 to 250 Mya. This icy epoch may well have been the coldest period in the last 600 Myr. It featured the expansion and contraction of a succession of major ice sheets, which at the greatest extent covered more than 50 million km^2 (four times the extent of the current Antarctic ice sheet). Its later stages, when all the Earth's land masses came together, Gondwanaland stretched from the equator to the South Pole. At various times, parts of what are now Antarctica, Australia, India, South America and South Africa were affected by massive ice sheets. For example, evidence suggests that around 280 Mya western Australia was covered by ice up to 5 km thick, although climatic conditions in other parts of the globe may have been rather warm. Also the interiors of the unglaciated continents became more arid.

Certain cataclysmic events, including possibly asteroid impacts with the Earth, immense volcanic eruptions, or abrupt climatic change have led to mass extinctions of flora and fauna. The **five** most clearly established examples of these events (the *Big Five*) were Late Ordovician 440 Mya; Late Devonian, 365 Mya; Late Permian and *Early Triassic*, 255 Mya; Late Triassic, 210 Mya; and end-Cretaceous, 65 Mya. The consequences of this process are breathtaking. Over the last 600 Myr, 99.9% of all species that ever lived have perished.

Mesozoic Era

During the early Mesozoic era, the continental masses amalgamated to form the super continent known as Pangaea. During the *Jurassic* and *Cretaceous* it drifted towards lower latitudes and broke up. The standard view is that this was a period of generally warm climate with relatively little difference in temperatures between the poles and the tropics and insignificant seasonal variations. This equable period is usually associated with the *Age of the Dinosaurs*. There is now new evidence, however, of some fluctuations in climate throughout this era, including a cooler period with cold winters at high latitudes around the end of the Jurassic and the beginning of the Cretaceous.

Following this cooler period, the mid-Cretaceous, around 100 Mya, was probably the warmest period in the Earth's history for which there is reasonable data. Globally the average temperature is estimated to have been 6 to 12° C warmer than the present day. In the tropics it was 0 to 5° C warmer, with the Arctic being 20 to 35° C warmer and the Antarctic being at a similar temperature to the Arctic, as opposed to being markedly colder now. The distribution of continents in the Cretaceous was probably the major factor in maintaining these balmy conditions. The existence of a circum-equatorial seaway and the absence of circum-polar currents may explain the warmth. Measurements of sediments from the Arctic Ocean dated to around 70 Mya, suggest ice-free conditions and an average temperature as high as 15° C. This would also have had a profound effect on the vertical circulation patterns in the oceans.

At the end of the Mesozoic era there was a sudden brief cooling. This coincided with the mass extinction that wiped out the dinosaurs. The termination of the Cretaceous is the best-known example of where a cataclysmic event appears to have caused a mass extinction.

Cenozoic era

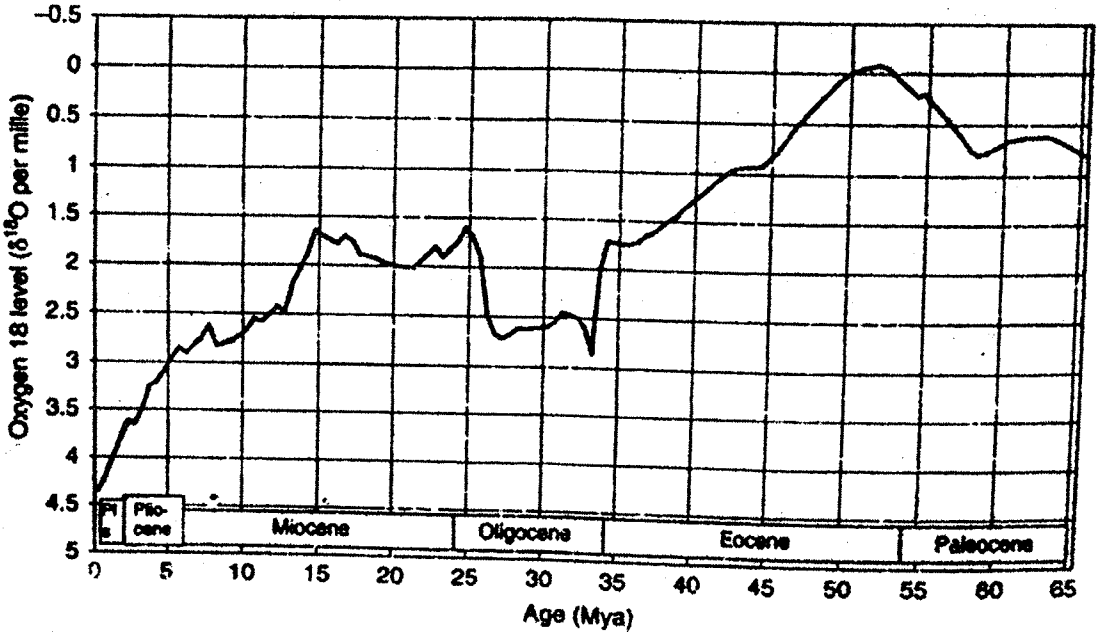
From greenhouse to icehouse

The changes that have taken place during the Cenozoic era (the most recent era of geologic history), which covers the last 65 Myr of the Earth's history, fall into three categories.

1. First, there are the long-term changes governed by plate tectonics, and possibly changes in the composition of the atmosphere. These effects have worked on timescales of hundreds of thousands to several million years.

2. Then there are the increasingly important effects of the Earth's orbital parameters that operate on timescales from thousands to hundreds of thousands of years.

3. Finally there are abrupt shorter-term events. Throughout virtually all of the Cenozoic there has been a cooling trend.



From the greenhouse to icehouse the decline in O_{18} in the oceanic sediments indicates long term cooling of the global climate during last 65 Myr.

Initially, during the Palaeocene remained global temperatures remained on a par with the late Cretaceous and even rose to a peak in the early Eocene. At around 54Mya there was a sudden rapid warming over less than 10 kyr of some 5 to 6 °C, known as the Late *Palaeocene Thermal Maximum*, caused by a giant release of methane. This event lasted around 100 kyr and the climate reverted to a gradual warming in the early Eocene reaching a climatic optimum between 52 and 50 Mya.

The real cooling started in earnest around 50 Mya, and was greatest at high latitudes. There was a relatively smooth decline until around 35 Mya, apart from a pause between 42 and 40 Mya. Glaciers first formed on Antarctic mountains around 50 Mya and by 36 Mya the first ephemeral ice sheets formed. The abrupt cooling around 34 Mya resulted in a 7 °C decline in ocean temperatures. This event, which appears to coincide with the Eocene-Oligocene boundary, lasted around 400 kyr. This event marked the onset of a cooler period that lasted some 7 Myr, during which a permanent ice sheet covered parts of East Antarctica.

The climate warmed appreciably around 26 Mya, and there is evidence that as late as 25 Mya there were forested areas on Antarctica. At the beginning of the Miocene, there was a short-lived setback around 24 Mya, which lasted about 200 kyr. Thereafter the climate returned to warmer conditions and reached an optimum between 17 and 15 Mya. Then around 14 Mya a marked cooling trend set in and a permanent ice sheet formed over East Antarctica. At the same time mountain glaciers started to form in the northern hemisphere.

With only minor interruptions the cooling continued throughout the rest of the Miocene. The final stages of the formation of the Antarctic ice cap occurred during a sharp cooling between 6 and 5 Mya. At the same time, ice started to form in the central Arctic Ocean. The other major climatic event of this period was the isolation and subsequent desiccation of the Mediterranean around 5.8 Mya. Known

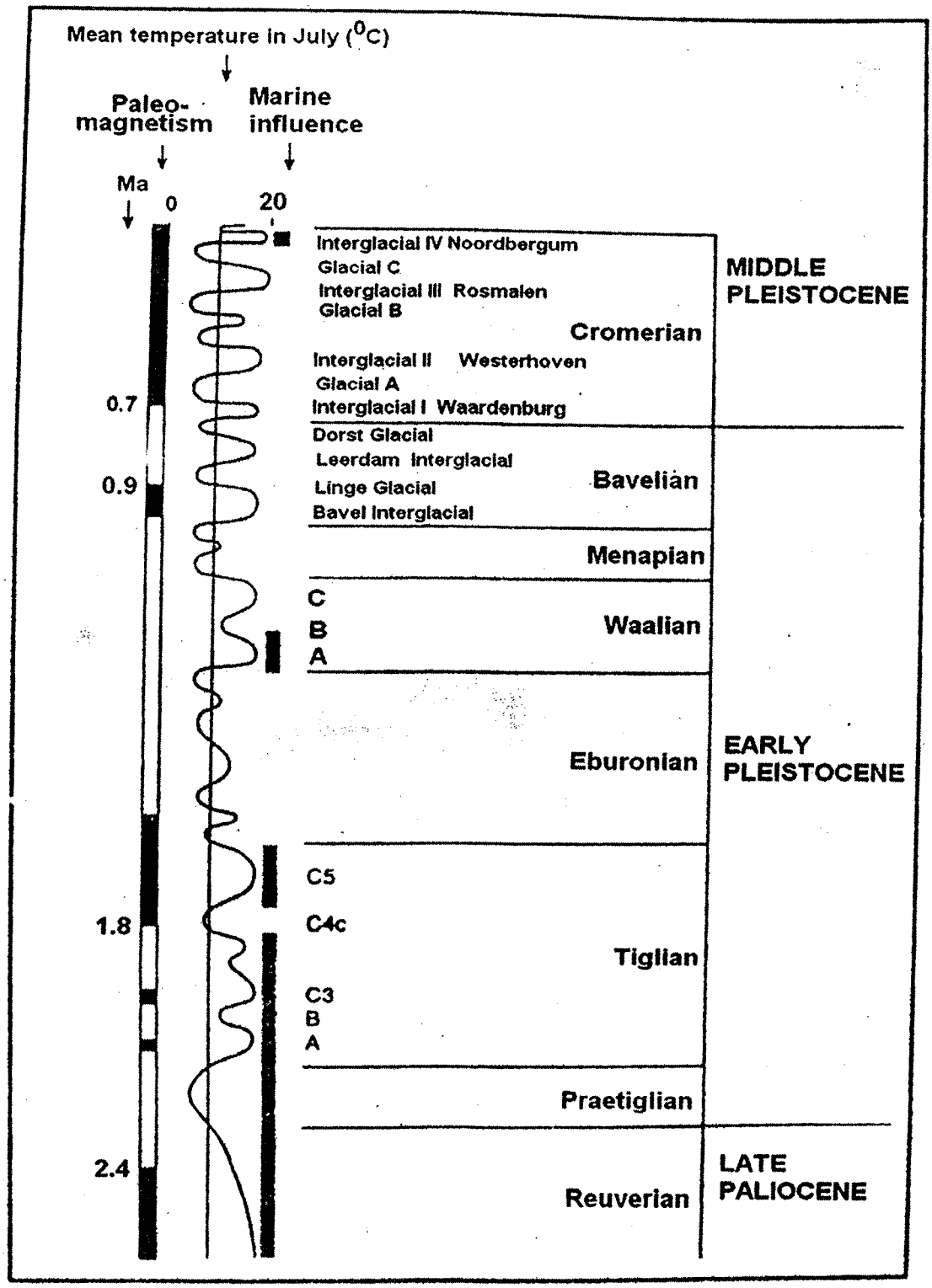
as the *Messinian Salinity Crisis,* the deposition of huge quantities of salt as the sea dried up and the water vapour entered the hydrological cycle. This would have reduced the salinity of the rest of the world's oceans. Then around 5.3 Mya tectonic activity opened the Straits of Gibraltar and a vast surge of water flooded back into the Mediterranean sending further pulses through the climatic system.

These changes, which coincide with the boundary between the Miocene and Pliocene, included a sharp increase in sea level and a marked warming. Thereafter, the cooling continued and accelerated around 3 Mya in the mid-Pliocene. At the same time the fluctuations increased and by around 2.5 Mya there was a marked cooling and fall in sea level, which is thought to have resulted from the initial rapid build-up of northern hemisphere ice sheets. A feature of these developments is the establishment of a well-defined 40-kyr cycle in ice ages.

The Cenozoic era culminated in the Quaternary period which started around 1.8 Mya and runs up to the present time. This period of repeated glaciations, when up to *32%* of the Earth's surface was covered by ice, is usually divided into the Pleistocene, covering the glaciations, and the *Holocene:* the warm period covering the last 10 kyr.

During the *Quaternary period,* covering the last 2 million years, glacial and interglacial periods alternated. Some workers suggest that there were as many as 20 glacial events; currently there were at least 7. Interglacials, each characterized by a warm period lasting 10 ± 2 thousand years, have occurred on average every 100 thousand years during at least the past 0.5 million years. About 125 ka the Eemian interglacial commenced and the warmest part persisted for about 10 thousand years. Between 115 ka and the Pleistocene glacial maximum at 18 ka, there were marked fluctuations superimposed on a generally declining temperature. Temperature thereafter increased so that at present we are within Holocene interglacial.

The last Pleistocene ice age reached a maximum 22,000 – 14,000 years ago. During this period two large ice sheets have been identified in the Northern Hemisphere: the 'Laurentide Ice Sheet' covering parts of Eastern North America and the 'Scandinavian Ice Sheet' covering parts of Northern Europe. The 'Cordilleran Ice Sheet' over western North America achieved a maximum somewhat later than these, about 14,000 years ago. During this last ice age, the maximum area of the Northern Hemisphere ice sheets was equal to 90% of the maximum achieved during the last million years of the Pleistocene. At the glacial maximum the sea level dropped by 85m and sea-surface temperature fell by as much as 10 °C in mid-latitudes of the North Atlantic and 3 °C in the Caribbean.



Widespread *deglaciation* began rather abruptly 14,000 years ago. The Cordilleran Ice Sheet melted rapidly and was gone by 10,000 years ago. The Scandinavian Ice Sheet lasted only slightly longer. Deglaciation was later in North America and the melting of the Laurentian Ice Sheet lagged by 2000 years. By 8500 years ago the conditions in Europe had reached their present state while this

situation was achieved in North America about 7000 years ago. Within this overall warming period were times of widespread cooling and glacial advance, seeming to occur about every 2500 years. One of these is called the *Younger Dryas event* which established itself within 100 years and lasted for 700 years (10.8-10.1 ka).

Historical climate change

As we approach the present time the range and diversity of climatic information increases. During the last two or three thousand years much can he inferred from archaeological evidence. Within the last thousand years documentary evidence is available, while starting in the seventeenth century direct observations become ever more numerous.

The *Iron Age* occurring at 2.9-2.3 ka (900-300 BC) was generally-wet and culminated in a cold epoch (probably around 500-300 BC). There is widespread evidence of regrowth of bogs throughout Europe.



At the height of the last Ice Age 18,000 years ago, large ice sheet several kilometres thick covered much of Northern Europe and North

The *Secondary optimum* in climate (AD 1000-1200) was a warming to a lesser degree and of a shorter duration than the post-glacial optimum. This led to melting of the pack ice and drift ice of the Arctic-margins and was coincident in time with the founding of Norse colonies throughout the north Atlantic land areas as far as America. Summer temperatures were probably 1°C higher than today in western and central Europe, where the period lasted until AD 1300. Although Antarctica also seems to have been warmer during this secondary optimum, in China there may have been a cooling.

The *Little Ice Age* occurred between 1430 and 1850, with two intense periods around 1470 and in the late 1600s. It was most harsh in Britain during the second half of the seventeenth century. There was preponderance over the entire period of harsher conditions than today but there were also some periods of relatively equable climate. Glaciers advanced in Europe, Asia and North America, although there were also times when summer temperatures were at or above present values. During this whole time the Arctic pack-ice expanded with important detrimental effects for Greenland and Iceland; by 1780-1820 (and probably by the late 1600s), the temperature across the north Atlantic north of 50°N was some 1-3 K less than today. The Southern Hemisphere seems to have partly escaped the cold period until 1830-1900. It may even have been warmer in Antarctica during the period 1760-1830.

The *warming trend* of the 1880s to 1940s was especially noted in the Atlantic sector of the Arctic and in northern Siberia. In the Southern Hemisphere, south of 30°S, there appears to have been a cooling.

A *cooling trend* was observed in the Northern Hemisphere following the high temperatures of the 1940s. Cooling at high latitudes (which seem to be predictive for other latitudes) stopped in the mid 1960s. Overall, sea-surface temperatures in the Northern Hemisphere cooled by 0.75 K but those in the Southern Hemisphere may have warmed during the 1935-1970 period by up to 1 K, especially at mid- and high latitudes. This has led to concern about the West Antarctic Ice Sheet, which is grounded on islands on the sea floor and so may be influenced by sea temperature or level changes. Increasing temperatures may cause a more rapid disintegration of this ice sheet and lead to a rise in sea level.

▲ 3.5.5.2 THE PRESENT CLIMATE

By the middle of the *nineteenth century* the effects of the Little Ice Age were waning in most parts of the world and begin the steady warming of the last century. The first phase of warming peaked in the 1940s, followed by a slight decline in global mean temperatures. At that time climatologists were predicting the return of cooler conditions and perhaps even another Ice Age. From the mid-1970s patterns may vary too. The most publicized example of what appears to be a significant recent change in climate has occurred in the Sahel area of Africa. From the rainfall record it is seen that at certain times there have been sequences of higher than average rainfall followed by periods with lower than average rainfall. From the later 1960s rainfall has nearly always been less than the long-term averages, with years such as 1984 being spectacularly dry. These changes may have major human impacts. The role of decreasing rainfall in desertification has been debated, but many of the countries affected by this trend experienced much political and social upheaval in the 1980s and 1990s, e.g. Niger, Sudan, Ethiopia and Somalia, to compound the problem. Such an example does confirm that change is still taking place in our present climatic regime, though increasingly there is debate about how much is natural and how much is the result of human activities.

■ 3.5.5.3 EVIDENCE FOR CLIMATE CHANGES

There are a number of different types of evidence that can be used to decipher what climatic conditions have prevailed in the past.

1. ***Instrumental Records***: The best evidences are where records of instrumental observations are available at particular site. In this case day to day information about the weather elements becomes available.

Temperature records: Early temperature records for both land and seas are available. But such information is confronted with following challenges.

- Earlier observations were made in less uniform arrangements.
- Early observations were made close to towns. Effects of urban heat islands have spoilt the data to a considerable extent.

- Temperature recording networks could not offer adequate coverage of the earth's surface until late 19th. Century although land surface temperature records for the last 300 years are available for few places.
- In most of the cases temperatures have been recorded during day time.
- Method of Sea Surface Temperature recording changed for several times.
- Only few data are available for the areas away from the shipping lines while oceans cover 71% of the land surface.

Global records extending back to 1860 have been analyzed combining measurements on both land and sea. Corrections have also been made for the anomalies in measurement, as stated above. The total uncertainty in measurement is reckoned to be ± 0.2°C. After taking care of the measurement anomalies there is a consensus of a rise in global surface temperature of 0.65 °C since the beginning of the 20th. Century.

Rainfall records: Reliability of the earlier rainfall data is less than that of temperature records. Rain gauges have been installed near the urban areas in most of the cases. Therefore, there have been probabilities of interference by winds near rain gauges distorting the amount of rainfall caught. Growth of vegetation / buildings near recording stations has even spoilt the records. Moreover, snowfall records of early days are very few. Change in design of instruments has been another source of error. Rainfall is spatially more variable than temperature requiring more observation stations for determining trend of rainfall. At regional level there are many lengthy precipitation records from which no significant conclusions can be drawn.

Satellite measurements: Since 1960s, the microwave and infrared radiometers of weather satellites are providing with reliable data sets. They supply continuous data; and cloud cover, snow cover data which were in no way available with the instruments. Moreover, temperature can be recorded at different levels of atmosphere.

Major observations made through satellites are-

- Snow cover in Northern. Hemisphere has declined since 1970s (Rate: 2.9% a decade)
- In Antarctica though there is an increase in ice cover at a rate of 1.3% per decade. But other records suggests that there had been 25% decrease between late 1950s and early 1970s., which far exceeds the increase after 1970s.

2. Historical records:

Where instrumental observations do not exist, information on the climate can sometimes be extracted from historical records, including personal diaries, of both the weather and weather-related activities, but to make a significant contribution to quantitative measurements they must meet sterner tests. Nonetheless, in Europe and China detailed reports of many annual events can provide valuable additional insights. In particular, this is possible where historical records overlap instrumental observations and so can be calibrated against these numbers. Most frequently, these records relate to agricultural activity. For example, the price of wheat is a good indicator of the abundance of the harvest, as bumper years led to low prices and dearth produced high prices, but these figures relate only to the summer half of the year and are a complex product of temperature and rainfall. This means that, while the extreme years stand out, many of the fluctuations cannot be attributed to one or other variable.

The limitation of many historical records is that often they only note exceptional events, but they do not give a measure of those extreme events. However, examination of all the extreme events recorded, it is sometimes possible to estimate the past climatic events. Use of these data in conjunction with proxy data enables to build up a more complete picture of change.

3. Floral evidence:

The distribution of plants provides important guidelines for the distribution of different types of climate. Identification and analysis of past vegetation can thus be used to interpret past climate or palaeoclimate. Similarly, the patterns of change in vegetation over time can be used to evaluate climatic trends in selected areas.

The required information is obtained from the physiology of plants, which show particular adaptation to the prevailing climate. Excessive heat and humidity gives rise to luxuriant growth of trees. There is, thus, a far greater variety of plants and animals in tropical climates than in the colder climates; therefore, great variety in the fossil record is an indicator of a warm climate. Tropical plants generally also have large leaves. These leaves tend to be 'entire margined' (i.e., have no side lobes). The existence of these leaves in the form of imprints, thus, indicates towards a tropical climate. The conifers dominate in cold climate and at their northern border are found spruce. The cone-shaped forests and their sunken stomata are an adaptation to cold climates and the plant fossils having them also point towards colder climate. Similarly, fossil remains of plants with thick, fleshy leaves are indicative of arid and semi arid climates.

4. Pollen records:

Where sediments have formed in shallow lakes or bogs, the presence of pollen grains can provide similar information on land, as foraminifera provide in the oceans. If these sediments have been laid down in a regular manner, the abundance of pollen from different species of trees and shrubs provide details of climate change. Because different species have distinct climatic ranges, it is possible to interpret their relative abundance in terms of shifts in the local climate. Given that this process can occur almost anywhere on the continents, it means that pollen records have the potential to fill many of the geographical gaps that ice cores and ocean-sediment records cannot cover.

Pollen records are of particular historical importance in studying climatic change because of the early work charting the emergence of northerly latitudes from the last glaciation. Most pollens (from flowering trees and plants) and spores (principally ferns and mosses) are tiny. Few exceed 100 μm (0.1mm) in diameter and the majority is around 30 μm. It is the outer portion of the cell (*exine*) that is preserved by means of a waxy coat of the material *sporopollenin*. The size and shape of this outer wall, along with the number and distribution of apertures in it, are specific to different species and can be readily identified. A typical pollen diagram will plot the proportion of the principal species found in a stratigraphic sequence and can be used to draw inference about how the climate has changed over the period covered by the record.

Pollens are selectively preserved and may not be representative of vegetation existing at that time. Pollens can be blown or carried away to enormous distances before it is deposited in entirely different climatic regions.

5. Ocean sediments:

The sediments that collect on the bed of the deep oceans provide one of the most valuable sources of information on longer-term climate change. Because this ooze is formed largely of the bodies of the fossil shells of both pelagic and benthic *foraminifera* species, it provides a measure of the conditions when these tiny creatures were living in either the surface or deep waters of the oceans. So taking a core down through this sediment, which has collected over hundreds of thousands years, provides a record of the species living above a spot in the past.

6. Ice Cores:

Ice cores are fruitful sources of climatic information. The thickness of annual ice layers records precipitation and chemical analysis of the ice reveals the temperature at which precipitation took place. Air bubbles trapped in the ice record the composition of the ancient atmosphere, the dust content is a measure of storminess and the acidity signals major volcanic events around the world.

Cores drilled in the ice sheets of Greenland enable us to count individual annual snow layers for the past 15,000 years and provide detailed insights into the climate for more than 100,000 years. They show, for example, that before the end of the last Ice Age, about 10,000 years ago, the climate was highly variable and average temperature could rise or fall by 10°C over the course of a few years.

7. Dendrochronology:

Dendrochronology is the study and analysis of tree rings. The tree rings can be used to detect climatic changes in the last few centuries or so, as the tree ring record significant events that happened during the life history of the tree. Growth rings are formed in the xylem wood of trees. In areas with regular seasonal changes of weather, trees generally produce one growth ring per annum. The thickness of the growth ring varies with climatic conditions. The growth rings are very thick when the climatic conditions are optimum for the growth of the trees. The ring is narrow, if conditions are not favourable for plant's growth e.g. dry climate. The light coloured part of each ring generally indicates growth during the spring and early summer, while the darker and denser wood indicates slower growth during the spring at the end of the summer.

8. Geomorphological evidences:

The use of geomorphology to determine former climate is based on the assumption that specific landforms can be identified that formed under a known climate type. In most cases these will be fossil landforms that are no longer forming under the present climatic conditions but they may still provide evidence of a different climate in the past. Landforms of glacial erosion and deposition are some of the best known indicators as, with careful surface mapping, they can reveal much information about the thickness, the areal extent and direction of flow of the former ice masses that produced the landforms. In many cases this may provide nothing more than the conclusion of extensive ice covers. However, using the relationship between the altitude at which ice starts to build up, and climatic conditions at present, it is possible to infer palaeoclimates for given equilibrium lines or ice limits in the past. In addition to landforms associated with full ice cover, we often find fossil features produced under severe climatic conditions but without ice cover. These are termed periglacial and form when winter temperatures fall

well below freezing point and produce ground ice. One of the best known is the ice-wedge polygon which develops either through ground cracking at low temperature or through selective sorting of material.
It is not only glacial landforms that provide an indication of former climates. In arid and semi-arid regions there is abundant evidence of saline lakes or playas that have expanded and retreated in response to climate change. Wetter and cooler conditions will favour expansion and drier and hotter conditions may lead to their disappearance as output through evaporation exceeds precipitation. Sand dunes are normally associated with arid environments (except along the coast) but in many humid parts of the tropics there is evidence of fossil sand dunes. As well as indicating previous aridity, they often provide information about wind directions and constancy when the dunes were actively forming.

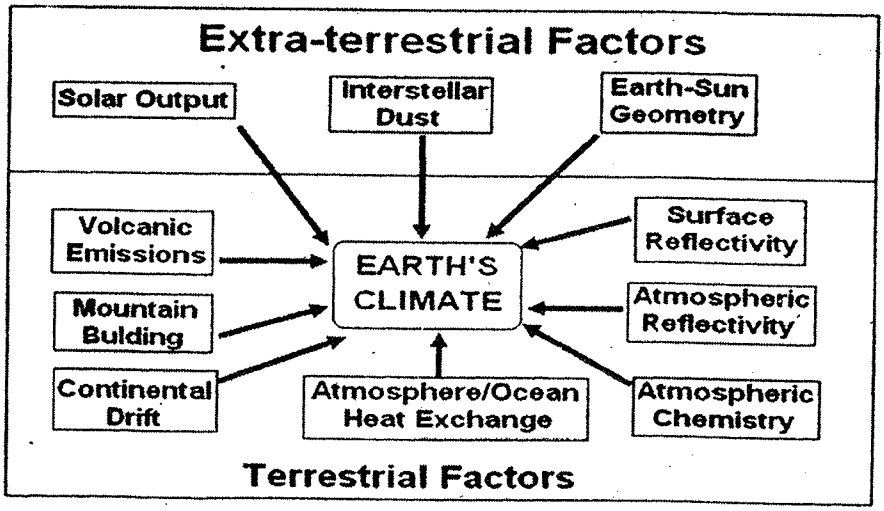
9. Lithological Evidences:

As well as the surface landforms, the subsurface sediments can sometimes allow an interpretation of the environmental conditions under which they formed and indirectly something about the climate at the time. In many cases this provides more information and, hopefully, confirmation of the environment suggested by the landforms. The sediment may be obtained from a surface exposure of material, suitably cleared to avoid contamination, or it may be retrieved from depth by coring devices. Laboratory examination of the physical and chemical properties of the sediments may then be conducted to allow interpretations of environmental history. With such information, glacial, fluvial, aeolian or marine sediments may be distinguished. Even where there are no geomorphological features, there are many parts of temperate latitudes covered by wind-blown sediments such as cover sands and loess. Analysis of some of these thick sequences of loess shows they contain signs of cyclical climatic change, with phases of loess accumulation interbedded with phases of soil accumulation during the warmer stages. The aeolian sediment may also give an indication of wind direction.

Sediments can be preserved in a vast number of environments but much of their paleoclimatic value comes from the biological material they contain as the final type of evidence.

▲ 3.5.5.4 CAUSES OF CLIMATE CHANGE

The general state of the Earth's climate is largely influence by how much heat is stored in the atmosphere. Processes which affect this storage of heat can instigate the climate of the Earth to change. It is not just man-made pollution of the atmosphere which can cause climate change. Changes in the amount of greenhouse gases in the air have occurred naturally during the history of the Earth, leading to climate changes. Changes in the way ocean water circulates around the world can also influence climate, because the oceans store even more heat than the atmosphere. Changes in the amount of heat from the Sun will affect the Earth's climate too.



1. Continental Drift:

On the longest time scales, plate tectonics will reposition continents, shape oceans, build and tear down mountains and generally serve to define the stage upon which climate exists. During the Carboniferous period, plate tectonics may have triggered the large-scale storage of Carbon and increased glaciation. More recently, plate motions have been implicated in the intensification of the present ice age when, approximately 3 million years ago, the North and South American plates collided to form the Isthmus of Panama and shut off direct mixing between the Atlantic and Pacific Oceans.

Over millions of years the changing configuration of landmasses and oceans affects the way that heat is stored in the atmosphere and in the oceans. This affects the Earth's climate. During the age of the dinosaurs 100 million years ago, the Earth was much warmer than it is today, with an average temperature perhaps as high as 25°C, and little or no snow and ice even at the poles. Since that time, the separation of the continents has changed the flow of ocean currents and of winds, and has isolated Antarctica at the South Pole, causing a slow cooling down of the Earth's climate to that of today, with large ice sheets covering Antarctica and Greenland. The size of these ice sheets has regularly grown and shrunk during the last few million years, but this is not due to continental drift but to changes in the Earth's orbit around the Sun.

2. Galactic Variations:

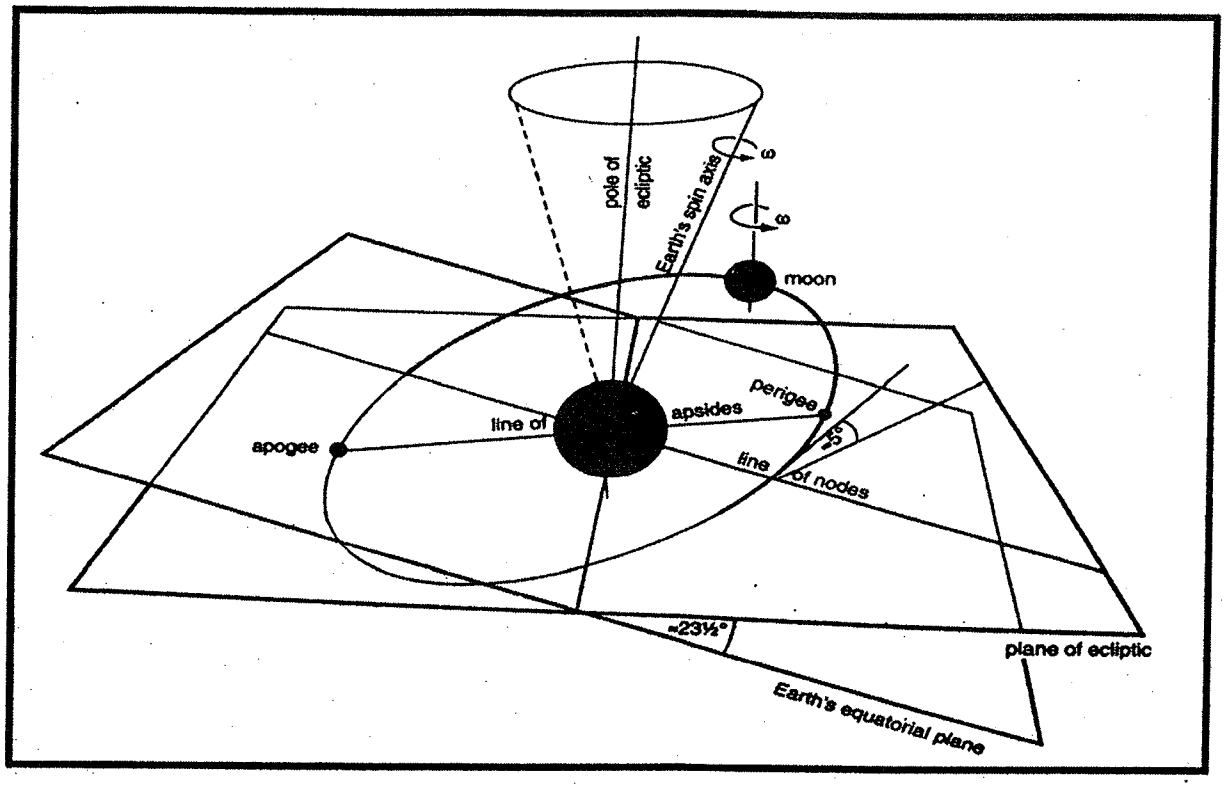
During the course of a galactic year (now estimated at 303 million years), variations in the interstellar medium (Williams, 1975a) may influence the amount of insolation. Williams (1975a) also suggested that variations in gravitational torque induced by our Galaxy's near neighbours, the Small and Large Magellanic Clouds, could have far-reaching consequences for the Earth's climate.

3. Orbital Variations:

Earth's orbit is influenced by gravitational interactions with moon and other planets. This produces cyclic perturbations in orbital obliquity, eccentricity and precision known as Milankovitch Cycle (Milutin Milankovitch; 1941). The theory could explain waxing and waning of ice ages during last million years.

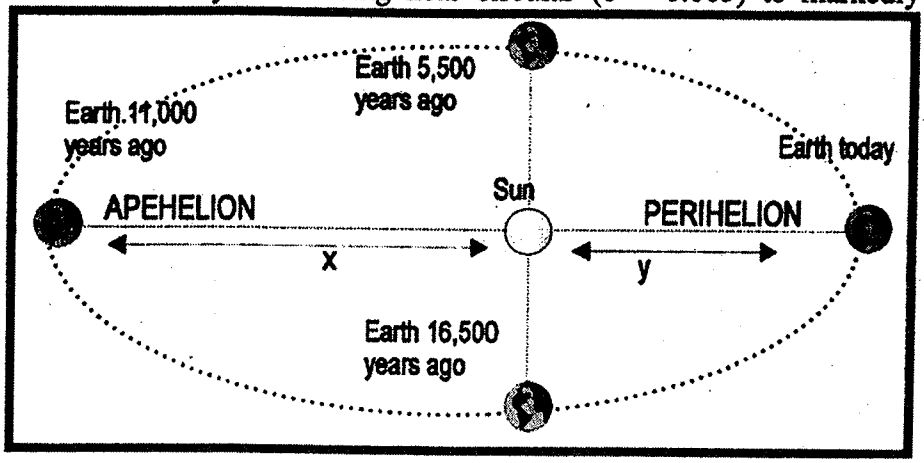
Obliquity-

Over a 41,000 year time period, the angle of inclination the earth's orbital plane and ecliptic plain fluctuates between 22° and 24.5°. Latitudinal distribution of solar radiation depends on obliquity. Obliquity does not influence the total amount of solar radiation received by the Earth, but affects the distribution of insolation in space and time. As obliquity increases, so does the amount of solar radiation received at high latitudes in summer, whilst insolation decreases in winter.



Eccentricity

The Earth's orbit has been found to vary from being near circular (e = 0.005) to markedly elliptical (e = 0.06) with two primary periodicities of approximately 96,000 (Berger, 1976). The current value of e is 0.018. With maximum eccentricity, differences in solar radiation receipt of about 30% may occur between perihelion and aphelion.



Precession

Due to the gravitational interaction of other planetary bodies (primarily the Moon and the planet Jupiter), the perihelion moves in space with a consequent shifting of the elliptical orbit. In a cycle of 21,000 years the Earth returns to its former perihelion position.

4. Sunspot and Solar Activity:

Sun is a massive ball of ionized gases subjected to gravitational, electrical and magnetic forces creating convective and circular motions. Under the influences of above forces, some darker areas of 4,000 K (umbra) develop in Sun between 30°N – 30°S, known as sunspots.They have an average

diameter of 103 km. Average area and number fluctuate over 11.2 years. Radiation from the Sun varies accordingly.

5. Volcanic Activity:

Explosive eruptions from vol canic eruption can inject large quantities of dust and gaseous material (such as sulphur dioxide) into the stratosphere. Sulphur dioxide is rapidly converted into sulphuric acid aerosols. Thus volcanic pollution of the lower atmosphere is removed within days, but stratospheric pollution may remain there for several years. The volcanic pollution results in a substantial reduction in the direct solar beam, largely through scattering with a net reduction of 5% to 10% in energy received. And also absorbs terrestrial radiation. An individual eruption may cause a global cooling of up to 0.3 °C, with the effects lasting 1 to 2 years (Example- Mount Pinatabo, June 1991).

6. Ocean variability:

On a timescale often measured in decades or more, climate changes can also result from the interaction between the atmosphere and the oceans. Many climate fluctuations, including the El Niño Southern oscillation, the Pacific decadal oscillation, the North Atlantic oscillation, and the Arctic oscillation, owe their existence at least in part to the different ways that heat may be stored in the oceans and also to the way it moves between various 'reservoirs'. On longer time scales (with a complete cycle often taking up to a thousand years to complete), ocean processes such as thermohaline circulation also play a key role in redistributing heat by carrying out a very slow and extremely deep movement of water, and the long-term redistribution of heat in the oceans.

7. Orogeny:

North-south orientated mountain ranges in particular have the ability to influence global atmospheric circulation patterns. The global winds usually maintain a more east-west trend on account of the Coriolis force. Therefore, the winds are more obstructed by the mountain ranges.

Due to uplift of mountains more rock are exposed, thereby increasing the rate of physical and chemical weathering. During chemical weathering, carbon dioxide is extracted from the atmosphere to react with the decomposing rock minerals to form bicarbonates.

Mountain uplift may also increase the land surface area covered by snow causing subsequent increase in planetary albedo.

8. Epeirogeny:

As the continental area occupying high latitudes increases, as a result of continental drift, so the land area with permanent ice cover may expand, thus raising the planetary albedo. Ocean circulation is involved in the latitudinal heat transport regulating global climate. Therefore, changes in the shape of the ocean basins due to epeirogeny, do have indirect influences on the climatic changes.

▲ 3.5.5.5 CAUSES OF GLOBAL WARMING

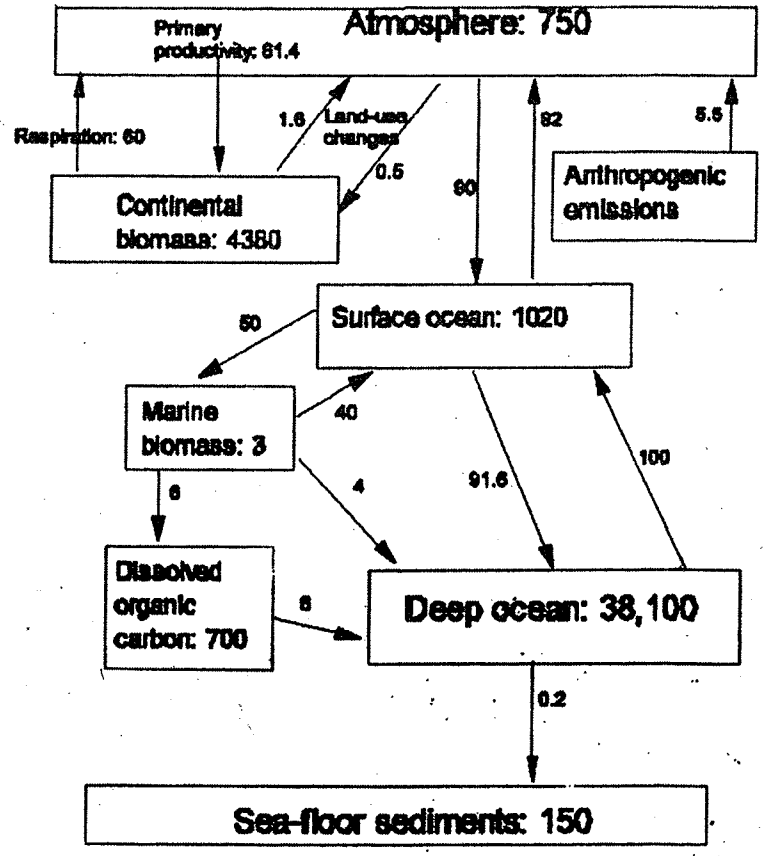
During the twentieth century, the earth's surface warmed by about 1.4 °F. There are a variety of potential causes for global climate change, including both natural and human-induced mechanisms. Science has made great strides recently in determining which potential causes are actually responsible for the climate change that occurred during the twentieth century, providing strong evidence that greenhouse gases released to the atmosphere by human activities are the main cause of contemporary global warming. Recent decades have seen record-high average global surface temperatures. Thermometer readings sufficient to provide reliable global averages are available back to 1850 (Brohan et al. 2006). In the past century, global surface temperature increased by about 1.4 °F Fig. 1). In the past quarter-century, according to satellite measurements, the lower atmosphere warmed by 0.22-0.34 °F per decade, equivalent to 2-3 °F per century (Christy and Spencer 2005; Mears and Wentz 2005). The past 20 years include the 18 warmest years on record (Hadley Centre 2005). This well-documented warming trend could result from several factors that influence the earth's climate, some of which are natural, such as changes in solar radiation and volcanic activity. Others, particularly the release of certain gases to the atmosphere and land-cover changes, are man made. This brief describes recent scientific progress in identifying the causes. The greenhouse effect is a natural phenomenon whereby certain gases in the earth's atmosphere, known as greenhouse gases, absorb heat that would otherwise escape to space. This heat originates from visible sunlight that warms the earth's surface. Subsequently, heat radiates from the surface to the atmosphere, where some of it is absorbed by greenhouse. Temperature rise during the twentieth century is much larger than the uncertainty range. Visible sunlight passes through the atmosphere without being absorbed. Some of the sunlight striking the earth is-

1. Absorbed and converted to infrared radiation (heat), which warms the surface.

2. The surface emits infrared radiation to the atmosphere, where some of it is absorbed by greenhouse gases and

3. Emitted toward the surface; some of the infrared radiation is not trapped by greenhouse gases and escapes into space

Human activities that emit additional greenhouse gases to the atmosphere increase the amount of infrared radiation that gets absorbed before escaping to space, thus enhancing the greenhouse effect and amplifying the warming of the earth and radiated back to the surface. Recent progress in climate modeling has generated a consensus among climate scientists that greenhouse gases emitted by human activities are likely (66-90% chance) to have caused most of the observed global temperature rise over the past 50 years (Mitchell et al. 2001). The increase in the strength of the greenhouse effect as a result of man-made greenhouse gases is known as the enhanced greenhouse effect. Factors that Influence Global Temperature Global climate varies over time in response to climate forcings—physical factors external to the climate system that force a net increase (positive forcing) or net decrease (negative forcing) of heat in the climate system as a whole (Hansen, Sato et al. 2005). This type of change is distinct from internal climate variability, in which heat is transported by winds or ocean currents between different components of the climate system with no net change in the total heat within the system. The El Niño–Southern Oscillation is a well-known example of internal climate variability. Because the observed climate change over the twentieth century results from a net increase of heat in the entire climate system, it can only be explained by external forcing (Hansen, Nazarenko et al. 2005). Hence, the task for climate change scientists is to identify one or more external forcing(s)—natural or man made—that can explain the



all led to a rise in the emission of carbon dioxide.

observed warming. Until recent centuries, climate forcings were exclusively natural, such as changes in the amount of sunlight reaching the earth's surface and changes in emissions of dust from volcanoes. During modern times, human activities have introduced a mix of additional forcings, such as increases in atmospheric greenhouse gases that cause warming (positive forcing), and sulfate aerosols, miniscule particles that reflect sunlight and cause cooling (negative forcing).

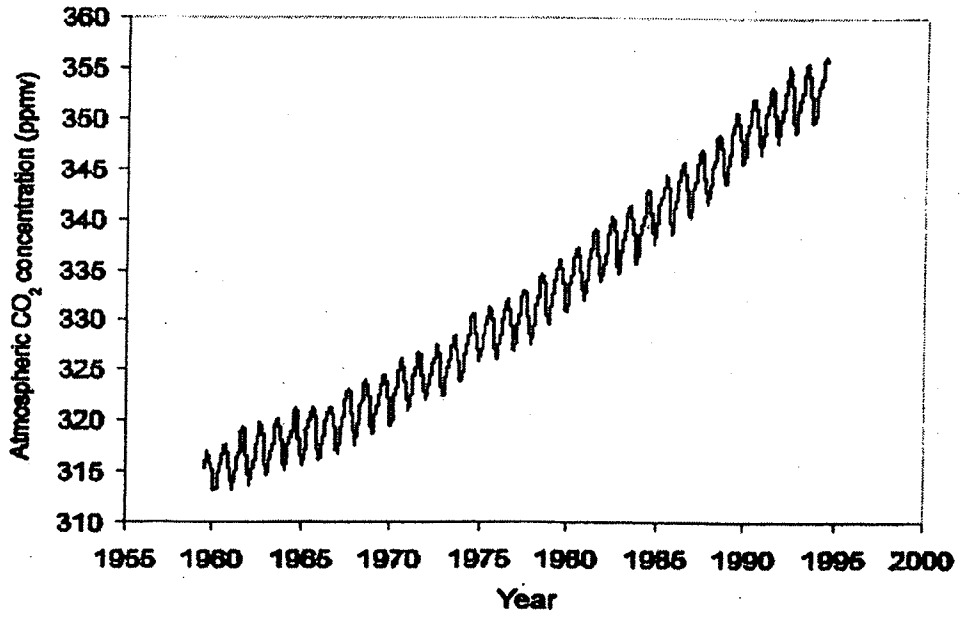
Greenhouse gases and their sources:

Carbon dioxide is undoubtedly, the most important greenhouse gas in the atmosphere. Changes in land use pattern, deforestation, land clearing, agriculture, and other activities have

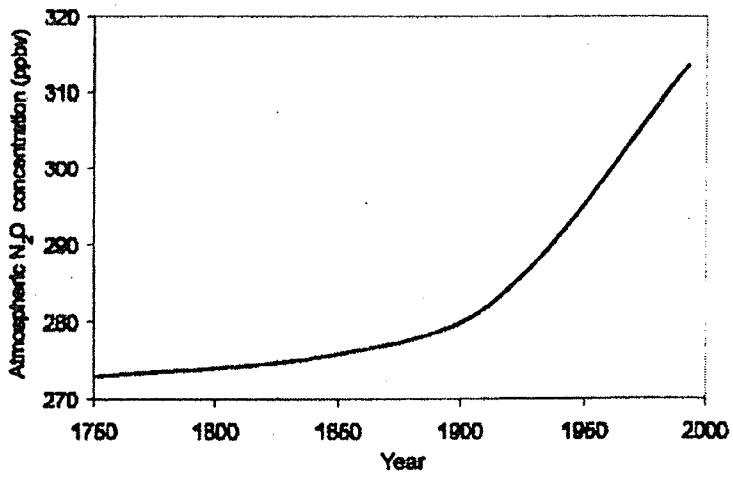
Methane is another important greenhouse gas in the atmosphere. About ¼ of all methane emissions are said to come from domesticated animals such as dairy cows, goats, pigs, buffaloes, camels, horses, and sheep. These animals produce methane during the cud-chewing process. Methane is also released from rice or paddy fields that are flooded during the sowing and maturing periods. When soil is covered with water it becomes anaerobic or lacking in oxygen. Under such conditions, methane-producing bacteria and other organisms decompose organic matter in the soil to form methane. Nearly 90% of the paddy-growing area in the world is found in Asia, as rice is the staple food there. China and India, between them, have 80-90% of the world's rice-growing areas.

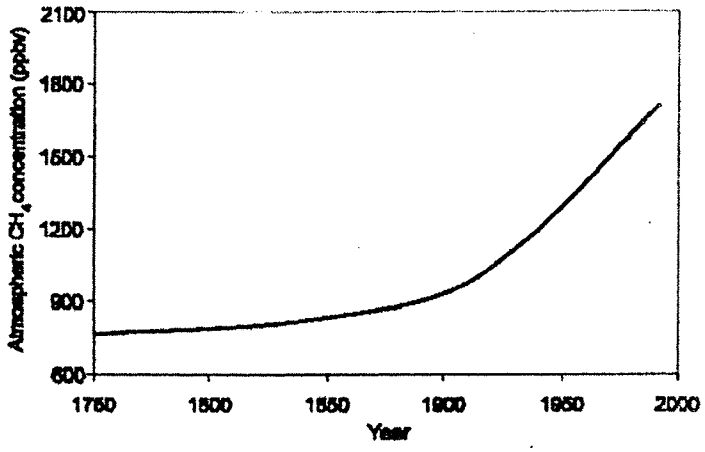
Natural Sources (CO_2)	Range (Gtons/yr)	Percent of Total (out of 158 Gtons/yr)
Oceans	90–92	57–58
Land biota	60–61	36–39
Natural Source Total	*150–153*	*93–97*
Human Sources		
Burning Fossil fuels	5.0–6.0	3.4–3.8
Deforestation	0.6–2.6	0.01–0.02
Human Source Total	*5.6–8.6*	*3.5–5.4*
Total	*157–160*	*100%*

Methane is also emitted from landfills and other waste dumps. If the waste is put into an incinerator or burnt in the open, carbon dioxide is emitted. Methane is also emitted during the process of oil drilling, coal mining and also from leaking gas pipelines (due to accidents and poor maintenance of sites).
A large amount of nitrous oxide emission has been attributed to fertilizer application. This in turn depends on the type of fertilizer that is used, how and when it is used and the methods of tilling that are followed. Contributions are also made by leguminous plants, such as beans and pulses that add nitrogen to the soil.
Error



Natural Sources of Methane	Range (Mtons)	IPCC Value	Percent of IPCC total
Wetlands	**100–200**	**115**	**22**
Termites	**10–50**	**20**	**4**
Ocean/freshwater	**6-45**	**15**	**3**
Methane hydrates	**0–5**	**5**	**1**
Natural Source Total	***117–325***	***150***	***30***
Human Sources			
Energy Use	**70–120**	**100**	**19**
Rice paddies	**20–150**	**60**	**12**
Enteric fermentation	**65–100**	**80**	**15**
Human / Animal wastes	**20–60**	**50**	**10**
Landfills	**20–70**	**30**	**6**
Biomass burning	**20–80**	**40**	**8**
Human Source Total	***215–580***	***360***	***70***
Total	***332-905***	***515***	***100***





Natural Sources of Nitrous Oxides	Range (in Mtons)
Oceans	1.4–2.6
Tropical Soils	Uncertain
Wet forests	2.2–3.7
Dry savannas	0.5–2.0
Temperate soils	Uncertain
Forests	0.5–2.0
Grasslands	Uncertain
Natural Source Total	*4.6–10.3*
Anthropogenic Sources	
Cultivated soils	0.3–3.0
Biomass burning	0.03–1.0
Combustion	0.1–0.3
Mobile sources	0.2–0.6
Acid production	0.5–0.9
Anthropogenic Source Total	*0.13–5.8*
IPCC Total	*5.2–16.1*

HALOCARBONS

Sources:
The CFCs and HCFCs are wholly anthropogenic and do not exist naturally. They have been widely used as propellants in aerosols, as blowing agents in foam manufacture, in air conditioning units and refrigerants.

Sinks

1. By photodissociation and photo-oxidation in the stratosphere but because of their relative inertness, remain in the atmosphere for long periods of time.

2. Reaction with OH, NO_3.

3. Removed by the ocean, presumably in hydrolysis reactions

Certain gases in the atmosphere, such as carbon dioxide, play a crucial role in determining the earth's climate. Although other factors are important as well, the composition of the atmosphere to a large extent controls our climate. Levels of so-called greenhouse gases are particularly important, because these gases determine how air absorbs and transmits radiant energy.

Atmospheric concentrations of greenhouse gases are rising rapidly, mainly because of human activity. By burning fossil fuels and deforesting the earth, mankind is increasing carbon dioxide levels. Our intensive agriculture and leaky natural-gas lines are major sources of methane. Our industry is emitting chlorofluorocarbons (CFCs). Nitrous oxide levels are also increasing rapidly, for reasons that are less clear. Less than 200 years since we began making major emissions, greenhouse gas concent rations are rising to levels higher than any yet seen while humans have existed on this planet and they will rise much further in the years ahead.

Changes in greenhouse gas concentrations have been associated with dramatic climatic changes in the past. The last time greenhouse gas levels changed as much as they are changing now was when the earth emerged from the most recent ice-age. There is strong evidence that greenhouse gases played a significant role in that post-ice-age warming.

The current increase in greenhouse gases will affect the climate but we don t yet know exactly how. The different components of the earth climate interact on many different time-scales in complex, often chaotic ways. Many of these interactions are still poorly understood. But even if we understood the present climate much better than we do, the future could still hold surprises. We are entering into a new, hitherto unexplored, climatic regime. Because the climate is a non-linear system, we will not be completely sure of the consequences of our actions until after climate change has already occurred.

Climate models indicate that one of the main effects of greenhouse gas emissions will be global warming. Assuming that no action is taken to reduce emissions, computer models of the earth s climate indicate that global average surface temperatures will rise by 1.5-4.5 C over the next 100 years. This rise is larger and probably faster than any such change over the past 9,000 years. Climate models are far from perfect, and they rely on projections of future greenhouse gas emissions that are far from certain. But, insofar as a consensus exists in the world scientific community, they are believed to provide the best estimates we have of future climate change. Emission scenarios and model predictions may overstate the risk, but they are equally likely to underestimate it. There is some evidence that this warming has already begun. Average world surface temperatures appear to have risen by 0.3-0.6 C over the past 100 years. But although many climatologists believe that this indicates a real change, the historical temperature record is poor. Moreover, the climate varies naturally, partly because of its chaotic nature, and this observed warming is still just within the range of natural variability. Nevertheless, this warming is broadly in line with what models predict should have resulted from emissions to date. The most plausible explanation is that it is due, at least in part, to mankind s greenhouse gas emissions.

If no action is taken to reduce greenhouse gas emissions, the consequences for many of the world s societies and ecosystems may be serious. Average sea-levels may rise, which would affect coastal communities through more frequent flooding and increased ground-water salinity. Changes in rainfall patterns and soil moisture levels are probable, but still difficult to predict. Both would have significant implications for agriculture. Not all climate change impacts would be negative, however, and the burden of adapting to them would be spread very unevenly over the world s societies. **Those most at risk from climate change are likely to be those least able to adapt.** For example, subsistence agricultural societies and many natural ecosystems have evolved over centuries to suit the present climate. Both are likely to find climate change on the scale and speed predicted for the coming decades to be traumatic.

Pre-industrial and 1992 atmospheric concentrations of greenhouse gases

	CO_2	CH_4	N_2O	CFC-12
Pre-industrial concentration	280 ppmv	700 ppbv	275ppbv	zero
Concentration in 1992	355 ppmv	1,715 ppbv	310ppbv	503pptv
Rate of change of concentration during 1980s	1.5 ppmv/a	13 ppbv/a	0.75 ppbv/a	20 pptv/a
Atmospheric adjustment time	50-200 yrs	12-17 yrs	120 yrs	102 yrs

CONSEQUENCES OF GLOBAL WARMING

Risks and impacts from global warming have been clearly mentioned in the Third Assessment Report of the Intergovernmental Panel on Climate Change (IPCC). It has been argued that both environment and human life are concerned with the effects of global warming. IPCC predicts that global warming will continue and get worse much faster than it was expected. Research by NOAA indicates that the effects of global warming are already irreversible. Many specific natural phenomena have been attributed to human causes. The expected long range effects of recent climate change may already be observed. Rising sea levels, glacier retreat, Arctic shrinkage, and altered patterns of agriculture are described as direct consequences of human activities. Besides these there are many secondary and regional effects like- extreme weather events, an expansion of tropical diseases, changes in the timing of seasonal patterns in ecosystems, and drastic economic impact.

In its Fourth Assessment Report, the IPCC (2007) has included a summary of the expected effects. Climate changes due to global warming are causing large-scale irreversible effects at continental and global scales. The magnitude of the effects are observed and predicted to be increasing and quickening. Many consequences of global warming once thought to be unlikely are now being perceived very clearly. Arctic ice cover shrinkage and Arctic methane release, large reductions in the Greenland and West Antarctic Ice Sheets, accelerated releases of terrestrial carbon from permafrost regions and methane from hydrates in coastal sediments etc. have been instrumental in introducing abnormalities in the climatic phenomena. The United States National Academy of Sciences has stated, "Greenhouse warming and other human alterations of the earth system may increase the possibility of large, abrupt, and unwelcome regional or global climatic events.... Future abrupt changes cannot be predicted with confidence, and climate surprises are to be expected."

The consequences of global warming are not uniformly felt around the World. Polar and inland regions are affected more rapidly and rigorously than are the oceans and tropics. Further, some areas are vulnerable to sudden climate change which may unexpectedly influence the climate of a region.

1. Increased frequency and intensity of extreme weather events:

The most damaging forms of weather extreme during the twentieth century have varied from one part of the world to another. In many parts of the tropics and subtropics, failure of seasonal rainfall causes the greatest hardship. The industrialized nations of the mid-latitudes experience a wider variety of damaging events. For example, in North America the combination of blizzard, flood, hurricanes, tornadoes, summer droughts, heat waves, winter freezes have caused immense economic damages. Europe experiences a similar mixture of extreme events.

Increasing temperature is likely to lead to increasing precipitation but the effects on storms are less clear. Extratropical storms partly depend on the temperature gradient, which is predicted to weaken in the northern hemisphere as the polar region warms more than the rest of the hemisphere.

Worldwide, the proportion of **hurricanes** reaching categories 4 or 5 – with wind speeds above 56 metres per second – has risen from 20% in the 1970s to 35% in the 1990s. Precipitation hitting the US from hurricanes has increased by 7% over the twentieth century. The extent to which this is due to global is unclear. Some studies have found that the increase in sea surface temperature may be offset by an increase in wind shear, leading to little or no change in hurricane activity. Hoyos *et al.* (2006) have linked the increasing trend in number of category 4 and 5 hurricanes for the period 1970-2004 directly to the trend in sea surface temperatures.

Increases in catastrophes resulting from extreme weather are mainly caused by increasing population densities, and anticipated future increases are similarly dominated by societal change rather than climate change. The World Meteorological Organization explains that "though there is evidence both for and against the existence of a detectable anthropogenic signal in the tropical cyclone climate record to date, no firm conclusion can be made on this point."

Highest Accumulated Cyclone Energy (ACE) hurricane seasons (since 1850, source)

Rank	Season	ACE
1	2005	248
2	1950	243
3	1893	231
4	1995	227
5	2004	224
6	1926	222
7	1933	213
8	1961	205
9	1955	199
10	1887	182

This figures in the table conforms with the conclusions of Knutson and Tuleya (2004) that maximum intensity reached by tropical storms is likely to increase, with a significant increase in the number of highly destructive category-5 storms.

Costliest U.S. Atlantic hurricanes
Total estimated property damage, adjusted for wealth normalization

Rank	Hurricane	Season	Cost (2005 USD)
1	"Miami"	1926	$157 billion
2	"Galveston"	1900	$99.4 billion
3	Katrina	2005	$81.0 billion
4	"Galveston"	1915	$68.0 billion
5	Andrew	1992	$55.8 billion
6	"New England"	1938	$39.2 billion
7	"Pinar del Río"	1944	$38.7 billion
8	"Okeechobee"	1928	$33.6 billion
9	Donna	1960	$26.8 billion
10	Camille	1969	$21.2 billion

List of costliest Atlantic hurricanes

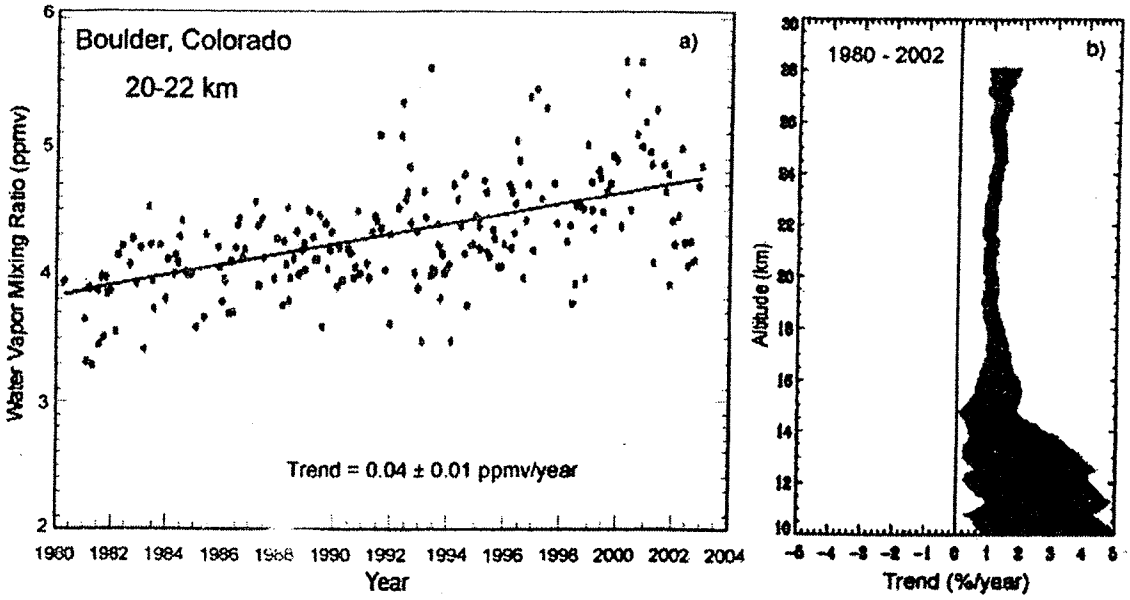
Cost of more extreme weather

The World Meteorological Organization attributed the recent increase in societal impact from tropical cyclones to rising concentrations of population and infrastructure in coastal regions. Pielke *et al.* (2008) normalized mainland U.S. hurricane damage from 1900–2005 to 2005 values and found no remaining trend of increasing absolute damage. The 1970s and 1980s were notable because of the extremely low amounts of damage compared to other decades. The decade 1996–2005 has the second most damage among the past 11 decades, with only the decade 1926–1935 surpassing its costs. The most damaging single storm is the 1926 Miami hurricane, with $157 billion of normalized damage.

The American *Insurance Journal* predicted that "catastrophe losses should be expected to double roughly every 10 years because of increases in construction costs, increases in the number of structures and changes in their characteristics.

Increased evaporation

Over the course of the 20th century, evaporation rates have reduced worldwide; this is thought by many to be explained by ***global dimming***. As the climate grows warmer and the causes of global dimming are reduced, evaporation will increase due to warmer oceans. Because the world is a closed system this will cause heavier rainfall, with more erosion. This erosion, in turn, can in vulnerable tropical areas (especially in Africa) lead to desertification. On the other hand, in other areas, increased rainfall may lead to growth of forests in dry desert areas.

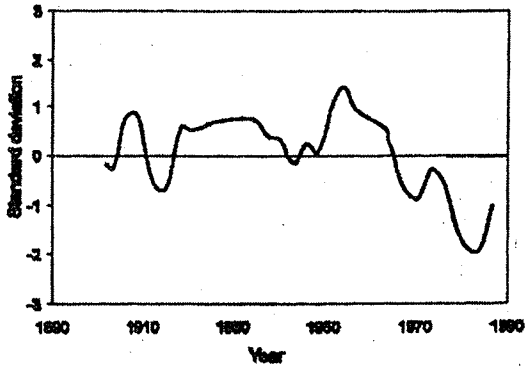


Scientists have found evidence that increased evaporation could result in more extreme weather as global warming progresses. The IPCC Third Annual Report says: "...global average water vapour concentration and precipitation are projected to increase during the 21st century. By the second half of the 21st century, it is likely that precipitation will have increased over northern mid- to high latitudes and Antarctica in winter. At low latitudes there are both regional increases and decreases over land areas. Larger year to year variations in precipitation are very likely over most areas where an increase in mean precipitation is projected."

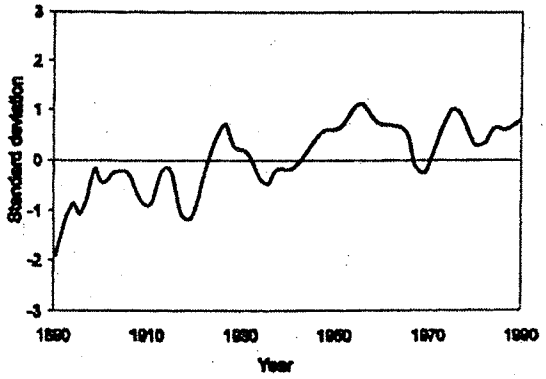
Precipitation:

A detailed view suggests that, taking an average over the Earth's land surface, precipitation increased from the start of the 20th. Century up to about 1960 and has decreased since about 1980. The precipitation data available are not sufficient to get any trend in the changes in precipitation amount. But some significant changes have been noticed. It seems that the precipitation has increased over land at high latitudes in the northern hemisphere especially during the cold seasons. One study also suggests that there has been an increase in the amount of rain received from high rainfall events, particularly in USA, former Soviet Union, and China. Decrease in precipitation has occurred after 1960s over the subtropics and the tropics from Africa to Indonesia. In terms of snowfall Antarctica has experienced an increase of 5-20% over last two decades while Greenland has lost about 20% of its snow that accumulated during the last 50 years.

Standardised deviation of precipitation in the Sahel region, N. Africa, smoothed curve (after Folland et al., 1990)



Standardised deviation of precipitation in the old USSR nations, smoothed curve (after Folland et al., 1990)



Monsoon Rainfall and flood:

The computer models do, however, suggest that the proportion of rainfall occurring as heavy rainfall has and will continue to increase, as will the year-to-year variability. This will increase the frequency of flooding events.

Two-fifths of the world's population lives under the monsoon belt which brings life-giving rains. Monsoons are driven by the temperature contrast between continents and oceans. For example, moisture-laden surface air blows from the Indian Ocean to the Asian continent and from the Atlantic Ocean into West Africa during northern hemisphere summers, when the land masses become much warmer than the adjacent, ocean. In winter the continents become colder than the adjacent oceans and high pressure develops at the surface, causing surface winds to blow towards the ocean. Climate models indicate an increase in the strength of the summer monsoons as a result of global warming over the next hundred years. There are three reasons to support that this should occur.

1. Global warming will cause continents to warm more than the ocean in summer and this is the primary driving force of the monsoon system.
2. Decreased snow cover on Tibet, expected in a warmer world, will increase this temperature difference between land and sea, increasing the strength of the-Asian summer.
3. Warmer climate means the air can hold more water vapour, so the monsoon winds will be able to carry more moisture. For the Asian summer monsoon this could mean an increase of 10-20% in average rainfall, with an interannual variability of 25-100% and a dramatic increase in the number of days with heavy rain.

Effects on El Nino:

There is also considerable debate over whether ENSO has been affected by global warming. The El Nino conditions generally occur every three to seven years; however, they have returned for three years out of four: 1991-2, 1993-4, and 1994-5. El Nino then returned again to cause havoc on global weather in 1997-8. Reconstruction of past climate using coral reefs in the western Pacific shows sea-surface temperature variations back 150 years, well beyond our historic records. The sea-surface

temperature shows the shifts in ocean current, which accompany shifts in the ENSO and reveal that there have been two major changes in the frequency and intensity of El Nino events. First, was a shift at the beginning of the 20th century from a 10-15-year cycle to a 3-5-year cycle. The second shift was a sharp threshold in 1976 when a marked shift to more intense and even more frequent El Nino events occurred. These are sobering results considering the huge weather disruption and disasters caused by recent El Nino events. Modeling results also suggest that the current heightened state of El Nino can permanently shift weather patterns. For example, it seems that the drought region in the USA could be shifting eastward. However, we have seen, to predict an El Nino event six months from, now is hard enough without trying to assess whether or not ENSO is going to get more extreme over the next 100 years. Most computer models of ENSO in the future are inconclusive; some have found an increase and others have found none.

2. Effects on Permafrost regions:

In the northern hemisphere, the southern part of the Arctic region has experienced a temperature rise of 1 °C to 3 °C over the last 50 years. Canada, Alaska and Russia are experiencing initial melting of permafrost. This may disrupt ecosystems and by increasing bacterial activity in the soil lead to these areas becoming carbon sources instead of carbon sinks. A study of changes to eastern Siberia's permafrost suggests that it is gradually disappearing in the southern regions, leading to the loss of nearly 11% of Siberia's nearly 11,000 lakes since 1971. At the same time, western Siberia is at the initial stage where melting permafrost is creating new lakes, which will eventually start disappearing as in the east. Furthermore, permafrost melting will eventually cause methane release from melting permafrost peat bogs.

3. Retreat of Continental Glaciers:

Glaciers grew during the Little Ice Age (from about 1550 to 1850). Subsequently, until about 1940, glaciers around the world retreated as the climate warmed. From 1950 to 1980, Glacier retreat declined and reversed in many cases due to slight global cooling. But since 1980, glacier retreat has become increasingly rapid and worldwide, and has threatened the existence of many of the glaciers of the world. This process has increased markedly since 1995.

Excepting the ice caps and ice sheets of the Arctic and Antarctic, the total surface area of glaciers worldwide has decreased by 50% since the end of the 19th century. Glacial retreat rates are currently increasing in the Andes, Alps, Pyrenees, Himalayas, Rocky Mountains and North Cascades.

The loss of glaciers not only directly causes- *landslides, flash floods and glacial lake overflow* but also *increases annual variation in water flows in rivers*. Glaciers retain water on mountains in high precipitation years, since the snow cover accumulating on glaciers protects the ice from melting. In warmer and drier years, glaciers offset the lower precipitation amounts with a higher melt water input.

The Hindu Kush and Himalayan glacial melts are of particular importance as those glaciers are the principal dry-season water source of many of the major rivers of the Central, South, East and Southeast Asia. According to a UN climate report, the Himalayan glaciers that are the sources of Asia's biggest rivers—Ganges, Indus, Brahmaputra, Yangtze, Mekong, Salween and Yellow—could disappear by 2035 as a consequence of temperature rise. Approximately 2.4 billion people live in the drainage basin of the Himalayan Rivers. India, China, Pakistan, Bangladesh, Nepal and Myanmar could experience floods

followed by droughts in coming decades. In India alone, the Ganges provides water for drinking and farming for more than 500 million people. It has to be remembered that, increased seasonal runoff of Himalayan glaciers is responsible for increased agricultural production in northern India throughout the 20th century.

The recession of mountain glaciers, notably in Western North America, Asia, Europe, Indonesia and Africa, and tropical and sub-tropical regions of South America, has been due to the rise in global temperatures since the late 19th century.

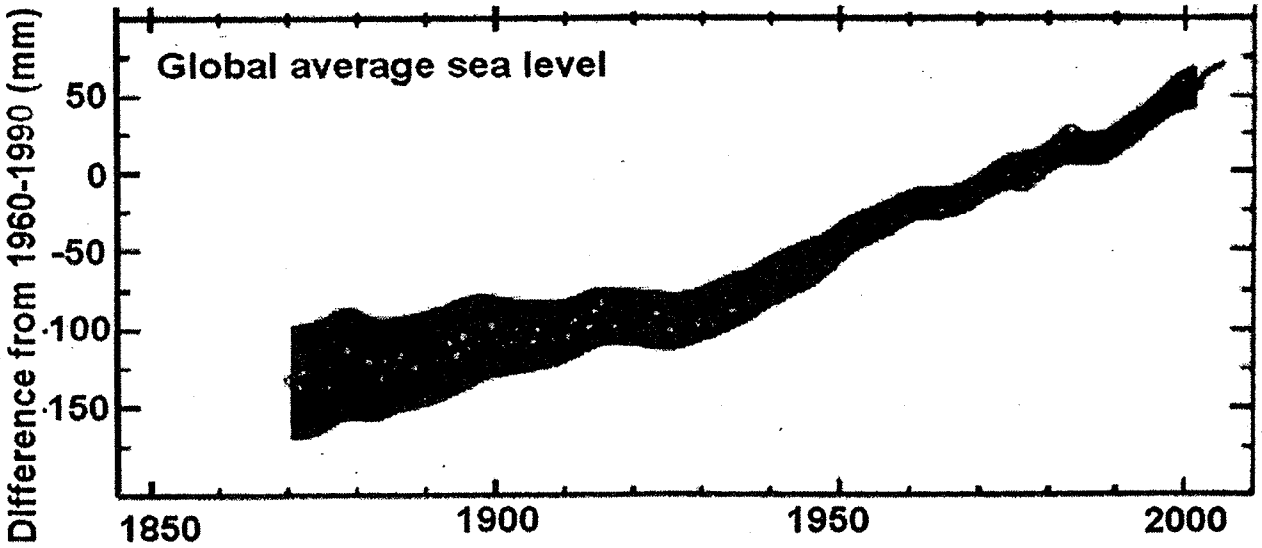
In Greenland several very large glaciers have been found to retreat that had long been stable. Satellite images and aerial photographs from the 1950s and 1970s show that the front of the glacier had remained in the same place for decades. But in 2001 it began retreating rapidly, retreating 7.2 km between 2001 and 2005. It has also accelerated from 20 m /day to 32 m/day.

4. Effects on the Oceans:

Global warming might have a number of effects on the oceans. They are discussed as under.

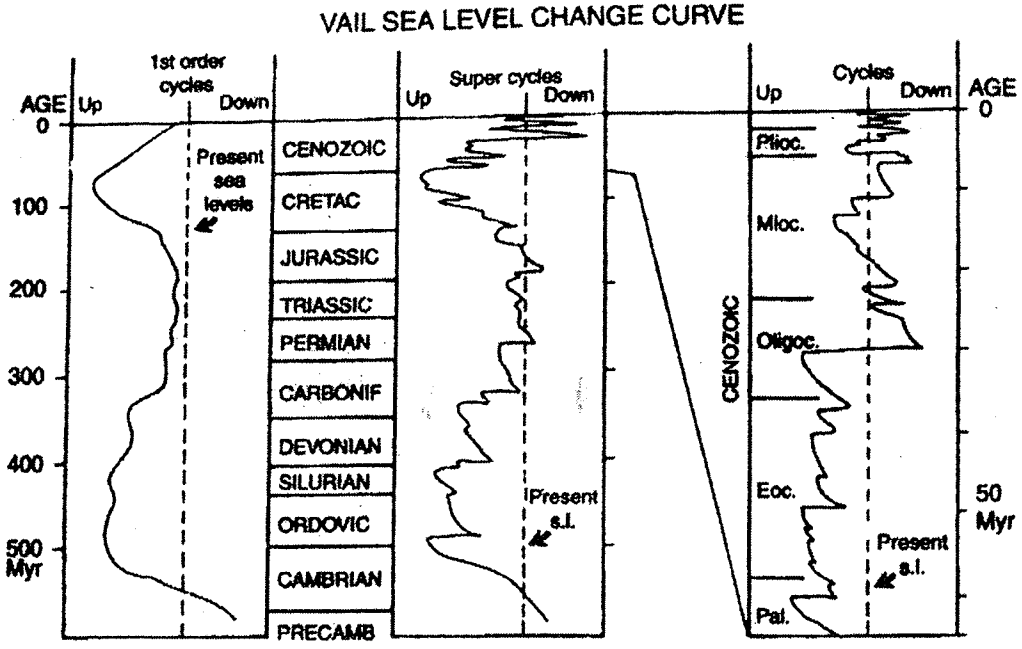
Relative Sea Level Rise:

The IPCC has also put together a key data set of sea level. In general it shows that over the last 100 years, the global sea level has risen by about 4 to 14 cm. But sea-level change is difficult to measure, as relative sea-level changes have been derived mainly from tide-gauge data. In the conventional tide-gauge system, the sea level is measured relative to a land-based tide-gauge benchmark. The major problem is that the land surface is much more dynamic that one would expect, with a lot of vertical movements, and these get incorporated into the measurements. Vertical movements can occur as a result of normal geological compaction of delta sediments, the withdrawal of groundwater from coastal aquifers, uplift associated with colliding tectonic plates (the most extreme of which is mountain building such as the Himalayas), or ongoing postglacial rebound and compensation elsewhere associated with the end of the last ice age. The latter is caused by the rapid removal of weight when the ice sheets melted, so



that the land which has been weighed down slowly rebounds back to its original position. An example of this is Scotland, which is rising at a rate of 3 mm/year while England is still sinking at a rate of 2 mm/year, despite the Scottish ice sheet having melted 10,000 years ago. Again, using a number of corrections, the global tide-gauge network suggests that the rise in sea level since the beginning of the 20th century could be as much as 18 cm (~1.8±0.1 mm/year). On this timescale, the warming and the consequent thermal expansion of the oceans may account for about 2-7 cm of the observed sea-level rise, while the observed retreat of glaciers may account for about 2-5 cm. Other factors are more difficult to quantify. The rate of observed sea-level rise suggests that there may have been a net positive contribution from the huge ice sheets of Greenland and Antarctica, but observations of these ice sheets suggest that there may have been a net expansion which would have contributed -0.05 mm/year to global sea level over the last 100 years. The ice sheets remain a major source of uncertainty in accounting for past changes in sea level because of insufficient data about these ice sheets over the last 100 years.

With increasing average global temperature, the water in the oceans expands in volume, and additional water enters them which had previously been locked up on land in glaciers, for example, the Greenland and the Antarctic ice sheets. For most glaciers worldwide, an average volume loss of 60% until 2050 is predicted. Meanwhile, the estimated total ice melting rate over Greenland is 239 ± 23 cubic kilometres (57 ± 5.5 cu mi) per year, mostly from East Greenland. The Antarctic ice sheet, however, is expected to grow during the 21st century because of increased precipitation. Under the IPCC Special Report on Emission Scenario (SRES), by the mid-2090s global sea level will reach 0.22 to 0.44 m above 1990 levels, and is currently rising at about 4 mm per year. Since 1900, the sea level has risen at an average of 1.7 mm per year; since 1993, satellite altimetry indicates a rate of about 3 mm per year.



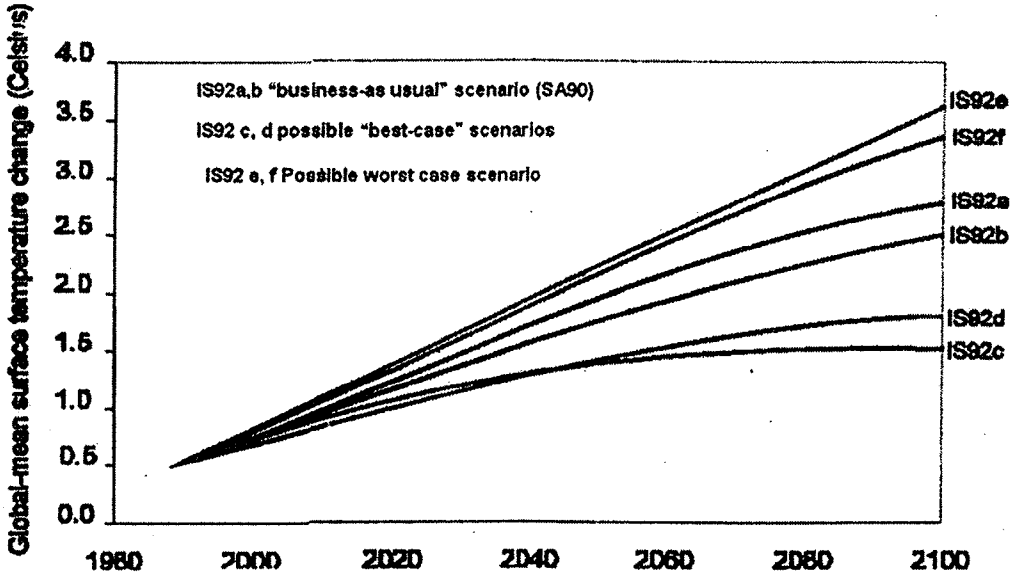
Sequence analysis of global sea level changes during the Phanerozoic

The sea level has risen more than 120 metres since the Last Glacial Maximum about 20,000 years ago. The bulk of that occurred before 7000 years ago. Global temperature declined after the Holocene Climatic Optimum, causing a sea level lowering of 0.7 ± 0.1 m between 4000 and 2500 years before present. From 3000 years ago to the start of the 19th century, sea level was almost constant, with only

minor fluctuations. However, the Medieval Warm Period may have caused some sea level rise; evidence has been found in the Pacific Ocean for a rise to perhaps 0.9 m above present level in 700 BP.

Future Global Temperature and Sea Level Rise (IPCC Projections):

Seven GCMs (Global Circulation Models) have been run using selected nature carbon dioxide emission scenarios for the IPCC 2001 report to produce global average temperature changes that may occur by 2100. These climate models show that the global mean surface temperature could rise by between 1.4°C and 5.8°C by 2100 (see Figure 25). The topmost curve assumes constant aerosol concentrations beyond 1990, high climate sensitivity, and a significant increase in the emissions of carbon dioxide, and produces an increase of 5.8°C by 2100. The lowest curve assumes constant aerosol concentrations beyond 1990, but much lower climate sensitivity and a slower increase in carbon dioxide emissions and produces an increase of 1.4 °C. What is most worrying is that there is a 4.4 °C temperature difference between the IPCC projections in the most extreme estimates. However, it should be noted that all the model predictions show an increase in global temperatures over the next hundred years.



Projected global mean surface temperature increases for the IPCC emission scenarios (after IPCC, 1992)

Again, using the different carbon dioxide emission scenarios, the IPCC has projected global mean sea level up to 2100. Taking into account the ranges in the estimate of climate sensitivity and ice-melt parameters, and the emission scenarios, the models projects an increase in global mean sea level of between 20 cm and 88 cm. It can be noted that during the first half of the 21st century, the choice of emission scenario has relatively little effect on the projected sea-level rise, as most of it is due to the large thermal inertia (i.e. it takes a lot of initial energy to get any noticeable change in temperature) of the ocean-ice-atmosphere climate system. However, it has an increasingly large effect in the latter part of this century, because of the uncertainty about how the ice sheets will react and melt. In addition, because of the thermal inertia of the oceans, sea level would continue to rise for many centuries beyond 2100, even if concentrations of greenhouse gases were stabilized at that time. What the sea-level calculation does not take into account is the possible melting of the world's ice sheets and glaciers. If the ice sheets completely melted, their contribution to sea-level rise would be as follows:

Mountain glaciers = 0.3 m, West Antarctic ice sheets = 8.5 m. Greenland = 7m, East Atlantic Ice Sheets = 65 m. NASA satellite measurements suggest that both Greenland and West Antarctic Ice Sheets are shrinking.

Sea Surface Temperature (SST) Rise:

From 1961 to 2003, the global ocean temperature has risen by 0.10 °C from the surface to a depth of 700 m. There is variability both year-to-year and over longer time scales, with global ocean heat content observations showing high rates of warming for 1991 to 2003, but some cooling from 2003 to 2007. The temperature of the Antarctic Southern Ocean rose by 0.17 °C between the 1950s and the 1980s, nearly twice the rate for the world's oceans as a whole. As well as having effects on ecosystems (e.g. by melting sea ice, affecting algae that grow on its underside), warming reduces the ocean's ability to absorb CO_2.

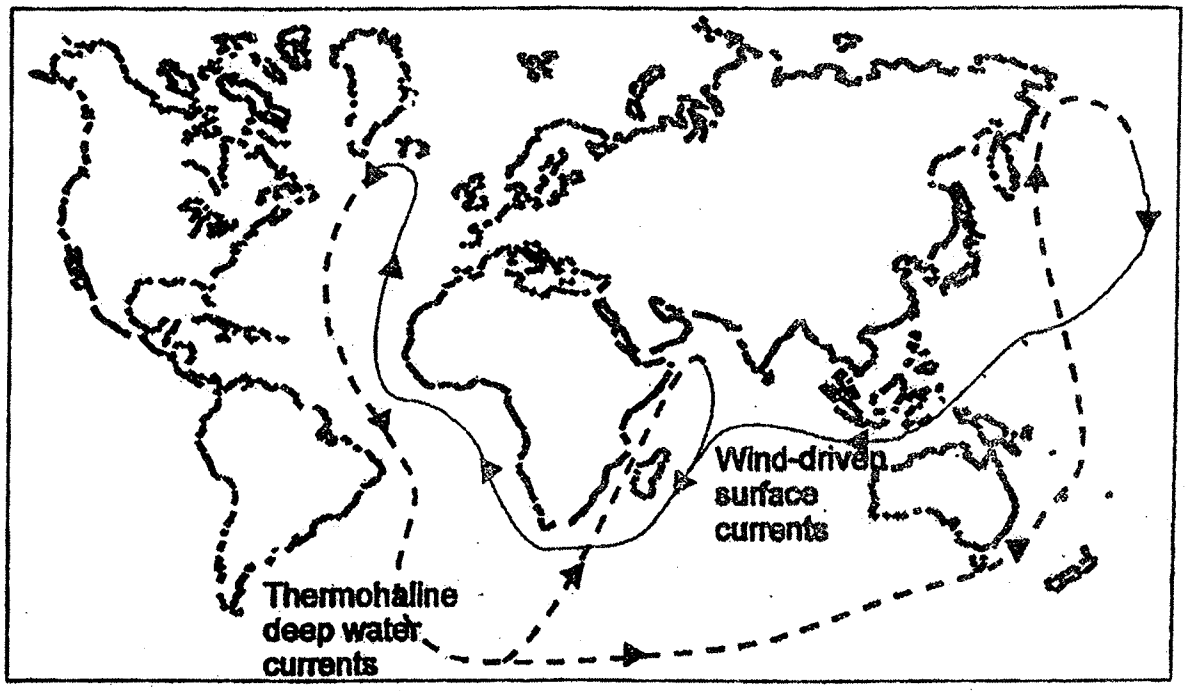
Ocean Acidification:

The oceans absorb much of the CO_2 produced by living organisms, either as dissolved gas, or in the skeletons of tiny marine creatures that fall to the bottom to become chalk or limestone. Oceans currently absorb about one tonne of CO_2 per person per year. It is estimated that the oceans have absorbed around half of all CO_2 generated by human activities since 1800. In water, CO_2 becomes a weak carbonic acid, and the increase in the greenhouse gas since the industrial revolution has already lowered the average pH of seawater by 0.1 units, to reach a value of 8.2. Predicted emissions could lower the pH by a further 0.5 by 2100, which is probably 100 times greater than at any time over this period. This will have detrimental effect on corals (16% of the world's coral reefs have died from bleaching caused by warm water in 1998) and other marine organisms with calcium carbonate shells.

Slowing Down of the Thermohaline Circulation:

It has been speculated the thermohaline circulations in the oceans that bear climatological significance in determining the weather of many of the North Atlantic countries will slow down and may even stop due to global warming. This may trigger localized cooling in the North Atlantic and lead to cooling or lesser warming, in that region. This would affect in particular areas like Scandinavia and Britain that are warmed by the North Atlantic drift.

The chances of this near-term collapse of the circulation are unclear; there is some evidence for the short-term stability of the Gulf Stream and possible weakening of the North Atlantic drift. However, the degree of weakening, and whether it will be sufficient to shut down the circulation, is under debate.



Dissolved Oxygen depletion:

The amount of oxygen dissolved in the oceans may decline, with adverse consequences for ocean life.

5. Positive Feedback Effects:

Gas Hydrates:

Gas hydrates are a mixture of water and methane, which is sustained as a solid at very low temperature and very high pressure. These gas hydrates are solid, structurally composed of water molecules which hold individual molecules of methane and other gases. The methane comes from decaying organic matter found deep in oceanic sediments and in soil beneath permafrost. These gas hydrate reservoirs are extremely unstable, as a slight increase in temperature or decrease in pressure can cause them to destabilize and thus release of methane which is a highly potential greenhouse gas. Impact of global warming includes the heating up of both oceans and permafrost, which could cause the gas hydrates to breakdown pumping huge amount of methane into the atmosphere. The release of this trapped methane is a potential major outcome of a rise in temperature; it is thought that this might increase the global temperature by an additional 5°C in itself.

Carbon cycle feedbacks:

This has been predicted that, global warming might cause loss of carbon from terrestrial ecosystems due to the response of the terrestrial carbon cycle to global warming, leading to an increase of atmospheric CO_2 levels. Several climate models indicate that, by the end of the twenty-first century, this additional CO_2 will vary between 20 and 200 ppm for the two extreme models, while majority of the models lying between 50 and 100 ppm. The higher CO_2 levels led to an additional climate warming ranging between 0.1° and 1.5 °C. However, there was still a large uncertainty on the magnitude of these

sensitivities. Observations show that soils in England have been losing carbon at the rate of four million tonnes a year for the past 25 years. The causes of CO_2 increases has been explained in terms of- *Landuse changes, deforestation, loss of forest due to global warming, release of dissolved organic carbon (DOC)* from peat bogs into water courses (from which it would in turn enter the atmosphere).

Decreased Earth's albedo:

In September 2007, the Arctic sea ice covered area had reached about half the size of the average summer minimum area between 1979 and 2000. Based on the loss rate data, it has been predicted that by 2030 the Arctic could be ice-free during part of the year. Also in September 2007, Arctic sea ice retreated far enough for the Northwest Passage to become navigable to shipping for the first time in recorded history. Retreating sea ice will allow the sun to warm the newly exposed sea water, thus decreasing the Earth's albedo, which will contribute to further warming. IPCC predict polar temperatures in the northern hemisphere to rise up to twice as much as those of the rest of the world. The polar amplification of global warming is not predicted to occur in the southern hemisphere.

Forest fires:

According to the IPCC Fourth Assessment Report (2007), in Mediterranean Europe rainfall will decrease and risk of drought will increase, which in turn would allow forest fires to occur on larger scale, and more regularly. As a consequence, more CO_2 will be released to the atmosphere creating a positive feedback loop.

6. Socio-Economic Impacts:

Impacts of climate change are expected to impose net annual costs, which will increase over time as global temperatures increase. Peer-reviewed estimates of the social cost of carbon (Net economic costs of damages from climate change aggregated across the world) in 2005 average US$12 per tonne of CO_2.

In 2006, Nicholas Stern, the former Chief Economist and Senior Vice-President of the World Bank, recommended that one percent of global GDP be invested to mitigate the effects of climate change, and that failure to do so could risk a recession worth up to twenty percent of global GDP. He also suggested that climate change threats to be the greatest and widest-ranging market failure ever seen.

In a 2004 comment on the economic effect of global warming, Professor Robert O. Mendelsohn of Yale School of Forestry and Environmental Studies stated that, countries in the polar region are likely to receive large benefits from warming, countries in the mid-latitudes will at first benefit and only begin to be harmed if temperatures rise above 2.5 °C.. Only countries in the tropical and subtropical regions are likely to be harmed immediately by warming. Summing these regional impacts across the globe implies that warming benefits and damages will likely offset each other until warming passes 2.5°C.

Agriculture:

One of the major worries concerning future climate change is the effect it will have on agriculture, both globally and regionally. The main question is whether the world can feed itself under the predicted future global warming conditions. There may be some positive impacts of global warming on agricultural practices.

1. Increased atmospheric carbon-dioxide acts as a fertilizer; thus scientific studies have shown that plants are expected to grow faster and better under increased level of CO_2, because CO_2 is essential for photosynthesis and the prime source of carbon for plants. So farm yields may increase in future in many regions.
2. In areas of higher latitudes, the growing period will be lengthened due to global warming. In Iceland, rising temperatures have made possible the widespread sowing of barley, which was untenable twenty years ago. Whilst there is evidence to suggest some areas like the US and Siberia will benefit significantly from global warming.

The probable negative impacts are likely to be felt severely in tropical developing countries. The region likely to be worst affected is Africa. The negative impacts are as follows.

1. The growing period will be shortened.
2. Availability of water for irrigation will decline in a situation of higher evaporation loss.
3. Uncertainty of seasonal rainfall will increase causing unrecoverable loss due to crop failure. Tanzania's official report on climate change suggests that the areas that usually get two rainfalls in the year will probably get more, and those that get only one rainy season will get far less. The net result is expected to be that 33% less maize—the country's staple crop—will be grown.

Probable adjustment strategies have been devised to survive the global warming effects on agriculture.

1. Shifts in planting date by ±1 month
2. Additional application of irrigation water
3. Changes in crop variety from currently available varieties to varieties more adapted to the altered climate
4. Increased fertilizer application

It is clear from the above that food production in future is going to be costlier. Developed nations may be able to adjust their production system with the changing climatic conditions but it will be difficult for the developing nations of the tropics.

Insurance:

Insurance industry has been directly affected by the increasing risks of global warming. This is due to the facts that-

- the number of major natural disasters has tripled since the 1960s
- insured losses increased fifteen fold in real terms
- 35–40% of the worst catastrophes have been climate change related
- the proportion of the global population affected by weather-related disasters has doubled from roughly 2% in 1975 to 4% in 2001
- weather risks for households and property were already increasing by 2-4 % per year due to changing weather
- claims for storm and flood damages in the UK had doubled over the period 1998–2003

As the results, insurance premiums are rising, and the risk that in some areas flood insurance will become unaffordable for some. This would burden customers, taxpayers, and industrialists equally.

Gross increases in such type of risks are mostly attributed to increased population and property values in vulnerable coastal areas.

Transport

Roads, airport runways, railway lines and pipelines, (including oil pipelines, sewers, water mains etc) may require increased maintenance and renewal as they become subject to greater temperature variation.

Cost of Flood defense:

The cost of building better coastal defenses at the face of the rising sea level) is likely to be considerable. Some countries will be more affected than others—low-lying countries such as Bangladesh and the Netherlands would be worst hit by any sea level rise. They will have to spend less than 0.1% of the country's gross domestic product., In developing countries, the poorest often live on flood plains, because it is the only available space, or fertile agricultural land. These settlements often lack infrastructure such as dykes and early warning systems. Poorer communities also tend to lack the insurance, savings or access to credit needed to recover from disasters. Hence, they will be worst affected due to sea level rise induced floods.

Refugees:

Some Pacific Ocean island nations, such as Tuvalu, are concerned about the possibility of an eventual evacuation, as flood defense may become economically unviable for them. Tuvalu already has an ad hoc agreement with New Zealand to allow phased relocation. IPCC has estimated that 150 million environmental refugees will exist in the year 2050, due mainly to the effects of coastal flooding, shoreline erosion and agricultural disruption.

Development:

The combined effects of global warming may have particularly harsh effects on people and countries without the resources and capabilities to mitigate those effects. This may slow economic development and poverty reduction.

7. Ecological impacts:

Rising temperature, sea level, concentration of greenhouse gases in the atmosphere; glacial retreat; ocean water acidification; increased rate of evaporation etc. have been expected to alter the ecosystem settings and expulsion of the organisms out of their habitats or even extinction.

Threats to Biodiversity

The IPCC report lists the following species as those most at threat from climate change as a result of global warming: the *mountain gorilla in Africa, amphibians that only live in the cloud forests* of the neotropics, the *spectacled bear of the Andes, forest birds of Tanzania*, the *Resplendent Quetzal in Central America*, the *Bengal tiger*, and other *species only found in the Sundarban wetlands*, rainfall-sensitive plants found only in the Cape Floral Kingdom of South Africa, *polar bears*, and *penguins*, Natural

habitats that are threatened include coral reefs, mangroves, other coastal wetlands, mountain ecosystems found in the upper 200-300 m of mountainous areas, prairie wetlands, permafrost ecosystems, and ice edge ecosystems which provide a habitat for polar bears and penguins. The primary reason for the threat to these species or ecosystems is that they are unable to migrate in response to climate change because of their particular geographical location or the encroachment of human activity, particularly farming and urbanization.

One example of an ecosystem under threat is the coral reefs. Coral reefs are a valuable economic resource for fisheries, recreation, tourism, and coastal protection. In addition, reefs are one of the largest global stores of marine biodiversity, with untapped genetic resources. Some estimate that the global cost of losing the coral reefs runs into hundreds of billions of dollars each year. The last few years have seen unprecedented declines in the health of coral reefs. In 1998 El Nino was associated with record sea-surface temperatures and associated coral bleaching, which is when the coral expels the algae that live within them and that are necessary to their survival. In some regions, as much as 70% of the coral may have died in a single season. There has also been an upsurge in the variety, incidence, and virulence of coral disease in recent years, with major die-offs in Florida and much of the Caribbean region. In addition, increasing atmospheric carbon dioxide concentrations could decrease the calcification rates of the reef-building corals, resulting in weaker skeletons, reduced growth rates, and increased vulnerability to erosion. Model results suggest these effects would be most severe at the current margins of coral reef distribution.

- Increased evaporation will cause loss of soil moisture, hence more loss of soil. In response to them, the rate of desertification would be accelerated.

- Due to increase in temperature (only by 1 – 2 °C), considerable areas of Alaska, Canada and Russia has become ice free creating environment favourable for bacterial activities. This has led to produce more CO_2.

- Defrosting in Western Siberia has led decomposition of Bog vegetation causing additional production of CH_4.

- ***Decrease in primary production:*** Many scientists have argued that increasing average temperature and carbon dioxide are supposed to improve ecosystems' productivity. But IPCC predicts that higher CO_2 concentrations would only encourage growth of flora up to a point, because in many parts of the world water or nutrients would become the limiting factors, not temperature or CO_2. After the threshold point, greenhouse effects and warming would continue but there would be no compensatory increase in growth.

- Species associations in different ecosystems have been expected to change in response to the changes in habitat characters. It has been simulated in a model that growth of Liana in rain forests will be fostered to become the dominant species.

- Natural biomes and the global phytogeographical realms may shift towards higher latitudes and to the higher elevations along the mountain slopes in response to the increase in average temperature.

- Ice free period has increased in Hudson Bay leading Polar bears to become vulnerable

- Rising temperatures are beginning to have a noticeable impact on birds, and butterflies have shifted their ranges northward by 200 km in Europe and North America.

- Seasonal behaviour by plant and animal species has also been observed to have changed. Of species showing recent change, 4 out of 5 shifted their ranges towards the poles or higher altitudes, creating "refugee species". Frogs were breeding, flowers blossoming and birds migrating an average 2.3 days earlier each decade; butterflies, birds and plants moving towards the poles by 6.1 km per decade. A 2005 study concludes human activity is the cause of the temperature rise and resultant changing species behaviour, and links these effects with the predictions of climate models to provide validation for them. Scientists have observed that Antarctic hair grass is colonizing areas of Antarctica where previously their survival range was limited.

- Many species of freshwater and saltwater plants and animals are dependent on glacier-fed waters to ensure a cold water habitat that they have adapted to. Some species of freshwater fish need cold water to survive and to reproduce, and this is especially true with Salmon and Cutthroat trout. Reduced glacier runoff can lead to insufficient stream flow to allow these species to thrive.

8. Water scarcity

Water resource of the globe as a whole, has been assessed to undergo following ways of threat under increased temperature condition.

- Sea level rise is projected to increase salt-water intrusion into groundwater in some regions, affecting drinking water and agriculture in coastal zones.

- Increased evaporation will reduce the effectiveness of reservoirs.

- Increased events of high intensity rainfall episodes means more water falls on hardened ground unable to absorb it, leading to flash floods and run-off instead of a replenishment of soil moisture or groundwater levels.

- Shrinking glaciers will threaten the water supply in the melt water fed rivers during summer months which is necessary to keep dams and reservoirs replenished. This may hinder irrigation practices and low yield thereby.

9. Effects on Health:

Higher temperature due to global warming is supposed to cause various types of impacts on human health.

1. Patients of heart diseases are vulnerable to global warming as the cardio-vascular system has to work harder to maintain internal body temperature amenable to the environmental temperature. Some respiratory problems are also supposed to increase.
2. Global warming has caused the heat and clod waves more severe by about 5°C more and less respectively. As such the death tolls due to such events have increased many folds. The European heat wave of 2003 killed 22,000–35,000 people. Cold spells in Europe during winter, have become severe and lengthier.

3. Pandemic diseases like Plague, Influenza, and Typhoid etc. have become more susceptible to spread out due to mixing of out migrated people having low immunity to such diseases with those with higher immunity during major extreme events.
4. Spread of endemic diseases of subtropical and tropical countries like Malaria towards higher latitudes as the temperature condition of higher latitudes have now become more suitable for the vectors of such diseases to thrive. About 1.5 – 2.7 million additional deaths in malaria per year have been recorded all over the world. Woman and children are more vulnerable to the situation.

T rise	Water	Food	Health	Land	Environment
1 °C	Glaciers in Andes melt, threatening water supplies to 50 million people	Cereal yields rise in temperate zones	At least 300 000 a year die from climate-related diseases. Winter mortality rates drop in Europe and US.	Permafrost in Arctic regions thaws threatening buildings and roads.	10% of land species may face extinction; coral reefs suffer 80% bleaching
2 °C	20 to 30% less water available in Southern Africa and the Mediterranean	Crop yields drop in tropical region (by up to 10% in Africa)	Up to 60 million more Africans would be exposed to malaria.	Coastal flooding affects 10 million more people each year	15-40% of species may face extinction, including polar bears and caribou
3 °C	Serious droughts in southern Europe; up to 4 billion suffer water shortages	Up to 550 million people are likely to go hungry.	Up to 3 million people would die of malnutrition (if carbon fertilization weak).	Coastal flooding affects up to 170 million people each year	20-50% of species face extinction; the Amazon rain-forest begins to die.
4 °C	Up to 50% less water available in the Mediterranean and Southern Africa	Agriculture stops in parts of Australia and crop output in Africa drops 35%.	Up to 80 million more Africans would be exposed to malaria	Coastal flooding affect up 300 million more people each year	Half the Arctic tundra disappears
5 °C	Himalayan glaciers could disappear affecting hundreds of millions in China and India.	Ocean acidity disrupts marine ecosystems and possibly fish stocks.		Cities such as London, New York and New York and low-lying coastal areas threatened by rising sea levels	

Predicted out comes of Global temperature Rise

■ 3.5.6 ENSO PHENOMENA

▲ 3.5.6.1 INTRODUCTION:

The El Nino/ Southern Oscillation (ENSO) events is perhaps one of the most misunderstood of all atmospheric processes. ENSO events affect global weather in a very profound way. Perhaps only earth-sun relationships exert more of an influence on the global climate system than ENSO. The term El Nino, translated from Spanish as "the boy", originally referred to the annual warming of the equatorial ocean

current off the western coast of South America during the Christmas season. This sea surface warming is associated with the change of seasons- the beginning of winter in the northern hemisphere. For most of the year in the tropics, strong winds known as trade winds push the warm surface waters of the pacific westward, allowing up-welling of cold, deep ocean waters in the eastern tropical Pacific. As the seasonal atmospheric circulation pattern becomes established during the transition of autumn and spring, trade winds along the equator weaken, allowing the warm water in the western equatorial Pacific to migrate back toward the east. This annual migration warms the Pacific's eastern equatorial rim, typically around December.

Over the years, the meaning of the term El Nino has changed from its original reference to the normal annual event described above. It is now used to refer only to the unusually extreme increases in sea surface temperatures (SST) occurring for several months approximately every three to seven years in the central and eastern equatorial Pacific ocean. By contrast, La Nina- the opposite to El Nino- refers to a strengthened "normal" situation, which typically reinforces cold water conditions in the eastern equatorial Pacific and warm water conditions in the western tropical Pacific near the maritime continent. In recent years, the neutral situation- one in which neither El Nino nor La Nina conditions occur- has been termed La Nada, or "the nothing".

The southern Oscillation, recognized by the climatologist Sir Gilbert Walker in the 1930s, refer to a sea saw effect of surface atmospheric pressure between the eastern and western equatorial Pacific Ocean in which higher-than-normal pressure in one of these two regions is coincident with lower-than-normal pressure in the other. Climatologist Jacob Bjerkens realized in 1969 that these pressure changes resulted from SST variations over several years in the equatorial Pacific, establishing the link between El Nino and La Nina events and the Southern Oscillation.

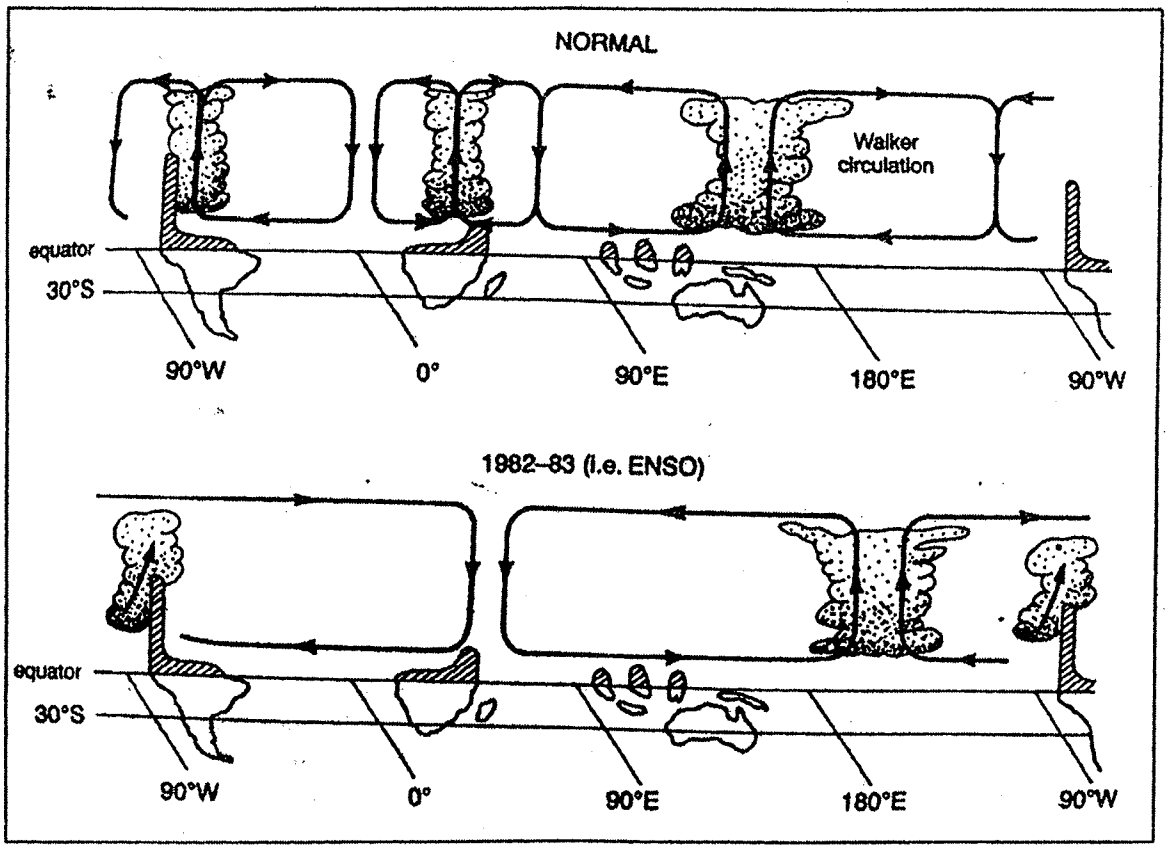
Today, most climatologists refer to the entire phenomenon as El Nino/ Southern Oscillation, or ENSO. The variations in atmospheric pressure associated with extremes in the Southern Oscillation and changes in the oceans during extreme phases of ENSO cause unusual global atmospheric circulation features and impacts. Because it is associated with a reversal of typical Pacific pressure patterns rather than an intensification of them, the El Nino phase usually has wider and stronger impacts than the La Nina phase.

▲ 3.5.6.2 Walker Circulation:

In 1969, Bjerkens coined the term Walker circulation to describe the connection between the atmospheric pressure centres in the equatorial Pacific associated with the Southern Oscillation, the SSTs, and the tropical trade winds that blow from east to west near the surface across the Pacific Ocean and other regions of the earth within the tropics. The walker circulation exists to balance the normally observed pressure gradients over the tropical Pacific Ocean. The Walker circulation represents "normal" or La Nada atmospheric and oceanic conditions in the equatorial Pacific Ocean, characterized by high surface atmospheric pressure in the east and relatively low surface pressure in the west. A pressure gradient forms in an east-to-west direction at the surface with atmospheric mass (winds) working to fill the low. Thus surface wind normally flows strongly from the east toward the west in this region, known as northeast trade winds, in the northern hemisphere and the southeast trade winds in the southern hemisphere., these winds comprise a major part of the global atmospheric circulation.

The frictional dragging of the sea surface by these winds causes the North and South equatorial currents to occur along the equator, approximating the atmospheric circulation pattern, flowing from east

to west in both hemispheres. The currents push the surface waters warmed by the sun westward. This results in an accumulation of warm water in the western tropical Pacific Ocean near Australia and the



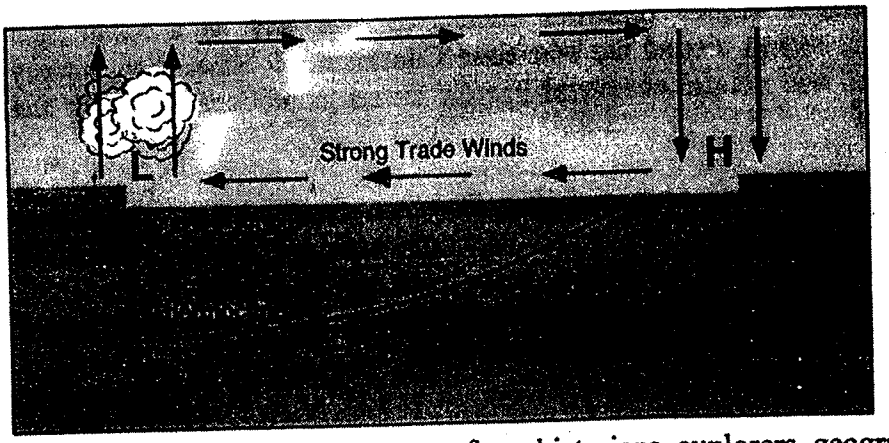
Maritime Continent. As sea level may be as much as 40 cm. higher and water temperatures 4 to 8° C higher in the western tropical Pacific than at the same latitude in the eastern Pacific near South America. The reduced SSTs in the east are caused by the colder eastern South Pacific and by upwelling of colder, deep water replacing the warmer surface waters that were displaced to the west by the equatorial currents.

These normal or La Nada ocean temperatures control the Walker circulation along the equator. Lower SSTs in the east Chile the overlying air, which in turn increases the air density, reducing its buoyancy. The sinking air causes high atmospheric pressure and usually restricts precipitation because cool air is less likely than warm air to rise vertically so that its moisture can condense and form vertical clouds. The eastern equatorial Pacific is normally dry as a result, and the extension of this dry area on the land surface is the exceedingly dry Atacama Desert. Warm waters in the western tropical Pacific case the density of overlying air to decrease. The rising air leads to lower atmospheric pressure and buoyancy that produces normally cloudy and wet conditions over the region.

▲ 3.5.6.2 Historical Observations of El Nino/Southern Oscillation:

Direct information about ENSO events first came from accounts of Spanish explorers in South America during the 1500s. Indirect data sources such as tree rings, flood frequency, sediment cores, and coral reef growth suggest that anomalous weather events associated with ENSO events have been occurring for thousands of years. There are many earliest written records that may be related to extreme El Nino phases.

- Variations in travel times from selling vessels
- Ship logs noting unusual weather and sea conditions
- Presence of "aguaje" or red tide, a bloom of toxic marine plankton
- Abnormally warm waters along the South America coast
- Severe and unusual weather events, such as heavy rains and flooding
- Property damage caused by floods
- Travel obstructions from washed-out roads of mudslides
- Agricultural destruction
- Increase in sea levels along the South American coast
- Mass mortality of marine sea life caused by decrease in the upwelling of nutrients
- Death and/or departure of birds
- Reductions in productivity in coastal fisheries



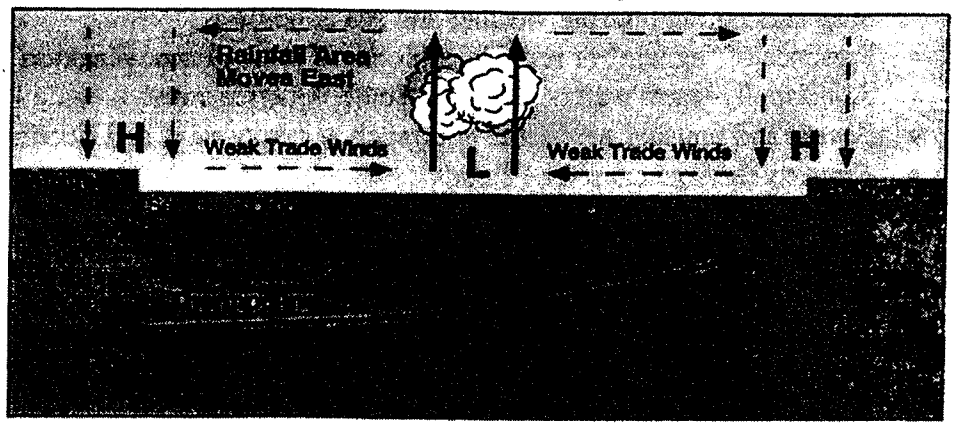
Most accounts are not direct observations of atmospheric or oceanic conditions but suggest indirect effects of ENSO on climate. Sources include ship logs in addition to writings by clergy members who reported unusual natural phenomena in great detail. These records became more detailed between 1600 and mid-1800s, when South American events were chronicled in European literature. Thus accounts from historians, explorers, geographers, pirates, and engineers became more detailed toward the end of the 1800s.

Since the late 1950's there have been seven major El Niño events: 1957-58, 1965, 1968-69, 1972-73, 1976-77, 1982-83, 1986-87, 1991-92 and 1994-95. The 1982-83 El Niño was the strongest of this century.

▲ 3.5.6.4 El Nino characteristics:

Each extreme of the ENSO cycle (El Nino and La Nina) occurs about every three to seven years. An El Nino event in the ocean coincides with a reversal of the normal Walker circulation. Trade wind flow weakens or may even reverse along the equator, allowing the pool of warm water piled up in the western Pacific to flow back and toward the east. Because La Nada and La Nina conditions pile warm water in the west, the ocean is simply regaining a somewhat uniform sea surface level when the trade wind flow weakens.

As the warm water migrates eastward, the overlying atmospheric low-pressure centre follows the warm water migration eastward as well. By the time



the warm water pool reaches the eastern boundary of the tropical Pacific Ocean, reduced atmospheric pressures and increased precipitation are well-established. At the same time, colder than normal water conditions become established in the western tropical Pacific. Higher pressures build over that area as a result, and precipitation is far below normal in the region around the Maritime Continent. El Nino, then, simply coincides with a reversal of the Normal and neutral equatorial Pacific air/sea conditions set up by the Walker circulation.

Movement of warm water pool from west to east during El Nino, usually taking about four months, appears in the form of an equatorial Kelvin wave- a pool of warm water moving eastward while surface waves are initiated by overlying winds that continue to blow from east to west as a part of the normal trade wind flow. However, during El Nino events, the trade winds are weaker than normal, which allows the warm water pool to move eastward as an equatorial Kelvin wave.

When the warm water pool reaches the eastern boundary, it splits into three primary components. The main component is the equatorial Rossby wave, which sloshes back westward along the equator, typically reaching the starting point within six to eight months, ending the El Nino event. Movement of the return flow in this wave is slower than the original Kelvin waves in that the bulk of water motion is in the same direction as the surface waves.

The remainder of the original eastward moving equatorial Kelvin waves splits into coastal Kelvin waves- smaller warm water pools that migrate north and south along the North and South American coasts, displacing cols currents off the west coasts of both continents. These waves are responsible for manv regional climate abnormalities.

The warm water pool in the eastern equatorial Pacific causes a downward movement of the thermocline- the boundary between warm surface waters and colder deep waters. Oceanic upwelling still occurs in the eastern ocean during El Nino events, but because of the deeper thermocline, the cold water involved in upwelling is confined to the deeper layers. Because of these abnormally warm waters neat the American coast, El Nino events are sometimes referred to as warm-ENSO events. In its entirety, an El Nino event usually lasts between 10 and 14 months.

Because so much energy is transported across such large distance regardless of the ENSO phase, disruptions to the Nada situation have worldwide atmospheric consequences. The most direct effects occur in the tropics during El Nino phase. The reversal of the usual atmospheric pressure and SST patterns during El Nino events causes atmospheric and oceanic circulation systems on the planetary scale to readjust. These anomalous circulation patterns cause seemingly chaotic weather conditions worldwide.

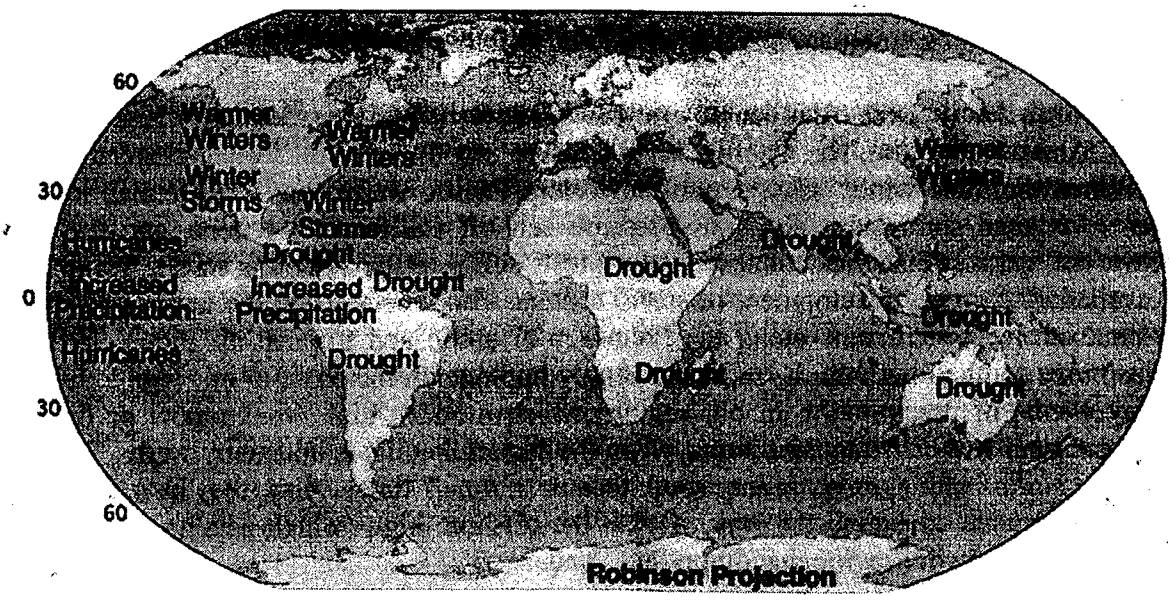
Normally dry regions, such as western north and South America and Western Australia, become much wetter than normal, wile characteristically wetter regions such as north western Brazil, eastern Australia, and the Maritime Continent become excessively dry. Such disruption of normal atmospheric and oceanic conditions leads to some devastating ecological and economic problems.

▲ 3.5.6.5 La Nina characteristics:

La Nina may be considered an extreme version of the normal La Nada characteristics in the sense that the Walker circulation does not reverse. During this phase, the trade wind flow along the equatorial Pacific Ocean becomes even stronger than normal, which increases warm water accumulation in the western equatorial Pacific and water upwelling in the east. This causes a deeper thermocline in the western tropical Pacific and shallower than normal thermocline in the east. Sea levels respond accordingly, as the west records higher than normal sea levels and temperatures, while in the east, lower than normal sea levels and temperatures occur. The enhanced cold water upwelling near the Americas has given La Nina another name in recent year "cold ENSO events."

▲ 3.5.6.6 Global Effects:

The consequences of ENSO events do not stop with the equatorial Pacific Ocean. The effects of warm-ENSO events carry through the downstream circulation patterns of the entire tropics. Because lower pressure builds over the western portion of South America during negative phase of the southern oscillation, the circulation regime of eastern regime of eastern South America is dominated by low atmospheric pressure associated with the abundant heat energy and humidity from the Amazon rain forest. During the El Nino phase, the western South American low disrupts the usual circulation over the eastern portion of the continent. As a result, higher than normal air pressure and subsiding airflow is initiated over tropical eastern South America, bringing drought to much of the rain forest region.



Just as the circulation is altered in South America during warm-ENSO events, the circulation regimes of other tropical locations are affected. The relatively high pressure regime that normally prevails

over southwest Africa near the Benguela current flips to lower atmospheric pressure and the region becomes anomalously wet. This in turn reverses the normally low pressures that occur near southeastern Africa, resulting in higher air pressures and drought near Madagascar. This induces a low-pressure region over the equatorial Indian Ocean, which is normally dominated by higher pressures, and the region becomes wetter than normal. Finally, the circulation is linked to the western side of the Walker circulation over eastern Indonesia and northeastern Australia, which experiences El Nino induced above normal air pressures and the drought conditions discussed previously. The effect is that the atmosphere seesaws to an opposite regime from normal.

Energy transfers during warm-ENSO events also alter temperate climates. Such interactions originate from increased heat energy transport from the equatorial Pacific into the midlatitude. Much of this energy transport is accomplished by the poleward-moving coastal Kelvin waves. These warm water pools displace cold currents along the west coasts of North and South America, overriding the colder, denser currents normally present in those locations. This position allows the abundant stored oceanic heat energy to be transferred easily into the atmosphere, particularly under the conditions of unusually low atmospheric pressure, initiating rising motions in the atmosphere. Such conditions are capable of providing energy for storms that then migrate across the normally dry western continental locations.

In a La Nina situations normal atmospheric circulation pattern across the tropics are strengthened. A normally dry region becomes exceedingly dry and a normally wet region becomes exceedingly wet. Such conditions have many negative ecological and economic consequences like El Nino events. Extreme phases of Southern Oscillation stress ecosystem in several ways. Large scale animal migrations and die outs occur in the affected regions. These factors in turn stress humans as food sources are affected and the landscapes are degraded. As for example, An El Niño situation occurs every three or four years or so, mainly in December, and is devastating to the fishing economies of Ecuador and Peru. Birds, sea lions and fishermen go hungry because there are not enough fish to go around. Also, torrential rainfall in the coastal zone frequently accompanies the offshore warming, causing devastating floods (as happened in 1982-1983). See below for a summary of costs associated with the 1982-1983 El Niño.

In the North Pacific, the Aleutian low-pressure region (over the Aleutian Islands chain to the southwest of Alaska) and the NE Pacific high-pressure region off California characterize normal conditions. When the trade winds weaken and the eastern Pacific warms up, the Aleutian low-pressure center tends to expand southward. The high-pressure cell off California weakens, and the California Current slows and warms. Fisheries collapse. Kelp forests suffer. Baby sea lions starve. Warm, moist air is widely available, favoring development of storm centers. The jet stream in the upper troposphere and the lower stratosphere, which runs along the boundary of arctic and tropical air moves farther south. Storm tracks move south along with it, and increasingly impinge on the coast of our region. In summary, extraordinary events of precipitation in our region (which produce high stream flow or flooding) are commonly associated with El Niño conditions, when the eastern Pacific is unusually warm. Winter storms generated in the North Pacific, move farther south than at "normal" times. Also, they have the opportunity to pick up moist tropical air along the way. Absent the offshore high (which acts as a road block), the storm systems can invade our region and dump their load.

▲ 3.5.6.7 Southern Oscillation Index (SOI):

A simple index was devised to describe the atmospheric pressure variations in the tropical Pacific Ocean. The Southern Oscillation Index (SOI) is derived from sea level pressure differences between the

eastern and western Pacific. The SOI is found by subtracting the air pressure at sea level in Darwin, Australia, from that in Tahiti. This value is often standardized statistically so that a value of zero represents La Nada, values exceeding +1 may be considered to coincide with La Nina in the ocean, and values below -1 may be considered to represent El Nino conditions. Another means of identifying El Nino and La Nina events involves monitoring SSTs in various regions of the equatorial Pacific Ocean. A temperature departure of ± 1° C away from normal conditions for three consecutive months constitutes a major event.

▲ 3.5.6.8 El Niño and Climate Change:

Although El Niño events are not new (there is evidence they have been occurring for hundreds of years), a distinct change in the behavior of this event beginning in the mid-1970 has some worried that human-induced climate change may be having its effect. These recent changes include two "extreme" El Niño events (the strongest in this century, the 1982 to 1983 event and the longest of this century, the 1990 to 1995 event) and an increased frequency of El Niño relative to the past 50 years. As is the case with most attempts to pen a modern day observation to global warming, this evidence cannot rule out "natural variation." Periods of high El Niño activity have occurred before, as for example from 1880 to 1925. That being said, some computer models of climate change predict precisely what is being observed today: increased likelihood of El Niño (with one study suggesting an increase of once every five years to once every three years); warming of the tropical Pacific with greater warming in the east than in the west (a pattern generally associated with El Niño); and a possible increase in El Niño severity. In so much as El Niño is a natural phenomenon, it is something we need to live with, just as we do with earthquakes and hurricanes. However, if the current El Niño trend continues, the consequences could take a heavy toll on the entire world, disrupting everything from the U.S. insurance industry to the prospect for worldwide sustainable development.

■ 3.5.7 SUMMARY

1. The climatic classification schemes of Stamp and Trewartha are of tremendous geographical significance as they are empirical in methods but have generic basis. As such, they can be conveniently adopted in understanding the global climate types and relate them with other themes of geographical interest.
2. Climate change is a natural phenomenon. Evidences and methods of their study are quite capable to reconstruct the past climate. The past climatic history of the Earth is punctuated with number of glacial and inter-glacial phases. Changes in climate are caused by many factors which internal as well as external to the climatic system.
3. Global warming of the twentieth century is believed to have been caused by anthropogenic production of greenhouse gases at an accelerated rate. In near future, probably every walks of human life is going to be affected by the impacts of global warming. Global community is still divided on almost every issue relating to combat the situation.
4. ENSO is a short duration climatic variability observed primarily in South and Central Pacific ocean and the adjoining countries. It affects the regional climate to become more extreme at certain seasons. The frequency and intensity of the phenomena have been believed to increase due to global warming.

3.5.8 SELF ASSESSMENT QUESTIONS

1. Describe the scheme of classifying Asian climate as proposed by L. D. Stamp.
2. Write the salient features of each of the climatic types found in Asia.
3. Classify the world climate according to Trewartha's scheme and describe the characteristics of each climatic type.
4. Describe the evidences that are put forward to demonstrate earth's climate change.
5. Describe the major episodes of global climate change during geological history.
6. What are the causes of global climate change?
7. What is global warming and what are its causes?
8. What are the probable impacts of global warming?
9. How are the coastal and marine environments going to face the consequences of global warming in near future?

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PART –I
PAPER – II
MODULE – IV ★ UNIT – 01

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- 4.1.0 Introduction
- 4.1.1 Objectives
- 4.1.2 Key words
- 4.1.3Environment
- 4.1.4 Systems
- 4.1.5 Environmental System
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Paper – II
Module – IV : Unit - 01

ENVIRONMENTAL STUDY

1. **Concept of environmental System; Components of physical environment and their interrelations**
2. **Concept of ecosystem; components and structure of ecosystem; food chain and food web; ecological pyramids**
3. **Major ecosystem of the world**

■ 4.1.0 Introduction

Environment is derived from the French word *Environ* or *Environner*, meaning 'around, found about, to surround to encompass' these intern original from the old French *virer* and *viron* which mean a circle, around or circuit. Environment is a comprehensive term requires holistic approach. Environment means the surroundings. It not only includes the physical environment i.e., topography soil, vegetation or river but also includes manmade environment. Ecology on the other hand includes all living and non living organisms, relationship between and among these components and with the environment.

■ 4.1.1 Objectives:

Objectives of this topic is to

i. Draw a clear concept about the environmental system in its totality
ii. Make an analysis about the functioning process of an ecosystem
iii. Make an outline about the components of environment
iv. Know the relationship among these components.
v. Know the man environment relationships.

■ 4.1.2 Key words : **Environment, system, lithosphere, atmosphere, hydrosphere, biosphere, ecosystem, biome.**

■ 4.1.3Environment

Since 1970's the term environment is in official use in academic circles. The term is also used by non-academics but there is no universal consensus about definition of the term. Physical scientists believe that environment is their prerogative and they define the term from physical environmental perspectives which is governed by physical laws, processes and factors. Different environmentalists define the term in different ways -

i. Environment refers to the entire range of external influences, natural and man made that can impinge on the life support system essential for health and survival.

ii. Environment refers not just to biophysical context but to human interaction with an interpretation of that context(Barnard et al ,1996)
iii. The dictionary meaning of the word 'Environment' is a surrounding, external condition influencing development and growth of people, animals or plants living or working conditions etc.
iv. Environment refers to the sum total of conditions which surrounded man at a given point of space and time (C. C. Park, 1980).
v. The whole sum of the surrounding external conditions within which an organism, a community or a subject exists often used in limited way in geography. Example , natural environment meaning either the non cultural and non social environment, or land space before man came, geographical environment means factors of the earth whose relationship are considered in terms of spatial location. The physical environment includes all phenomena apart from man and the things he creates, while the non human environment includes everything not in social system, whether made by man or not. These are all slightly different and unqualified use of the term environment and can be misleading. (Monkhouse et al, 1978).

4.1.4 Systems

A system is a set of objects or attributes that are linked together in some discernable relationships. R. J. Chorley and B.A. Leneday (1971) defined system as structured set of objects or attributes. Systems may be of two types, open system and closed system. In open system inflow and out flow of energy are able to cross the boundaries of system where as in closed system flow of energy is limited within the boundary of a particular system. Isolated systems are those where the boundaries for input and out put of energy are fixed or closed. Process of a system is mechanized by homeostatic or equilibrating and steady state or condition of stability.

4.1.5 Environmental System

Environmental system is defined differently by different disciplines. According to an ecologist environment is the natural place where an individual organism or group of organisms interact i.e. environment is the place of interaction of organisms. Environment literally means the surroundings. In other words environment is an aggregate of a set of condition that directly or indirectly influenced the growth as well as the quality and quantity of organisms at a particular place. From the geographers point of view environment is the spatial attributes of all phenomena in its totality (including man) in a given space and time. Geographers are studying environment from holistic view.
Environmental system from geographic point of view encompasses both physical environmental system and socio-economic and politico-cultural environmental system.

1.6 Environmental components

Environment encompasses three basic components. These are –biotic components, abiotic components and the energy components. Biotic components consist of all living organisms, plants, animals (including man) and micro organisms. Abiotic components comprise atmosphere, lithosphere components and energy components include both solar and geothermal energy.

4.1.6.1 Biotic component

Biotic components are those living organisms of the biosphere. In other words biosphere is that zone which is occupied by living organisms at the common boundary of the earth's lithosphere and atmosphere. According to J. Tivy (1982) biosphere is that part of the earth which contains living organisms. Biotic component may be categories in to two major categories viz. *autotrophs* and *heterotrophs* based on the functions of organisms. The green plants, algae and autotrophic bacteria are the *autotrophs* that are able to capture solar energy using inorganic substances and produce food for the heterotrophs. Heterotrophs are unable to produce food for their own. The heterotrophs are divisible into

macro consumers or *phagotrophs* or the animals and micro consumers or *saprotrophs* or the decomposers. Thus biotic components can be categorized under three groups.

▲ **4.1.6.1.1** ***Autotrophs*** **or the green plants:** The autotrophic components includes all living plants which fix the radiant energy of the sun and generate food from inorganic substances through photosynthesis process. For this reason the autotrophs are called the producers. In photosynthesis process carbon dioxide is assimilated and radiant energy is transformed into chemical energy. The chemical energy is locked in the form of carbohydrate compound s and oxygen is released as bi product. Photosynthesis process can be summarized in the following equation

$Co_2+4H_2O \rightarrow [CH_2] + 3H_2O+O_2$

Algae, grasses and trees are the examples of autotrophs.

▲ **4.1.6.1.2.** ***Heterotrophs*** **or the animals or the** ***phagotrophs*****:** It includes chiefly the animals that ingest other organisms or particulate organic matter. The phagotrophs are further divisible as

i. ***Herbivores***: they are referred as the primary consumers of an ecosystem. They totally depend on producers or green plants for the supply of food. Elton (1939) named the herbivores as the 'Key industry animal' as they serve the chief food source for the carnivores. Examples of herbivores are insects, rodents, rabbit, deer, cow, buffalo, goat and mollusks etc.

ii. ***Carnivores:*** carnivores are the second consumers that are adapted to consume herbivores as well as plants as their food. Examples are crow, fox, wolves, cats and snakes etc.

iii. ***Omnivores:*** omnivores are the top most carnivores which prey upon other carnivores and herbivores. Lions, tigers, hawks, vulture and man are the examples of omnivores.

▲ **4.1.6.1.3 Decomposers or the** ***saprotrophs*****:** They chiefly include bacteria and fungi which break down complex protoplasm, absorb some of the decomposition products and release inorganic nutrients that are reused by the producers. Decomposers are also called the transformer. Decomposers play an important role to maintain the dynamic nature of the ecosystem.

▲ **4.1.6.2 Abiotic component**

Abiotic or physical component of environment is characterized by the quantity and distribution of non living materials or inorganic substances. On the basis of physical characteristics and state, abiotic or environment is broadly categorize as

▲ **4.1.6.2.1 Lithosphere:** Lithosphere is the outer portion of the earth including the crust and the upper mantle. The lithospheric component includes rocks, minerals, soils, macro land forms as well as the meso and micro land forms. Among all the components of physical components lithosphere is one of the important components because it is the base for living organisms. Lithospheric components hold 29% of the total earth's area.

The internal structure of the earth consists of three main zones, core, mantle and crust.

a. Core –The centre of the earth is occupied by the core. The radius of the core is about 3475km. the core is that part of the interior where S wave can't penetrate. The core is mainly formed by nickel and iron alloy with platinum group of elements. This zone is marked by abrupt increase of pressure. Core is divided into two layers-

i. Inner core - 5000km-6370km below the earth's surface and 2% of the total earth's mass.

ii. Outer core- 2900km-5000km below the earth's surface and 30% of the earths total mass.

Mantle- Out side the core lays the mantle. This layer is about 2895km thick. The mantle is composed of ultra basic rock reach in Mg and Fe and poor in silica. P and S wave passes quickly through this layer. From the changes of seismic velocity through this layer, it is divided into three layers, upper mantle, transitional zone and lower mantle. Another zone in upper mantle is as low velocity zone where S wave speed decreases rapidly to a minimum and then increased again. Magmas are mostly generated here.

Upper mantle-It extends 400 km. down the crust and occupies 10% of the earth's total mass. Density of this layer varies between3.25gm/cm^3 and 3.40 gm/cm^3. it is composed of peridotite along with plagioclase(<30km depth), spinel (30-70km.) and garnet(>70 km depth). Tectonically active regions are composed of eclogite (amphibole +garnet) is a major component. The upper mantle is mainly divided into upper peridotite zone and underlying primitive mantle or pyrotite zone where the basaltic magmas are generated.

Transition zone- This zone lies from 400km to 1000km below the earth's surface. 17% of the total mass of the earth is hold by this layer. The components which form this layer are MgO and Sio_2. Seismic velocity becomes irregular in this layer.

Lower mantle-this layer extends between 1000km.and 2900km. below the earth. The lower mantle is solid and composed of dense and rigid rocks with predominance of iron and magnesium. It is a region of low seismic velocity gradients.

Crust-Crust is perhaps the thinnest layer of the lithosphere. It makes only 0.5% of the earth's total mass. Depending on the thickness, density and composition, crust is divided into continental crust and oceanic crust.

Continental crust - Continental crust comprises 30% of crustal mass .Its depth beneath the earth varies from 30km -60km.Continental crust is stratified and where exposed is less dense than the oceanic crust. Continental crust is designed by different rocks like granite, volcanic, sedimentary and metamorphic rocks in older areas. Based on the nature of crust it is subdivided into

Stable continental crust- Sediments of Pre Cambrian craters, platforms on crystalline basement are some of the examples of stable continental crust. Thickness varies form 35km to 45 km. the density of the upper crust is 2.69gm/cm^3-2.74gm/cm^3. This layer is consisting of upper crust and lower crust. Upper crust is composed by *Sial* or *felsic* igneous and metamorphic rocks. Lower crust is composed by *Sima.*

Tectonically active regions- Tectonically active zones include Andes or Himalayan mountainous zones. It is mainly consists of amphibolites and intermediate rocks of *mafic, ultramafic* and *felsic* nature.

Oceanic crust- It includes earth down10km to 12km. based on the thickness and composition of rocks this layer further segregated into

Oceanic basin

Layer 1- Thickness <1km. It includes foraminifera ooze and stone.

Layer 2- 1.6km to 2km, includes basalt and dolerite dykes and sills.

Layer 3- 3.0km to 5.7km, includes dolerite, gabbros and amphibolites. It is the main crust.

Mid oceanic ridge –This is one of the three major divisions of the ocean basin with submarine topography and volcanic igneous rocks.

Island arcs- It is a chain of volcanic islands consisting of igneous rocks mainly volcanic andesites.

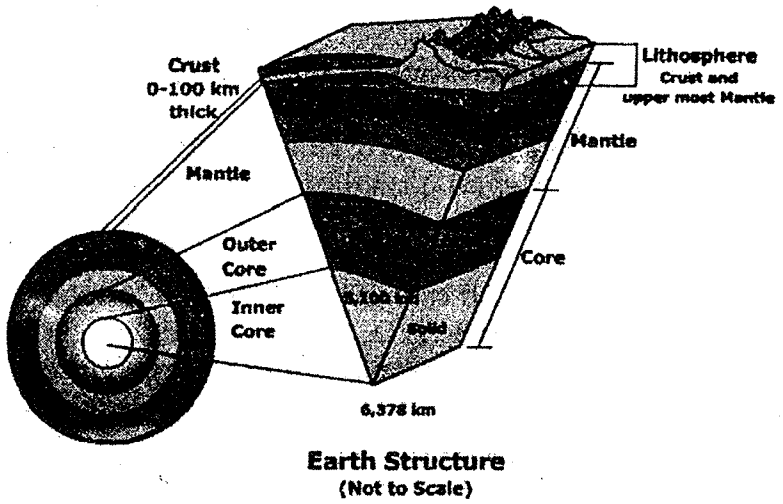


Fig. 1 Diagram of Layering of earth structure

Boundary of earth's layers- *Mohorovicic* discontinuity-Boundary between the crust and mantle is known as the *Moho* or *Mohorovicic* discontinuity.*Gutenburg* discontinuity-Boundary between mantle and core is known as *Gutenburg* discontinuity.

Types of seismic waves

Body waves

P waves or primary waves are the compress ional fastest type of wave with a velocity of 5km/sec-9km/sec, it can travel through solids and liquids and can pass through earth's core. S wave or secondary waves or transverse waves that travel at slower speeds than P waves(1-2 km/sec). They are responsible for shaking, shear and side-to-side movement and can travel only through solids. For this reason they can't pass through the core

Surface waves

They often referred to as L-waves or long waves. They are of Complex motion, Up-and-down and side-to-side movement. Speed is slowest and Causes damage to structures during an earthquake.

Lithospheric components

As revealed from the seismic wave studies earth has a layered structure. Traveling speed of P and S wave depends on the properties of rock material or on the density and elasticity of rocks. Seismic waves traveled faster in denser rocks and its speed increased with depth. From this behavior of the seismic wave Geophysicists, Mathematician and Geologists become able to extend their knowledge about the composition of the earth.

Core: The composition of the core varies in inner and outer portion. Composition of the inner core – 1216 Km radius solid Fe (85%) with Ni generation of magnetic field in core is due to dominance of iron in the core .

Outer core: Radius of the outer core is 2270 Km and is mainly composed of molten Fe 85% with Ni.

Mantle: It is 2885 Km thick. It is composed of peridotite (Mg Fe and silicate) kimberlitic and ecologite. The upper part of mantle i.e. outer most 100 km. of earth is called lithosphere and zones between 100km and 250 km depth in earth is known as asthenosphere.

Crust: Granitic composition in continental crust and basaltic composition in oceanic crust.The over all composition of the earth is dominated by the elements Fe, O, Si, Mg, Ni and sulfur. The reason behind it is that most of the earths mass occur within the mantle and mantle is largely composed by Ferro magnesium silicate minerals, Olivine and pyroxenes. The core of the earth is composed by iron and nickel. The crust is comprising of minerals of plagioclase, quartz, and hornblende and is dominated by oxygen, silicon, aluminum and potassium.

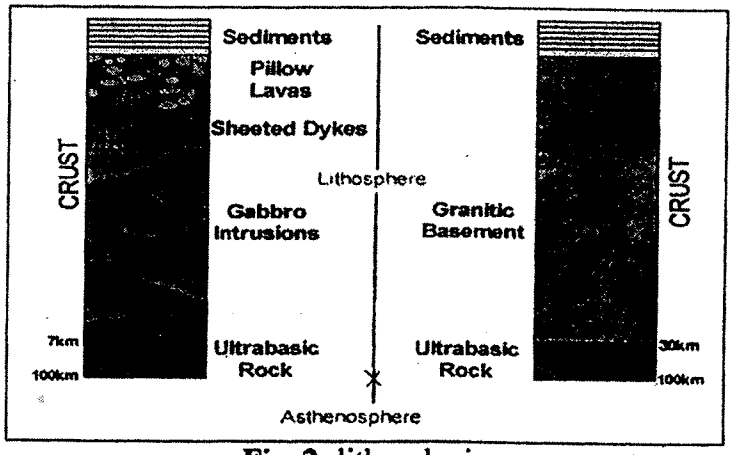


Fig. 2: lithospheric components

Components of lithosphere are governed by various processes and sub cycles. These cycles play important role for the creation, maintenance, changes or the destruction of the materials of the earth.

Tectonic cycle means the tectonic processes which are responsible for the formation or destruction of the earth's crust. Tectonic process is based on the movement of plates. Lithosphere is consists of a mosaic of interlocking rigid plates with active boundaries and comparatively stable interiors. Plates are divided into continental plates and oceanic plates. Continental plates are lighter in weight than the oceanic plates. There are seven major plates (more than $10^7 km^2$ area individually) and six minor .plates ($10^{6-7} km^2$ each). These plates are continuously moving due to thermal convection currents originating from the mantle and the upper core. Plates are moving towards each other or diverged from each other or may be slide past each other. Thus these three types of movement give birth to three different plate boundaries which are responsible for the formation and or destruction of different types of landforms. Seafloor spreading, paleomagnetism and continental drift are related concepts to plate tectonic.

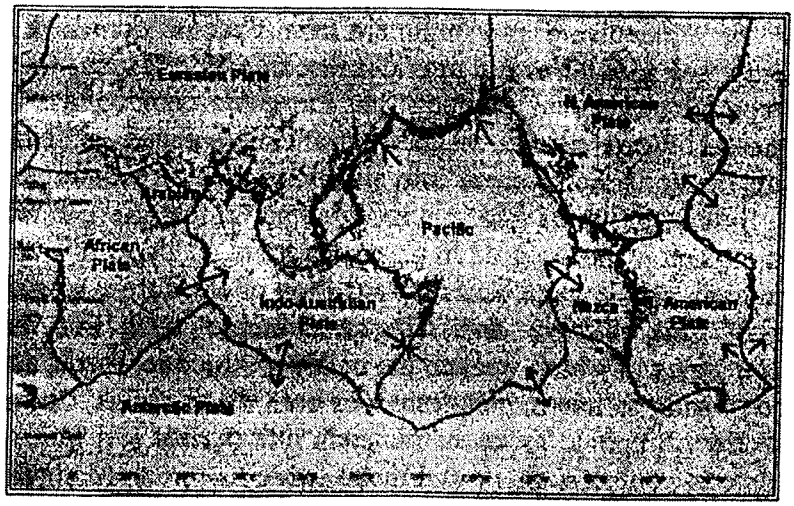


Fig. 3: Different plate margins

Constructive plate margin or boundary is known as the divergent plate boundary. It is related to formation and extension of crust. The spreading rate is different in different boundaries. In case of American and Eurasian plate it is 20-40mm yr^{-1} and in Mid Atlantic Ocean and between the Antarctic plate and Southern Australian and Pacific plates the spreading rate is 20-100 mm yr^{-1}.

Destructive margins are those where two moving plates converge face to face and collides each other. Subduction or destruction occurs due to ridge push or slab pull. Active slabpull subducts back into the mantle. In the western pacific the velocity of subduction is 60-100 mm yr^{-1} and in eastern pacific boundaries it is 50-120 mm yr^{-1}. Conservative plate boundaries occur where plates slide past each other and the crust is neither destroyed nor created.

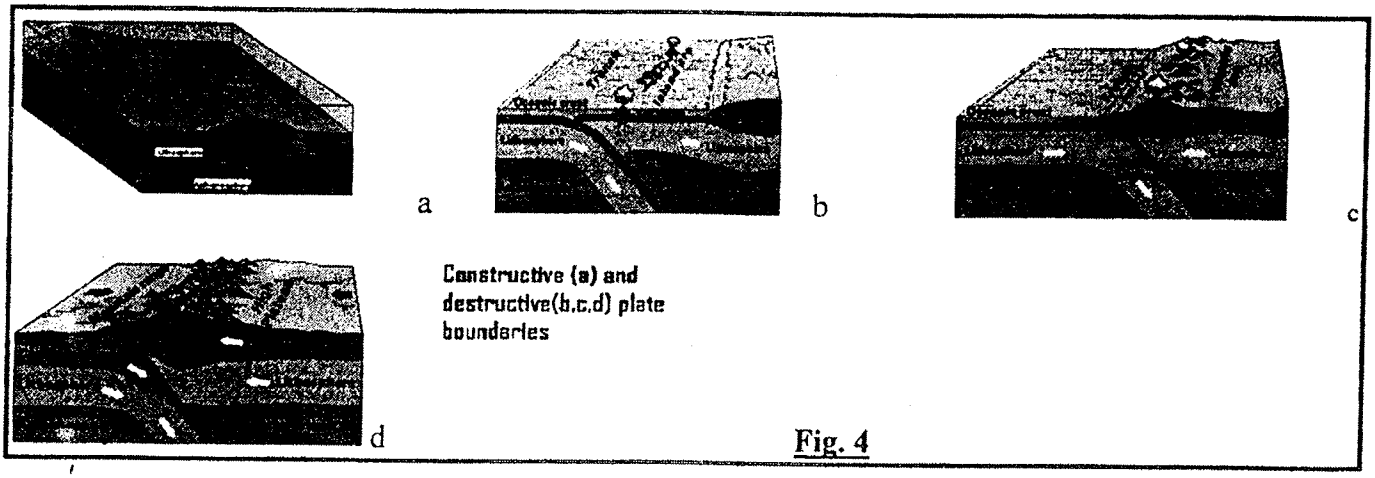


Fig. 4

■ **4.1.6.2.2 Rock cycle:**

Physical environmental system is largely controlled by the plate movements and associated phenomena like mountain building, vulcancity, earthquake, formation of lands or continents and plateaus that are providing habitat to the living organisms and these phenomena further effect other physical processes (like climatic processes, temperature, vegetation, species variation etc.) have effects on humankinds.

Crustal materials mainly the minerals are also important from the environmental point of view because they help to form different types of features and provides resource base for human development. Minerals are the aggregation of complex chemical elements and inorganic compounds. On the earth the most abundant elements are iron, Oxygen, silicon, magnesium, nickel, sulphur, calcium, ammonium, sodium and potassium. Important minerals are grouped into silicate group, carbonate group, sulphide minerals group and metal oxides. Silicate group of minerals include quartz, feldspar and ferromagnesium. Quartz composed of silicon and oxygen is mostly used in glass industries. Feldspar is a compound of silicates of aluminum, potassium, sodium, calcium and barium. Formation of clays from weathering of weak feldspar increases the fertility of soil. Silicon and oxygen combine with iron and magnesium form ferromagnesium, overindulgence of which weaken the building structure, roads, and dams etc. Carbonate group of minerals include mainly calcium, magnesium or both the minerals. Dolomites of this group are largely used for construction. Sulphide group of minerals like pyrites and iron sulphides may become hazardous when they come in contact with air and metal oxide like iron aluminum are important for the industries. Mineral as a component of the physical environment is important because distribution and concentration of minerals have impact on the fertility of soil, water holding capacity, resource base or source of pollutants of an area. Economic development is based on the distribution of minerals resources. Soviet Union and South Africa produce 55% of the world's manganese, 62% of Chromites and Zaire and Zambia produce about 2/3 of the world Cobalt.

Rock cycle on the other hand plays an important role to characterize particular physical environment. It makes us understand not only the formation of rocks but also the dynamic evolving materials of soils, nutrient cycle, biospheric cycle, atmospheric cycle, and the oceanic cycle. The primary or the igneous rock is concerned with cycling oceanic lithosphere between magma formation and its resorption. Sedimentary rocks are the retained magmas on the continental environments faced exogenesis weathering, erosion and denudation. Metamorphic rocks are transformation of igneous and sedimentary rock due to excessive pressure and temperature. These sequences of rock formation may be interrupted at any time by reentering of any group to other before time or completion of the whole cycle through volcano- tectonic activity. The process of such formation is known as geochemical cycle of which the fragmented parts are rock cycle, litho logical cycle and soil formation process etc.

Igneous rocks are important because 99% of the common silicate minerals are coming from silicate magma, capable of yielding silicate minerals. Apart from silicate the magma consists of other volatiles which remain in gaseous or liquid state. After dropping temperature these volatiles are separated from the magma and crystallized into solid state. According to the geologists' analysis, silicate magma follows a definite order to form silicate minerals due to temperature decrease. These are as follows-

Olivine

Calcic plagioclase

Pyroxene (augite)

Intermediate plagioclase

Amphibole group (Hornblende)

Sodic plagioclase

Biotite

Potash feldspar (orthoclase)

Quartz

This process of change from liquid state to solid state is known as crystallization. Crystal size is largely dependent on the cooling rate of magma. As general rule rapid cooling results very small crystals while extremely sudden cooling produces a natural glass and very slow cooling tends to produce large crystals. From this principle we can deduce that large coarse grained crystals as granites are used to crystallize slowly at great depth below the surface and they are known as plutonic rock of intrusive origin. Intrusive rocks solidify beneath the surface completely enclosed in preexisting solid rock. Pegmatite is an example of plutonic rock. Igneous rock that emerges at the earth's surface, cooling rapidly in contact with the atmosphere or ocean is referred to as extrusive igneous rock. Magma pouring out from a vent in form of lava and spreads over the surface is an extrusive action. Extrusive igneous rocks are fine grained. Some time they become crystallize in form of volcanic glass. Basalt is an example of extrusive igneous rock. Igneous rocks are further classified according to bulk composition of minerals as granite, gabro rocks or felsic or mafic igneous rocks.

External processes of the atmosphere and hydrosphere have impact on the exposed rocks and as a result they transforms into sediments. Thus formation of a second rock class through the lithification and compression of settled sediments are known as sedimentary rocks.

Depending on the origin of sediment forming technique, sedimentary rocks are classified into clastic and non clastic sedimentary rock. Clastic sedimentary rock consist individual particles broken away from parent rock. It is further subdivided into two, pyroclastic sediments and detrital sediments. Clastic sedimentary rocks consist of quartz, rock fragments, feldspar and clay minerals. Breccia, conglomerate, mudstone, sand stone and silt stone are examples of such kind of rocks. The non clastic division includes two subdivisions i.e. chemical precipitates and organically derived sediments. Chemical precipitates are inorganic compounds representing solid mineral matter precipitated from water solution. On the other hand organically derived sediment consists of both the remains of plants and animals. The non clastic sedimentary rocks are mainly formed by carbonate like calcite and dolomite. Most of the non clastic rocks are either carbonate or evaporates. Lime stone is an example of carbonate rock and halite or rock salt is an example of evaporates.

The third major class of rocks is the metamorphic rock. The process of formation of metamorphic rock is known as metamorphism. Metamorphism may affect both igneous and sedimentary rock. Unequal stress during mountain building, high confining pressure and high temperature are mainly responsible for metamorphism, For this reason the process of rock change is referred to as dynamothermal metamorphism. It is able to affect enormous bodies of rock within the root of mountain chains of alpine region. Besides, large igneous intrusions cause contact metamorphism which is caused by emanation of hot watery solutions containing many different compounds. It is able to change mineral alteration to the rock which is known as metasomanism. Feldspar is a form of contact metamorphism. Hornblende, biotite, olivine and muscovite are formed of metamorphosis of clay rich sediments. Gneiss is a metamorphosed form of granite. Limestone and dolomite are metamorphosed into marble. With the help of the above ternary diagram three major classes of rock; their formation deformation can be analyzed.

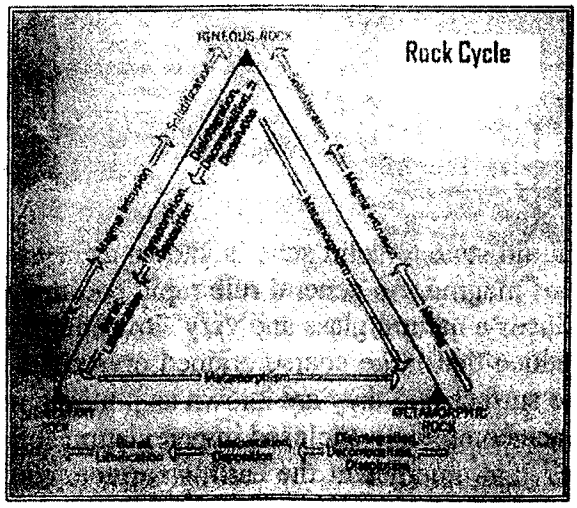


Fig.5 Rock cycle, Strahler p. 67.

The schematic diagram (fig 6) is showing how rising magma may bring igneous material to various intermediate positions, where it solidifies into plutonic rock bodies or by extrusion it may rich the surface to form volcanic rock in the one hand. On the other hand rock formed at depth may appear at the surface of the earth by uncovering, as a result of crustal uplift and denudation. Thus large bodies of igneous, metamorphic, or sedimentary can migrate upward from the deep environment to the surface environment.

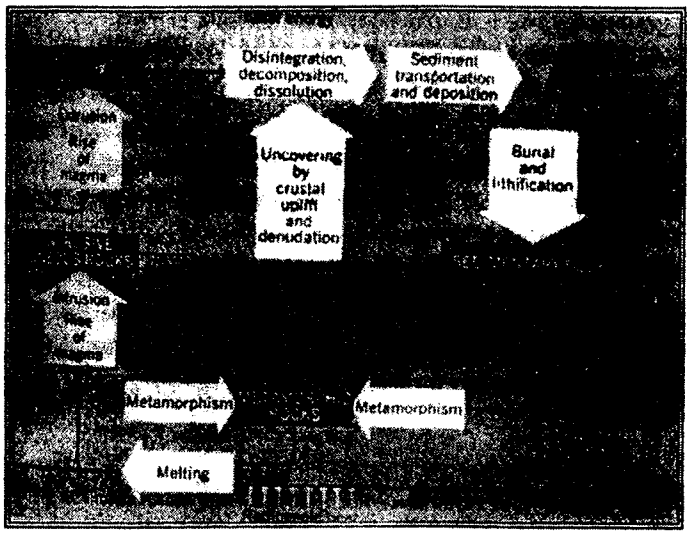


Fig. 6

▲ **4.1.6.2.3 Soil system-** soils are derived from the rocks and minerals which make up the surface of the earth. Development of soil profile is known as a soil formation. It occurs on the zone of weathering of rock decomposition. Formation of profile from the parent rock gives a layered structure to the profile. In the lower most zones lays the parent rock above which lays the regolith zone. The upper layer is covered by decomposed or partly decomposed organic components. Thus the profile looks like O, A, B, C layer from the surface to the depth of parent rock. The nature of the soil profile at any particular place depends upon five main factors.

S=f (Cl, O, R, P, T)

Where S=soil profile, C=climate, O= organic matter, R=relief or topography, P = parent rock and T= time. Human activities are also affecting soil characteristics. Introduction of alien species in place of indigenous species may also change the soil character.

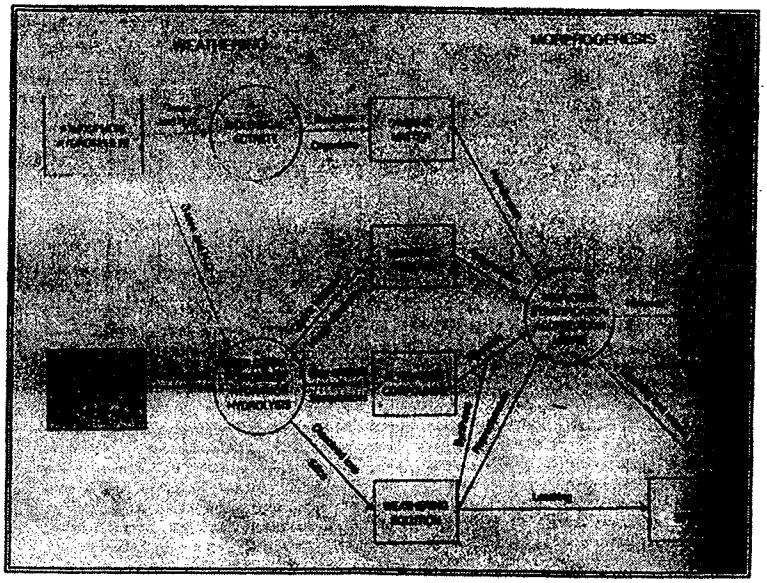


Fig.7: A scheme of soil development.

The five factors of soil formation influenced or produced a set of soil formation process with the temporal and spatial variations. These processes are- leaching, calcification, podzolization , gleization, salinization, alkalization , solodization which are responsible for the formation of brown earth soil, podzol soil, laterite clay, saline, alkaline, solonchak soil respectively. Physical as well as chemical characteristics of soil have impact only on the nature of soil but it also affects the agricultural system, inevitable for human kind. Texture, structure, pore space, pH, organic nature etc. play important role in agriculture.

▲ 4.1.6.2.4 Bio-geo Chemical cycle:

Water is not the only substance that circulates through the various earth systems. So, too, do six other substances or, rather, chemical elements. These elements are composed of a single type of atom, meaning that they cannot be broken down chemically to make a simpler substance, as is the case with such compounds as water. The six elements that cycle throughout Earth's systems are hydrogen, oxygen, carbon, nitrogen, phosphorus, and sulfur. These six chemical elements are collectively known as biogeochemical cycle. These cycles are important for both plant and animal species.

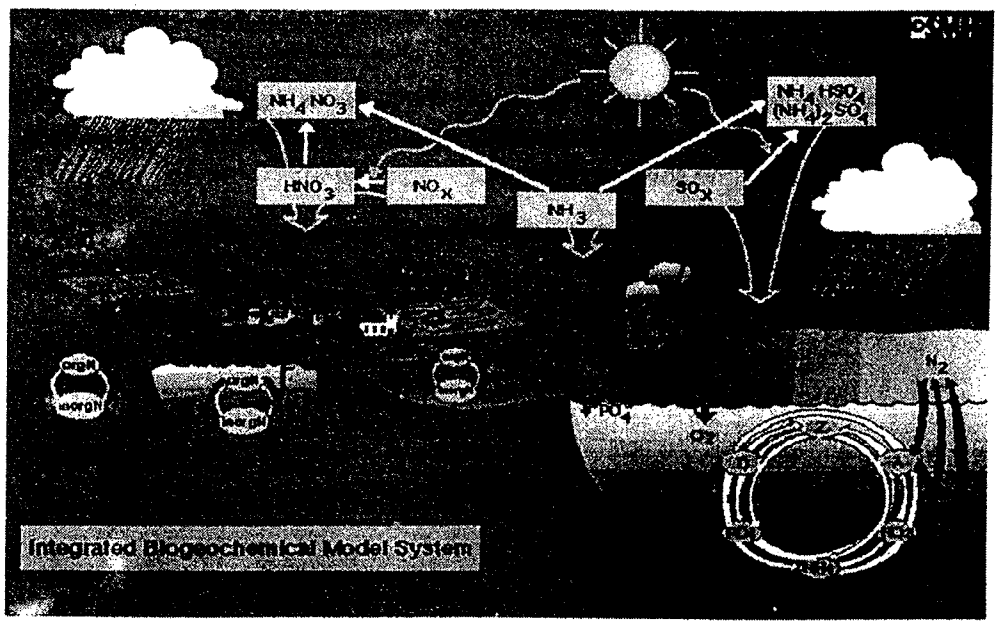


Fig.7: Bio geo chemical cycle

▲ 4.1.6.2.5 Energy cycle:

Solar energy is the driving force of all systems. Energy exists in various forms concern with environmental processes. The important energy sources that affect environmental systems as well as ecosystems are radiant energy, thermal energy, kinetic energy, chemical and potential energy. Radiant energy is the most important energy because sun's energy transmitted into earth in the form of electromagnetic radiation. Wavelength of an electromagnetic radiation varies from 0.2 – 5.0 m. Only a few are visible to human eyes but all transmit energy from the sun to the earth. Radiation energy takes 8.3 minutes to reach the earth where the estimated mean distance is 15x10 km.

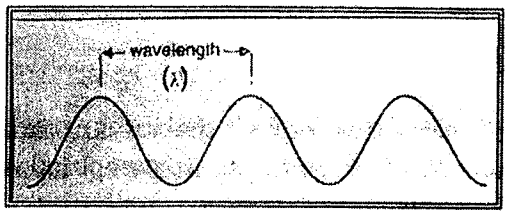


Fig.8.-(EMR, Briggs pp-11)Electromagnetic radiation: the distance from one crest to another crest is known as the wave length(λ).

Radiant solar energy transforms into thermal (heat) energy when it reaches the earth. It warms earth's surface and atmosphere by heating the molecules of atmosphere. In a nutshell radiant energy of magnetic and electric field is transmitted onto the molecules making up the atmosphere and resulting change in the type of energy. Kinetic energy refers to the energy in motion and for this reason thermal energy is sometimes described as kinetic energy. By the effect of kinetic energy a stone thrown to water can be able to disturb the water and produce waves. Thermal or kinetic energy when released by the breaking

down of substances it forms chemical energy related to the chemical structure of any substance. Burning of coal or digestion of food gives rise to such kind of energy. Potential energy is another form of energy which is related to gravity. By the effect of this energy any material is drawn towards the earth's centre within the gravitational field. Potential energy is converted to kinetic energy in the lower levels. Energy transfers and moves in the earth through radiation, convection and conduction. Radiant energy is converted to kinetic energy. Kinetic energy may transform into heat energy. Thus a continuous circulation of energy transformation controls the physical environmental system. Energy system is operating internally and so it can not be observed directly from space but its significance lies within the physical structure and movement of earth.

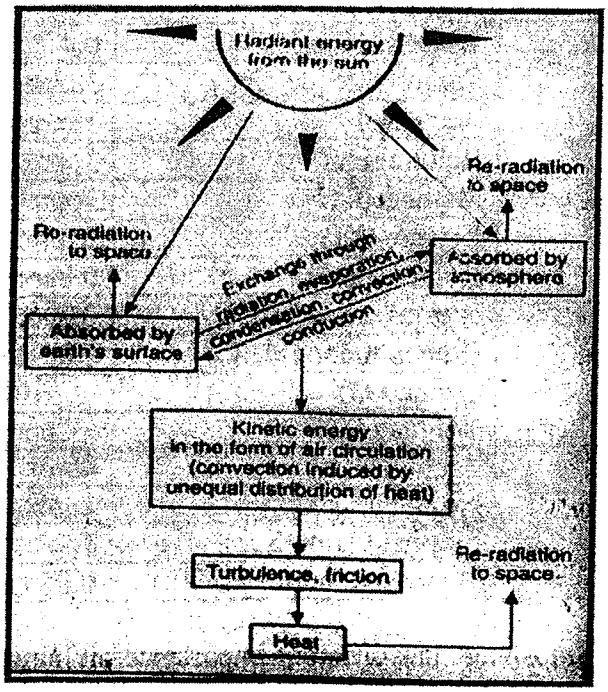


Fig.9- Energy cycle (Page – 114, 2.6 Brigges)

▲ 4.1.6.2.6 The atmosphere:

The early earth had no atmosphere. But as the formation process continued atmosphere and hydrosphere originated. The earth's atmosphere is very different from that of other planets. Earth's atmosphere is composed of gases, liquids and aerosols. About 97% of the mass of atmosphere lies within 29 km from earth's surface. However the atmosphere extends up to 10,000 km from the surface of the earth. From the earth's surface upward, to an altitude of about 100 km, the chemical composition of the atmosphere is highly uniform in terms of properties of gases present in this layer. Above 100 km the very thin gases become separated into layerising composition to environmental process. The lower layer is important because all atmospheric phenomena occur in this layer.

Based on the elements present in the atmosphere they are divided into

a. Gasses

b. Water vapor and

c. Aerosols

a. Gases –The atmospheric gases can be categories under three heads according to the abundance. These are major, minor and trace.

Type of component	Name of the gas	% value
Major components	Nitrogen(N2)	78.08
	Oxygen(O2)	20.95
	Argon(Ar)	0.93
Minor components	Water(H2O)	0.4
	Carbon dioxide(Co2)	325ppm
	Neon(Ne)	18ppm
	Helium9He)	5ppm
	Methane(CH4)	2ppm
	Krypton(Kr)	1ppm
	Hydrogen(H2)	0.5ppm
	Nitrous oxide(N2O)	0.3ppm
	Carbon monoxide(Co)	0.05-0.02ppm
	Ozone(O3)	.02-10ppm
	Xenon(xe)	.08ppm
Trace components	Ammonia(NH3)	4ppb
	Nitrogen oxide(no)	1ppb
	Sulpher Oxide(So2)	1ppb
	Hydrogen Sulphide(H2S)	0.05ppb

Oxygen gas present in the atmosphere has different importance on human life forms. Among all the gasses oxygen is the most important. Living organisms can not living without oxygen. Oxygen when combined with other element can form different compounds. It is also essential for combustion. The proportion of oxygen present in the atmosphere is about 1/5 of the total gas.

Nitrogen

In the atmosphere the percentage of nitrogen is 78. Nitrogen is good diluents. It is an important constituent for formation of many organic compounds. Nitrogen is chemically in active but many compounds of nitrogen are very active. The most important role of nitrogen is to regulate combustion by diluting oxygen and oxidation of different kinds.

Carbon-dioxide

The co_2 present in the atmosphere is coming mainly form fossil fuels. The concentration of atmospheric co_2 is increasing at a rate of 0.2 -0.7% per year. At present co_2 content of the atmosphere is about $129X10^{18}g$ Most of the CO_2, however, is of natural origin, and represents the smallest part of the total carbonate reservoir that includes oceanic CO_2, HCO_3^-, and carbonate sediments. The latter contain about 600 times as much CO_2 as the atmosphere, and the oceans contain about 50 times as

much. These relative amounts are controlled by the rates of the reactions that interconvert the various forms of carbonate.

The surface condition of the earth is sensitively dependent on the concentration of carbon dioxide in the atmosphere because carbon dioxide has a strong infra red absorption capacity (See below). Since CO_2 acts as an acid in aqueous solution, the pH of the oceans is also dependent on the concentration of CO_2 in the atmosphere; it has been estimated that if only 1% of the carbonate presently in sediments were still in the atmosphere, the pH of the oceans would be 5.9, instead of the present 8.2 It takes a vital role in terrestrial heat balance.

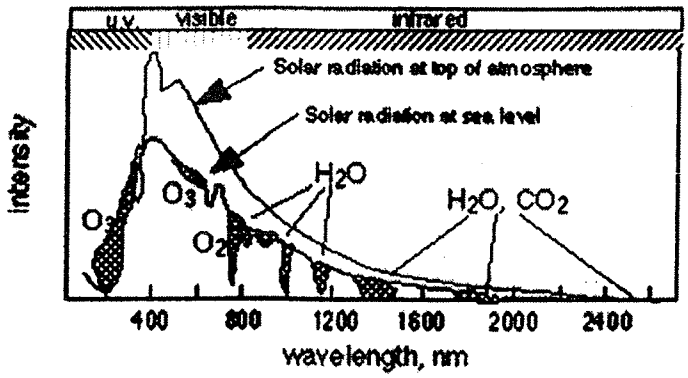


Fig.10

Ozone

Ozone is formed by the reaction of oxygen O_2 with oxygen atom produced photochemically. As a consequence the abundance of Ozone varies with time of day. The concentration of O atoms from other sources and particularly with altitude at 30 km, the Ozone concentration reaches a maximum of 12 ppm. At present Ozone depletion is a dangerous problem for the existence of life forms. The atmospheric Ozone layer helps to protect from excessive quantities of UVA, UVB rays. CFC_{11}, CFC_{12} and Nitrogen oxide gasses are responsible for the depletion of Ozone layer.

Besides these main gasses Argon, neon, helium, krypton, xenon etc. acts as nutrient gases, On the other hand sulfur dioxide , nitrogen dioxide , ammonia are toxic gases.

b. Water vapour

Water vapor is another important factor which plays a significant role in atmospheric phenomena. The percentage of atmospheric moisture concentration of water vapour is mostly found in the lower layer of atmosphere (within 6 km from the surface of earth). Within 10 km concentration of water vapour is only one percent of the total atmospheric moisture present in the atmosphere. Generally it is found that the concentration of moisture decreases with increasing distance from equator to temperate regions. Atmospheric moisture helps the formation of cloud, fog, dew, rain, hailstorm, frost etc. In a word it is important fot condensation and precipitation which are important for life forms. Water vapour also plays an important role for warming of lower layers of the atmosphere. The incoming solar radiation is easily penetrated through moisture layer but protects outgoing solar radiation and thus increases temperature in the lower atmosphere.

The maximum possible quantity of water vapour that the air can hold at any given temperature and pressure is present, the air is said to be saturated. With changing temperature the water holding capacity of air also changes, as the temperature increases water holding capacity also increases. The table below depicts the amount of water vapour in saturated air with different temperature

Temperature0C	Grams	Temperature0C	Grams
-5	3.261	20	17.300
0	4.847	25	23.049
5	6.797	30	39.371
10	9.401	35	39.599
15	12.832	40	51.117

c. Aerosols

Aerosols are tiny floating particles suspended in the atmosphere. They include dust particles, sea salt from streaking sea waves, pollen from various organisms, smoke and soot from fires, tiny sand particles, and fly ash from volcanoes. The percentages of aerosols are high in lower altitudes and its density decreases with height. The presence of aerosols is nearly to zero values in the upper atmosphere, above 100km.

Collectively the aerosols or impurities play an active role in the atmosphere. Many of them help in the development of cloud, fog, smog and rain drops etc. these small particles are responsible for various color of the sky. During dawn and dusk the red yellow orange colors are found for the presence of dust particle in the atmosphere. The smallest dust particles act as hygroscopic nuclei for condensation.

- **Atmospheric density and pressure:**

Molecules of the atmosphere are attached to earth due to gravitational forces. Layers of gases always create pressure on the surface which is known as atmospheric pressure. It has an average value at the sea level of 14.7 kg/sq cm.

Atmospheric pressure rapidly decreases with increasing altitude above sea level. Air pressure is measured by Barometer. Air pressure is represented in terms of millibars. One mercury column is equivalent to 33.9 mb. Standard sea level pressure is 1013.2mb.

- **Atmospheric Pressure and Altitude**:

With the increase of altitude, pressure decreases up to 1000 ft but this rate steadily becomes less at higher altitudes. As one moves from the equator towards the pole, steadily decreasing temperature is observed. The same phenomenon is applicable to increase of altitude and change in pressure. Thus a vertical temperature gradient is found. It is controlled by energy transfers and motion of the air.

Laps rate is the observed rate of vertical decrease in temperature which is not constant but varies with height location and season. According to Haurtz and Austin the normal laps rate in the low layer of atmosphere is 6.5 ^{0}C/km while in the upper part it is 7 ^{0}C/km. Laps rate in tropical region decreases with increasing height of 16-18 km in troposphere where the temperature reduced to -10 ^{0}C. but in the polar

region laps rate continues up to 6 km. only. Another important feature is that the laps rate is lower in winter than in summer.

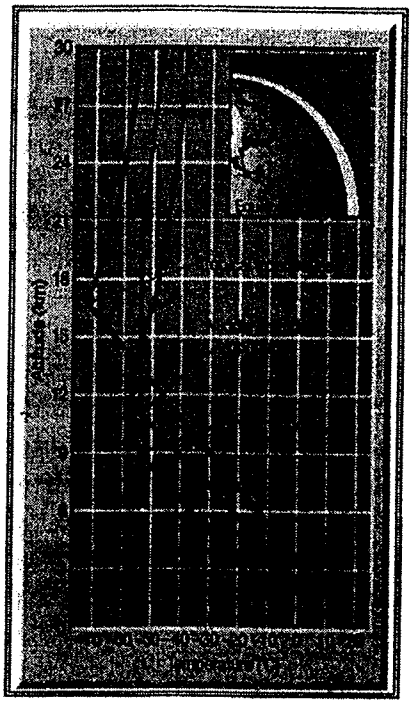


Fig.11

(page 21 in Lutgens and Tarbuck's *The Atmosphere*, 2001) Observed lapse rate and the tropopause

Temperature inversion-in the lower part of the atmosphere, the temperature gradually decreases up to 18 km. from the earth's surface. But sometimes under special circumstances it is reversed and the temperature is increasing instead decreasing with increasing elevation. Or the vertical temperature gradient is inverted. In meteorology it is known as temperature inversion.

Layers of atmosphere-

From the times immemorial men have an interest about the structure of the atmosphere. Different types of expeditions were made with the help of balloons, airplanes, rockets, sounds and radio waves, satellites and sputniks to gather information abut the structure of the atmosphere. According to Peterson there are five layers in the atmosphere. These are –

i. Troposphere
ii. Stratosphere
iii. Mesosphere or ozonosphere
iv. Thermosphere or ionosphere and
v. Exosphere or the outer layer

• **i. Troposphere** (meaning the layer of disturbance) is the lower layer of the atmosphere. Most of the weathering phenomena occur in this layer. The temperature decreases with increasing altitude. The laps rate (rate of a decline in temperature) in troposphere is 6.5^0C/1000m (3.5^0F/1000ft.). Troposphere extends up to 10-15 km from the earth surface. The upper boundary of the troposphere along which a reversal in temperature gradient is found is known as ***tropopause***. The inversion acts as

a ceiling to weather generated in the troposphere. The height of the tropopause varies latitudinally and seasonally. It is seen that it is higher in the summer than in winter and higher in equator than at the poles.

• **ii .Stratosphere** is the next temperature layer. Stratosphere is generally divided in to two parts. The lower part is just above the tropopause. It is isothermal in general or temperature increases slowly with increasing height but the upper stratosphere above 30m height, there is a rapid change in temperature found and it is called warm stratosphere. The reason behind such increase is due to concentration of O_3 at this level. The thickness of the stratosphere is highest at the poles. The upper boundary of the stratosphere is called ***stratopause***. Above stratopause the temperature increases at a high rate.

• **iii Mesosphere or ozonosphere** is that layer where maximum concentration of O_3 is found (between 30and 60kmabove the earth surface). Mesosphere extends 50-80km from the surface of the earth. According to the scientists the warmness of this layer is due to selective absorption of UV radiation by ozone. This layer acts as a layer for the atmosphere. Stratosphere protects human beings from dangerous effects of ultra violet rays. With the advancement of human civilization, establishment of industries, emission of carbon gasses from transport etc. are negatively affecting this layer and creates ozone hole which is dangerous for life forms. The temperature increases with increasing height. The upper part mesosphere is called ***mesopause***.

• **iv. Thermosphere or ionosphere** lies within 60-400km in height and it is electrically charged as shortwave solar radiation ionizes the gas molecules. The electrical structure of the ionosphere is not uniform and it is arranged into –

D layer-60km-99 km
E layer-90km-110 km
Sporadic E layer-110 km
E_2 layer -150 km
F1 layer&
F2 layer-150-380 km
G layer-400 km and above

The thickness of each layer, particularly D layer changes from day to night. The layers weaken and disappear at night and reappear during the day. F layer is present during both day and night. The ***auroras*** take place in the ionosphere. The ***aurora borealis*** (northern light) and ***aurora austrialis*** (southern lights) happen by highly energetic electrons and protons trapped within the lines of force of the external magnetic field. The energetic particles excite molecules of oxygen and nitrogen, causing them to emit light. The aurora is most commonly greenish in color, but red and violet colors are seen on rare occasions. The aurora is associated with exceptionally intense bursts of electrons and protons from the sun. The arrival of such phenomena is called magnetic storm.

• **v. Exosphere** is the outer most layer of the atmosphere. it extends between 400 km to 1000 km. due to extreme height the concentration of atom is extremely low. Hydrogen and helium are the two important gases in this layer. Molecules in the exosphere have enough kinetic energy to escape the earth's gravity and thus fly into the space.

Atmospheric system and human impact- rapid increase of population, urbanization and industrialization have affected the atmosphere and modifies or bring changes to the natute and

composition of the atmosphere. global warming, greenhouse effect, ozone depletion and acid rain are some of the results of atmospheric pollution. Acid rain is that precipitation (in form of rain, snow and fog etc.) of P^H about 5.0. It is caused due to air pollution. The primary pollutants are SO2 and NOx. In polluted urban environments SO2 dissolved in water may cause acidification in its own right; thus

$$SO2(g) + 2H2O(l) \quad == \quad HSO3(aq) + H3O(aq)$$

For which K=2.1x10-2 mol l-1 atm-1. On this basis at equilibrium, an atmospheric sulphur dioxide concentration of 0.2 ppm will give a rain water pH of 4.2.

Green House Effect:

During the period 1890 to 1990 the global mean surface air temperature increased between 0.3-0.6 degree C. It is associated with marked climatic change. Though this overall temperature increase is known completely but it is certain that we are in a period of global warming due to anthropogenic emission of Green House gases. These gases have in common the ability to absorb some of the infrared radiation emitted by the earth. By doing this, current levels of green house gases keep the surface of the earth warm and hospitable. The main natural green house gases are H2O, CO2, CH4 and N2O. To these must now be added anthropogenic Chlorofluorocarbons (CFCs). Human activity has directly caused a marked increase in concentrations of other green house gases. It is alarming for global climate.

Ozone Depletion:

Ozone is formed at trace levels through out the atmosphere below stratopause. Highest concentration of ozone is formed in the stratosphere for what it is called ozone layer. Stratospheric ozone is created and destroyed throughout the hours of daylight by splitting and addition of oxygen molecules. When a single oxygen atom collides with an ordinary diatomic oxygen molecule, an ozone molecule is formed. The process is reversible so that ozone eventually breaks down and reforms into ordinary oxygen molecules.

$$O + O2 \rightarrow O3 \quad \text{(Ozone production)}$$

$$O + O3 \rightarrow 2O2 \quad \text{(Ozone destruction)}$$

Large concentration of ozone is a deadly poison. Ozone layer absorbs much of the longer ultraviolet radiation and some visible and infrared as well. So it works as a shield for incoming UV rays. In 1985, Scientists of British Antarctic Survey published results that showed a massive decline in the Spring-time concentration of ozone over the Antarctic. This phenomenon is known as ozone hole. Consequence of ozone depletion in Stratosphere is hazardous because UV-B has a long term effect on biological systems including DNA. It has a severe effect on plants, phytoplantations and of course, on human health.

▲ 4.1.6.2.7 Hydrosphere:

Among the abiotic components hydrosphere is an important factor. The water of earth's surface constitutes the hydrosphere. About 70% of the surface of the globe is covered with liquid water and 10% is covered in ice. About 97% of the hydrosphere is oceanic, 2% are ice and only 1%, that is fresh water. This figure remains more or less constant because water is cycled through the hydrosphere.

Hydrosphere has remarkable properties and ubiquitous distribution. It helps to circulate the nutrient matter in the biosphere. For this water became an important environmental phenomenon.

Reservoir	Vol (cubic km X 1000,000)	Percent
Oceans	1370	97.25
Ice caps & glaciers	29	2.05
Ground water	9.5	.68
Lakes	.125	.01
Soil moisture	.065	.005
Atmosphere	.013	.001
Streams and rivers	.0017	.0001
Biosphere	.0006	.00004

Table showing distribution of water

Components of physical environment are intricately related to each other. Lithospheric change can affect the atmosphere which further affects the biosphere. Thus the total earth system is an assimilation of various subsystems like atmospheric systems, lithospheric system, biospheric system and hydrospheric system and all these systems are regulated by energy system.

■ 4.1.7.1 Concept and definition of Ecosystem

The term ecology is the combination of two terms; the Greek term oikos (house) and logos (study of). The term was first coined by Hanns Reitler (1885). Though Ernst Haeckel, the German biologist is credited but he popularized by giving a definition and substance to the term. The term ecology concerns itself with the relationship of living organisms, plant or animal, and their environment. The perspective to study ecology is to discover the principles which govern the relationship.

The term ecosystem is an abbreviated form of 'ecological system'. Ecosystems consist of organisms or the living or biotic factors and their environment or non-living or abiotic factors, and all the interactions which take place between them. Therefore an ecosystem is a complex and dynamic system constantly in motion. Solar energy is the regulating force of an ecosystem and the nutrients are continually recycled within the ecosystem by this energy

Tansley in 1935 defined ecosystem as a system resulting from the integration of all living and non-living factors of the environment. E.P.Odum (1953) established the concept of ecosystem as 'the basic functional unit of nature which includes organisms and their non-living environment, each interacting with the other and influencing each other's properties and both necessary for maintenance and development of system'. He later elaborated the definition and stated that 'Any unit that includes all of the organisms in a given area interacting with the physical environment so that a flow of energy leads to clearly defined, trophic structure, biotic diversity and material cycle (exchange of material between organic and inorganic parts) within the system is an ecological system or an ecosystem.

The spatial extension of an ecosystem may vary from a square kilometer to the whole global ecosystem. Thus ecosystem may vary from a localized pond ecosystem to terrestrial biomes or from a grassland ecosystem to the marine ecosystem.

■ 4.1.7.2 Structure of an ecosystem:

From the very definition of ecosystem it derives that ecosystem is the relationship between and among biotic components and with their physical environment. Thus ecosystem is a composition of two factors, the biotic factors and the abiotic components.

▲ 4.1.7.2.1 Abiotic Components:

Abiotic or non-living components of an ecosystem includes (a) C, N, CO2, H2O, organic components e.g., proteins, carbohydrates and humus substances. Organic compounds are not always bound in organisms but they are always moving in biotic and abiotic components. (b) the climatic components like temperature, light etc. Radiant energy of sun is the only significant energy source of any ecosystem.

■ 4.1.7.2.2 Biotic components:

The organisms that make up the living part of the ecosystem are divisible into two parts based on the function of the organism: (a) Autotrophs and (b) Heterotrophs .

The autotrophic components include all green plants which fire solar energy and produce food from inorganic nutrients, mineral matters and water. On the other hand the heterotrophic components include non-green plants and all animals which take food from autotrophs. The structure of an ecosystem is composed of distinct functions of three components.

▲ 4.1.7.2.2.1 Producers: Producer organisms are able to build organic molecules and hydrogen derived from water and carbon dioxide and for this reason they are called autotrophs. Most do this by photosynthesis and therefore they are confined to the sun-lit parts of the earth—the surface of the lands and the upper waters to the atmosphere. The radiant energy of the sun converted to chemical energy by the production of carbon-rich compounds. Oxygen is evolved as the byproduct in the photosynthesis which is used by the organisms for respiration.

About half of the world's production is carried on by photosynthetic protoctists (mainly the phytoplankton of the oceans), and about half by terrestrial metaphytes. A very small part is contributed by chemolithotrophic bacteria using chemical reaction around springs on the sea-floor and in soils.

$$6\,H_2O + 6\,CO_2 \rightarrow C_6H_{12}O_6 + 6O_2 \text{ (Photosynthesis)}$$

$$C_6H_{12}O_6 + 6\,O_2 \rightarrow 6CO_2 + 6H_2O \text{ (Respiration)}$$

Examples of ecosystem are algal and others hydrophytes of a pond, grasses of a field and trees of forests. Some chemosynthetic bacteria also belong to this category.

▲ 4.1.7.2.2.2 Consumers: They are the living organisms which consume food synthesized by producers. Animals of different kinds and some carnivory plants are lying within this category. There are various feeding levels or trophic level in an ecosystem. Based on that, consumers can be categorized as:

a. Primary Consumers: These are purely herbivorous animals that are dependent for their food on green plants. They are known as 'key industry animals'. Insects, rodents, rabbits, deer, cow, buffalo,

goat (terrestrial) and mollusks (aquatic) are some of the examples of terrestrial and aquatic primary consumers.

b. Secondary Consumers: These are the carnivores and omnivores. Carnivores are mainly flesh eaters whereas omnivores consume both flesh and plants as their food. Sparrow, Crow, fox, wolves, dogs, cats and snakes are the examples of secondary consumers.

c. Tertiary Consumers: The carnivores which prey on the carnivores of second trophic level are called the tertiary consumers. They also consume omnivores and co-herbivores. Lions, tigers, hawk, vulture etc are considered as tertiary consumers.

d. Besides these three categories of consumers, the parasites, scavengers and saprobes are also included in the consumers. Parasites depend on living tissues of plants and animals for their food whereas scavengers and saprobes used to utilize dead remains of animals and plants as their food.

▲ **4.1.7.2.2.3 Decomposers:** Besides the herbivores and carnivores there are another group of heterotrophs in the ecosystem which are called the decomposers or the reducers and consist chiefly of bacteria and fungi. Decomposers do not consume food in the ingestive manner of the herbivore or carnivore but they do so by absorption. The released enzymes from their body degrade and digested dead plant and animal matter and absorb them. Generally bacteria act on animal tissue and fungi on plant tissue. Decomposers are significant because they make the complex dead material into simple inorganic forms through mineralization and make available to green plants. The process of decomposition is like sugars starch hemicelluloses, proteins, pectin cellulose, lignin, subesibs, and cutins ; where sign stands for less resistant than.

■ **4.1.7.3 Energy flow in Ecosystem:** The energy needed for functioning of most ecosystems comes from the sun. Unlike nutrients which are continuously recycled in the ecosystem, energy also flows through the ecosystem. It is noted that there is a progressive diminution of energy in the food chain and the nutrient components is not diminished. It is because energy flows through the ecosystem only once and must therefore be continuously replenished. In the food chain of producers transfers energy to primary consumer, secondary consumers and tertiary consumers and finally to the decomposers. At each trophic level some energy is lost due to respiration and loss of heat. This lost energy can not be reused by organisms and therefore energy flow is a one way process.

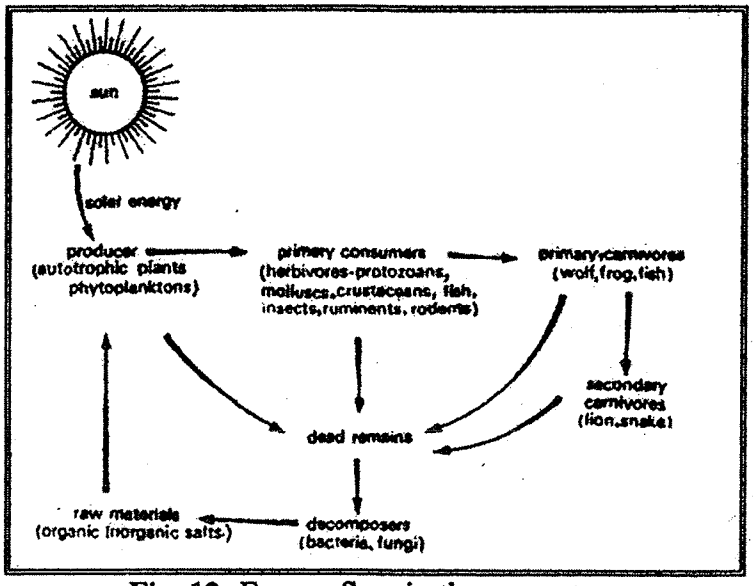


Fig. 12: Energy flow in the ecosystem

■ 4.1.7.4 Food chain and food web:

In ecosystem the feeding relationship between animals and plants are of fundamental importance to facilitate the flow of energy and the cycling of nutrients i.e. the functioning of a system as a whole. Very simply plants and animals are our objective of study from prey predator angle which is known as food chain. The concept of food chain was proposed by Charls Elton in 1927. Example of a food chain is

PHYTOPLANKTON→ ZOOPLANKTON → KRILL → BLUE WHALE

Nature of food chain is very complex as there are enormous types of relationships between and among the organisms. The situation is usually very complex and the myriad feeding relationships exist between animal and plant species with in an ecosystem are more accurately described by the term food web. Thus food web consists of a number of trophic levels.

Trophic level	Producer/ consumer	Autrophs/ Heterotrophs	Herbivores/Carnivores
1st	Primary producer	Autotrophs	
2nd	Primary consumer	Heterotrophs	Herbivores
3rd	Secondary consumer	Heterotrophs	Carnivore
4th	Tertiary consumer	Heterotrophs	Carnivore

Food chains are of three types

a. Grazing food chains- grazing food chain starting from the green plant to the herbivores and from the herbivores to the carnivores of top most level. An ecosystem must meet the following facts.
   - ➢ It may oxidized in respiration
   - ➢ It may die and decay
   - ➢ It may be eaten by herbivores

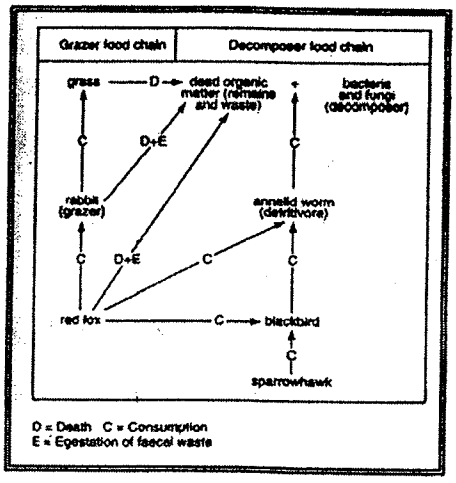


Fig. 13: The link between grazer and decomposer food chain

The assimilated food is stored as carbohydrates, proteins and fats and it transforms into complex organic molecules. In the same way the energy transformed from primary to secondary and tertiary consumers. Thus energy flow in the ecosystem following

AUTOTROPH → HERBIVORES →PRIMARY CARNIVORE →SECONDARY CARNIVORE

a. Parasitic food chain- In parasitic food chain the energy goes into the large organisms to smaller ones with out killing out right as in case of prey predator relationship.
b. Detritus food chain- Distinct from grazing and parasitic food chain but linked to them are other type of food chain which is known as decomposer food chain. Dead organic matter in form of plant animal remains and faecal waste provides an alternative food source utilized by a vast array of decomposers and detritivores.

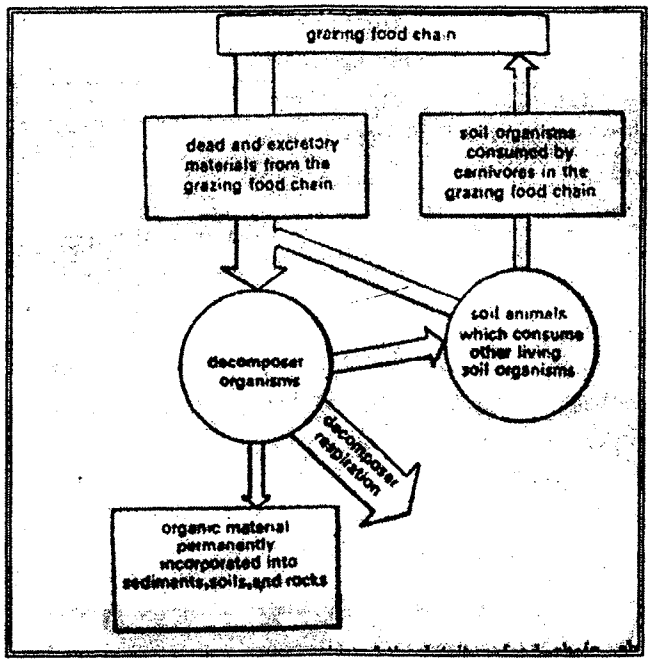


Fig.15: Detritus food chain showing energy transfer and losses between detritus and grazing food chain

Food web- They are stated as the interconnected network of food chain. There are mainly three types of food webs

a. Connected ness web- who eats whom is the main theme and emphasizing the feeding relationship. These are also known as topological food webs.
b. Energy flow food web- in this food web energy flow through the web is estimated interconnected population is quantified in terms of energy
c. Functional food web- It detects the impact of species on the structure of community.

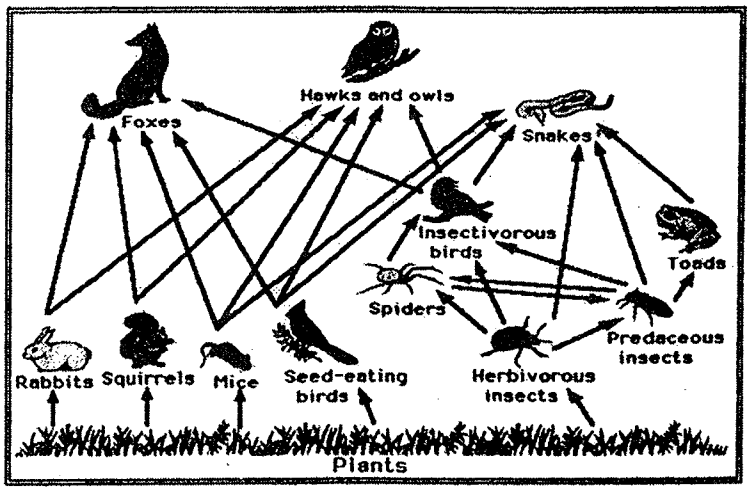


Fig.16: Food web

■ 4.1.7.5 Ecological pyramid:

The graphic representation of trophic structure in which the first trophic level or producer level forms the base and higher trophic levels from successive tires is called ecological pyramid. There are three types of ecological pyramids

a. pyramid of number-Individuals of each trophic level counted per unit area and their number is represented through a pyramid
b. Pyramid of biomass- The total biomass existing at each successive trophic level in terms dry weight or caloric value per unit area.
c. Pyramid of productivity- In which productivity or energy flow per unit time at each of the successive trophic level is measured and plotted.

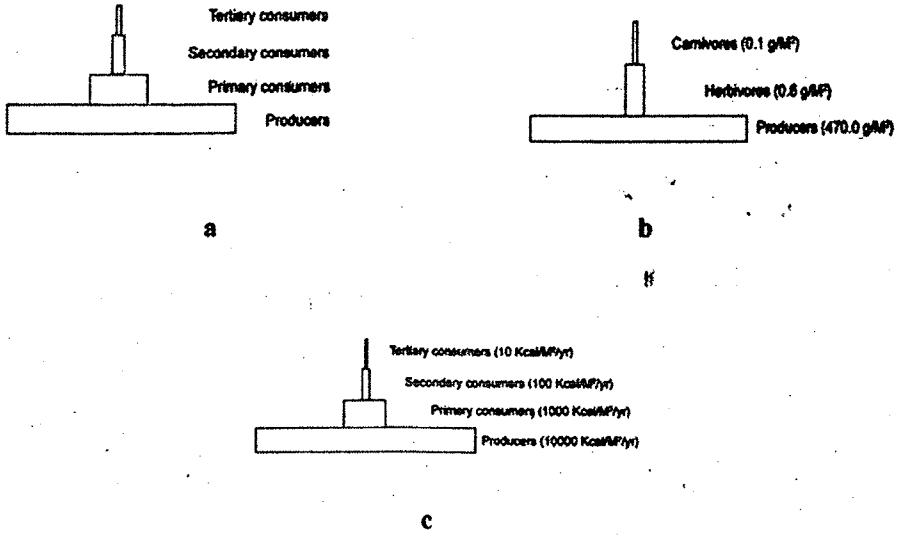


fig.17: Different types of pyramids.

■ 4.1.8.0 Major ecosystems of the world

The characteristic vegetation community associated with particular latitude or biogeographical region (such as tropical forests or temperate grass lands) primarily defined by climate. According to Simmons (1982) Biome is the most extensive ecosystem unit. Though climate is an important factor for classification of biomes but other factors like soil water are also important. Based on location and climatic variation biomes are classified into terrestrial biome and aquatic biome. Major terrestrial ecosystems are forest, grass land, tundra and desert. They are so classified by their regimes of precipitation and temperature. On the other hand aquatic habitats are defined by their animal community and its adaptation to depth, rate of water flow, salinity and nutrient source. In one physiognomic type more than one biome may exist.

■ 4.1.8.1Tropical forest-

Location: These forests are found in the humid tropics in absence of dry season or of very short period. Tropical rainforests straddle the equator roughly within the tropic of cancer and Capricorn, in Central and South America, Southeast Asia and islands near it, and West Africa. There are smaller rainforests in northern Australia and other small islands.

Climatic characteristics: Generally, there is a flow of air that comes from the poles of the Earth, towards the equator. These winds are filled with moisture and the intense heat that is located at the equator causes the moisture to rise, cool and then condense to create rain. This continuous cycle causes it to rain almost 24 hours a day around most of the tropical areas. In some regions there can be more than 15 feet of rain a year. All tropical rainforests are found along the equator where the mean temperatures (20°-30° C) and the humidity (200 mm.) are always high, with the days being equal length over the year. In India such type of climate are seen in the Western Ghats region. Tropical rainforest have the net primary productivity of all terrestrial ecosystems.

Characteristics:

Soil Characteristics: Soil is poor in nutrient concentration due to high leaching. The soils are very old (up to Tertiary period, Laterization is very common and $P^{H\ is}$ acidic in nature. Thick layer of decomposed organic matter is formed by high temperature and abundant moisture. Lack of binding material in the soil is another characteristic of soil.

Vegetation characteristics: Trees are tall (generally up to 50-55m) and broad leaved. Biodiversity is rich with numerous species. Over 750 species of trees, 1500 different kinds of flowering plants, Trees are smooth barked with no bud protection because of favorable climate. Most of the species are resemble to each other and it is very difficult to identify each other. Plants are generally having very similar oval, medium sized leaves, with drip tip and entire margin. More than three canopies are found. Canopy height ranges from 30-40m. Competition for light among the trees is a common factor. Woody climber and creepers are one of the main characteristics. Epiphytes, orchids, lianas and stranglers are abundant. Branches are festooned with mosses, lichens and ferns, and when the mosses become dense they are hanging and make the stands visually and physically impenetrable.



Fig.18: The shapes of leaves in tropical and temperate forest ecosystem

Fauna: Invertebrate fauna is very rich, striking in color, size and adaptations for defense by mimicry and other means. 125 species of mammals, 400 species of birds, 100 reptiles , 60 amphibians, and countless insect and150 species of butterflies are found in tropical rain forest zone. Mammals and reptiles are predominantly arboreal (living in canopy) and nocturnal. Birds' niche is found in the upper strata of the rainforest.

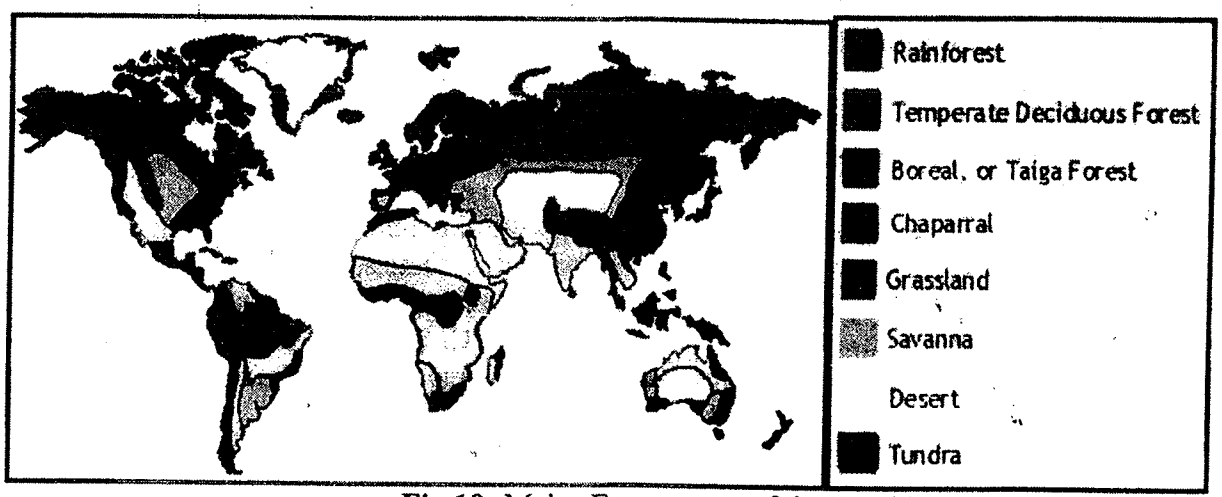


Fig.19: Major Ecosystems of the World

■ 4.2.8.2 Tropical grass land or Savanna:

Location: Savanna are tropical grassland with scattered trees (tree savanna) or shrubs (scrub savanna) or with out woody plants. Savannas are found in Africa, Australia, South America and southern Asia. In India they are found with in dry deciduous forests and in degraded deciduous forests.

Climatic characteristics: summer rain less than 50 cm, down to as little as 20-10 cm is favorable for the development of savanna. Temperature does not fall below 20°C(maximum 32°C). The climate is too dry for the growth of trees. The Indian savanna is characterized by highest temperature (45^0c-48^0C) and mean rainfall 1500mm. rain fall

Soils: Soils are ancient and infertile

Vegetation: Vegetation with little open woodland, thorn scrubs and most of the trees are acacia species with small leaves to protect browsers. Grasses are the dominating vegetation of savanna region. Grasses

are generally coarse, stiff, hard and of 80cm to 350 cm height. Grasses are generally penetrating their roots parallel and continually. Elephant grass (*Hyparrhenia*) is an important genre. Besides grasses and scrubs, scattered distributions of trees are also characterizing savanna biome. Based on the dominant species savanna is named by tree savanna, grass savanna and shrub savanna.

Animals: Grazers are less selective. Locusts, ants, grasshoppers and insects are important herbivores. Termites are also present with their mounds. Giraffe, elephants, zebra, hyenas, jackals, big cats, kangaroo (in Australian savanna) and lions are important mammals. Besides toucans, parrots, kingfisher, nightjars, doves and many other birds are seen here. Insects like ants, earwigs, locusts, grasshopper, beetles and small cricket are also found here.

■ 4.1.8.3 Temperate grass land biome:

Location: Temperate grass lands are located in the interiors of the continents which come under westerly winds. Due to interior location these countries do not get sufficient rain. In the southern hemisphere they are located in the south eastern margins of continents and therefore they faced more moderate climate than the countries of northern hemisphere. Temperate grasslands are located in North America and Eurasia known as Steppe and prairies respectively. Pampas of South America, the veldt of South Africa, Canterbury of New Zealand and surrounding the deserts in Australia are examples of temperate grass lands of the world. Steps are found on every continent except Antarctica.

Climatic characteristics: The height of grass correlates with the amount of rainfall it receives. Grasslands receive about 500 to 900 mm of rain per year compared to deserts, which receive less than 300 mm and tropical forests, which receive more than 2,000 mm. While temperatures are often extreme in some grass lands, the average temperatures are about -20°C to 30°C. Tropical grasslands have dry and wet seasons that remain warm all the time. Temperate grasslands have cold winters and warm summers with some rain.
Soils: Deep and fine Flat or gently landscape or old and eroded plateaux with thick humus layer.

Vegetation: Grasses (prairie clover, salvia, oats, wheat, barley, coneflowers). Grasslands are generally open and continuous, fairly flat areas of grass. They are often located between temperate forests at high latitudes and deserts at subtropical latitudes. Grasses vary in size from 2.1 m (7 ft) tall with roots extending down into the soil 1.8 m (6 ft), to the short grasses growing to a height of only 20 to 25 cm (8 to 10 in) tall. These short grasses can have roots that extend 1 m (about 3 ft) deep. Seasonal growth and flowering are seen. Grazing and fires dominate the growth. Thorn scrub and trees developed where grazing lifted. The grasses die back to their roots annually and the soil and the sod protect the roots and the new buds from the cold of winter or dry conditions. A few trees may be found in this biome along the streams, but not many due to the lack of rainfall.
Animals: Insects borrowing animals both vertebrates and invertebrates. Animal community includes mammals like wild antelope, gazelles, kangaroo, horse and buffalo, wolf, coyote, etc. among the borrowing animal's rodents and mole rat are important species. Eagles, large hawks are also found here.

■ 4.1.8.4 Tundra biome:

This biome circles the world in the highest northern latitude and in the southern hemisphere is found only in the Antarctica Peninsula and Islands close by. Here temperatures often reach about -50°F in the winter. Tundra covers about one-fifth of the Earth's land surface. Because of the cold climate it is impossible for

trees to grow, thus leaving room for low-growing plant life and wildflowers. For this reason the Tundra biome looks like a frozen-over prairie land.

In the Ice Age, massive glaciers dwelled here. As the Earth warmed these glaciers retreated leaving bare rock and scoured soils. The freezing temperatures leave deeper layers of soil frozen throughout most of the year- this condition is called permafrost. Only the top layer on the surface is able to thaw out in summer conditions. However, this occurs just briefly because summers are extremely short here. The combination of a harsh climate, the lack of nutrients in the soil, and soil being so sparse make it very hard for any type of plant life to grow.

Despite these harsh living conditions animals still manage to survive here. During the Tundra's brief summer, insects hatch out of eggs which were frozen in the top soil. Creating a vast feeding ground for birds, thousands migrate here during this time to feed on these insects. Millions of migrating waterfowl and shore birds come to the shore and lake areas in the artic tundra of Alaska during the summer months. Also, ravens, hawks, ptarmigans, and the open country owl are common. Besides birds and insects mammals dwell in this icy zone. The Caribou, artic hare, mink, weasel, lemming, wolf, wolverine, brown bear, vole and reindeer, roam this land. And the Polar bear, walrus and artic fox are commonly seen on the ice pack and coastal areas.

■ 4.1.8.5 Taiga forest biome:

Location: The most extensive coniferous forests are found in this biome. Canada, Europe, Asia, and the United States

Temperature: -40°C to 20°C, average summer temperature is 10°C

Precipitation: 300 to 900 millimeters of rain per year

Vegetation: Coniferous-evergreen trees (trees that produce cones and needles; some needles remain on the trees all year long)

Other: Coniferous forest regions have cold, long, snowy winters, and warm, humid summers; well-defined seasons, at least four to six frost-free months

■ 4.1.8.6 Temperate deciduous forest:

Location: Temperate deciduous forests are located in the mid-latitude areas which means that they are found between the Polar Regions and the tropics. Eastern United States, Canada, Europe, China, and Japan

Temperature: The temperature varies widely from season to season with cold winters and hot, wet summers. The average yearly temperature is about 10°C. -30°C to 30°C, yearly average is 10°C, hot summers, cold winters.

Precipitation: The deciduous forest regions are exposed to warm and cold air masses, which cause this area to have four seasons. The areas in which deciduous forests are located get about 750 to 1,500 mm of precipitation spread fairly evenly throughout the year.

Vegetation: Temperate deciduous forests are most notable because they go through four seasons. Leaves change color in autumn, fall off in the winter, and grow back in the spring; this adaptation allows plants to

survive cold winters. During the fall, trees change color and then lose their leaves. This is in preparation for the winter season. Because it gets so cold, the trees have adapted to the winter by going into a period of dormancy or sleep. They also have thick bark to protect them from the cold weather. Trees flower and grow during the spring and summer growing season. Broadleaf trees (oaks, maples, beeches), shrubs, perennial herbs, and mosses
Many different kinds of trees, shrubs, and herbs grow in deciduous forests. Most of the trees are broadleaf trees such as oak, maple, beech, hickory and chestnut. There are also several different kinds of plants like mountain laurel, azaleas and mosses that live on the shady forest floor where only small amounts of sunlight get through.

■ 4.1.8.7 Desert biome:

Desert biomes are the driest of all the biomes. In fact, the most important characteristic of a desert is that it receives very little rainfall.

Location: Between 15° and 35° latitude (North and South of the equator); examples are Mojave, Sonoran, Chihuahua, and Great Basin (North America); Sahara (Africa); Negev (Middle East); and Gobi (Asia) .

Temperature:
The temperature in the desert can change drastically from day to night because the air is so dry that heat escapes rapidly at night. The daytime temperature averages 38°C while in some deserts it can get down to -4°C at night. The temperature also varies greatly depending on the location of the desert.

Precipitation: Most deserts receive less than 300 mm a year compared to rainforests, which receive over 2,000 mm. That means that the desert only gets 10 percent of the rain that a rainforest gets!

Vegetation: Since desert conditions are so severe, the plants that live there need to have adaptations to compensate for the lack of water. Some plants, such as cacti, store water in their stems and use it very slowly, while others like bushes conserve water by growing few leaves or by having large root systems to gather water or few leaves. Some desert plant species have a short life cycle of a few weeks that lasts only during periods of rain. Cacti, small bushes and short grasses are the main vegetation of desert biome.

Other: Perennials survive for several years by becoming dormant and flourishing when water is available. Annuals are referred to as ephemerals because some can complete an entire life cycle in weeks.

■ 4.1.8.8 Aquatic Ecosystems

Aquatic ecosystem is divided in to two ecosystems i.e. fresh water ecosystem and marine ecosystem.

▲ 4.1.8.8.1 Fresh water ecosystem:

Fresh water ecosystems further divided in to
i. *Lentic* or standing water ecosystem: Most of the *lentic* ecosystems are geologically young. Ponds and Lake Ecosystem are fall under this category. Generally there are three distinct zones in lentic ecosystem. Littoral zone which is close to shore line, sun light penetrates to the bottom and supporting rooted plants.

Limnetic zone or open water where adequate sunlight helps the plankton to its full bloom and profundal zone of deep water with absence of inadequate light. This zone is occupied by heterotrophs. The bottom is referred to as benthic zone. This zone is stratified by differential temperature. Temperature gradient is declining to wards the depth where density is higher than the upper zones. It is difficult to group communities of lakes and ponds into biomes, because of many factors. One of the important cause is climate has no control over the development of such kind of ecosystem. Except the ancient lakes the species diversity is very low.

ii. *Lotic* ecosystem is markedly different from those of *lentic* ecosystem. River system is an example of *lotic* ecosystem. It is an open ecosystem. In the rivers and streams the velocity of current is great to keep the bottom clear. Filamentus algae and fishes are common examples. In the zone of deep water the velocity of water is reduced and silt and other loose materials tend to settle at the bottom.

iii. Wetland ecosystem occurs in shallow fresh waters or in the areas which are inundated by water for a long period. This type of ecosystem is suitable for ducks and other semi aquatic animals. It also supports large trees and shrubs. Aquatic insects, reptiles and dirds are common in wet land ecosystem

▲ **4.1.8.8.2 Marine ecosystem:** It constitutes 70% of the earth's surface. Sea has unusual stability in temperature, salinity and gaseous content. Depending on the depth the marine ecosystem is divided into three.

i. The upper portion of the oceanic region where light penetrates is called *euphotic* zone. Planktons (algae, diatoms, small crausceans and their eggs) are present in the upper layer. They are moving with the tides. Littoral zone lives besides planktons are barnacle, oysters, limpet, kelp or red algae are common.

ii. The region of the ocean below the *euphotic* zone (below 200m) is known as aphotic zone or *nertic* zone. Here temperature changes with season. Depending on the availability of light extensive communities of algae (red, blue and green), fish, and crustaceans are found.

iii. Pelagic zone is lying below the nertic zone. Zooplanktons are the dominating fauna of this zone. Apart from this other animals like shrimp, krill, arrow worms, comb jellies tunicates are seen.

iv. Deep ocean benthos zone is extends from the continental shelf to the deepest oceans. Due to absence of light, absence of plants is one of the features of this zone. Heterotrophic animals of strange character are seen here. Most of the animals are embedded in the mud.

• **Humans and ecosystems**

Humans are the ultimate ecosystem engineers, routinely reshaping ecosystem form and process using tools and technologies, such as fire, that are beyond the capacity of any other organism. This exceptional capacity for ecosystem engineering, expressed in the form of agriculture, forestry, industry and other activities, has helped to sustain unprecedented population growth, such that humans now consume about one third of all terrestrial net primary production, move more earth and produce more reactive nitrogen than all other terrestrial processes combined, and are causing global extinctions and changes in climate that are comparable to any observed in the natural record. Clearly, humans are now a force of nature rivaling climate and geology in shaping the terrestrial biosphere and its processes. As a result, the vegetation forms predicted by conventional biome systems are now rarely observed across large areas of Earth's land surface.

• **Summary:** The term environment is defined in different ways. Definition of the term is depending on the subjects view point as it has multidisciplinary applications. Geographers approach is spatial approach.

Environment to a geographer includes both the physical and cultural environment. Components of physical environment include atmospheric, biospheric, lithospheric and hydrospheric factors. These

components are working together. Intervention on any sphere may generate impact on the other. Biosphere of the earth includes different systems and subsystems. Ecosystem is one of them. System or the process of the ecosystem depends on the prey predator relationship. Thus they form food chains webs and pyramids of energy and number. Differences in temperature, rainfall, natural vegetation give rise to different ecosystems or biomes as an expression of interrelationship between and among these components. Main theme of this unit is about the components of physical environment and relation among these components as well as expressions of these relations on space.

4.1.9 Self Assessment Questions :

1. **What is environment? What are the components of environment?**
2. **What is ecosystem? What are the different components of an ecosystem?**
3. **What are the major ecosystems of the world? Describe forest and marine ecosystem in detail.**
4. **What is meant by energy flow in an ecosystem?**
5. **Write short notes on: producers, food chain and food web, ecological pyramids, bio geo chemical cycle, pedogenesis, autecology and synecology.**
6. **Describe in detail about the tropical rainforest biome and temperate grass land biome with proper diagram.**
7. **Give an account on the abiotic components of the earth system and their interrelations.**
8. **Give an account on the structure and components of atmosphere with proper diagrams.**
9. **What are the soil formation processes responsible for the formation of different soils?**
10. **What are the impacts of humans on natural ecosystems?**

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M.A. / M.Sc.
PART - I
Paper - II :: Module - IV :: Unit - 02

Module Structure

- 4.2.1.0 Introduction
- 4.2.1.1 Defining environmental degradation
- 4.2.1.2 Environmental pollution and degradation
- 4.2.1.3 Changing man environment relationship
- 4.2.1.4 Environmental degradation and causing pollutants
- 4.2.1.5 Types of environmental degradation
- 4.2.1.5.1Air Pollution
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- 4.2.2.1Agricultural ecosystem
- 4.2.2.2Urban Ecology
- Summary
- Keywords
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4.2.1.0 Introduction

Environmental system from holistic point of view is an assimilation of many subsystems. It includes both physical and manmade environmental system. Physical environmental system includes atmospheric system, lithosphere system, soil system, hydrosphere system, soil system and many more where as cultural environmental system includes systems related to cultural environmental components, as urban system, agricultural system etc. The physical environmental system is governed by physical laws, processes and factors. Contrary to this cultural environmental system is controlled by technology, belief, values, norms and ethics etc. Both physical and cultural environmental system has a mechanism to run the system which is known as homeostatic mechanism or the stage of equilibrium. Whenever any system fails to maintain this state, it may face some problems and its imprints are seen on space in the form of deterioration or pollution or degradation.

4.2.1.1 Defining environmental degradation

As previously stated that environment is an umbrella term and includes physical, chemical and biological processes in its realm. Every system, be it natural or man-made has its own processes to run the system smoothly towards the end. Every system is intricately related to each other. Any change or modification in any system may have impact on the other system. Though every system is regulating on its inbuilt criteria but negative feed back due to interruption in any stage may occur in form of environmental degradation.

4.2.1.2 Environmental pollution and degradation

Environmental degradation and environmental pollution are two confusing terms, often used synonymous to each other. Environmental pollution is the unfavorable alteration of our surroundings, wholly or partly, largely as a consequence of mans action (direct or indirect) which effects and make changes in the energy patterns, radiation levels, physical and chemical constituents and abundance of organisms. Pollution is defined as the addition of extraneous materials to air, water, and land which adversely affect the natural quality of environment. Pollution is occurring all over the world due to various causes.

Environmental degradation on the other hand is said to occur when the environment becomes less valuable or damaged. There are many forms of environmental degradation. When habitats are destroyed, biodiversity is lost or natural resources are depleted, the environment is hurt. Environmental degradation can occur naturally, or through human processes. The largest areas of concern at present are the loss of rainforests, air pollution and smog, ozone depletion and the destruction of the marine environment.

According to S. Singh (1997), environmental pollution means lowering of the quality of environment at local level caused exclusively by human activities where as environmental degradation means, lowering of environmental quality at local regional and global scales by both natural processes and human activities. So the main difference is the scale of impact and reasoning factors.

4.2.1.3 Changing man environment relationship

The long term record of changing man environment relation is relevant because constant research on this issue is showing that "change takes place all the time, all sorts of direction and at all sorts of scales,

catastrophically, gradually and unpredictably" (Scott, 1998). It is inevitable then to identify the change in environment due to human impact. Haggett (1997) prepared a model on spatial and temporal scales of environmental change, where he described the relationship between man and environment and its impact on space both in sort and long term period.

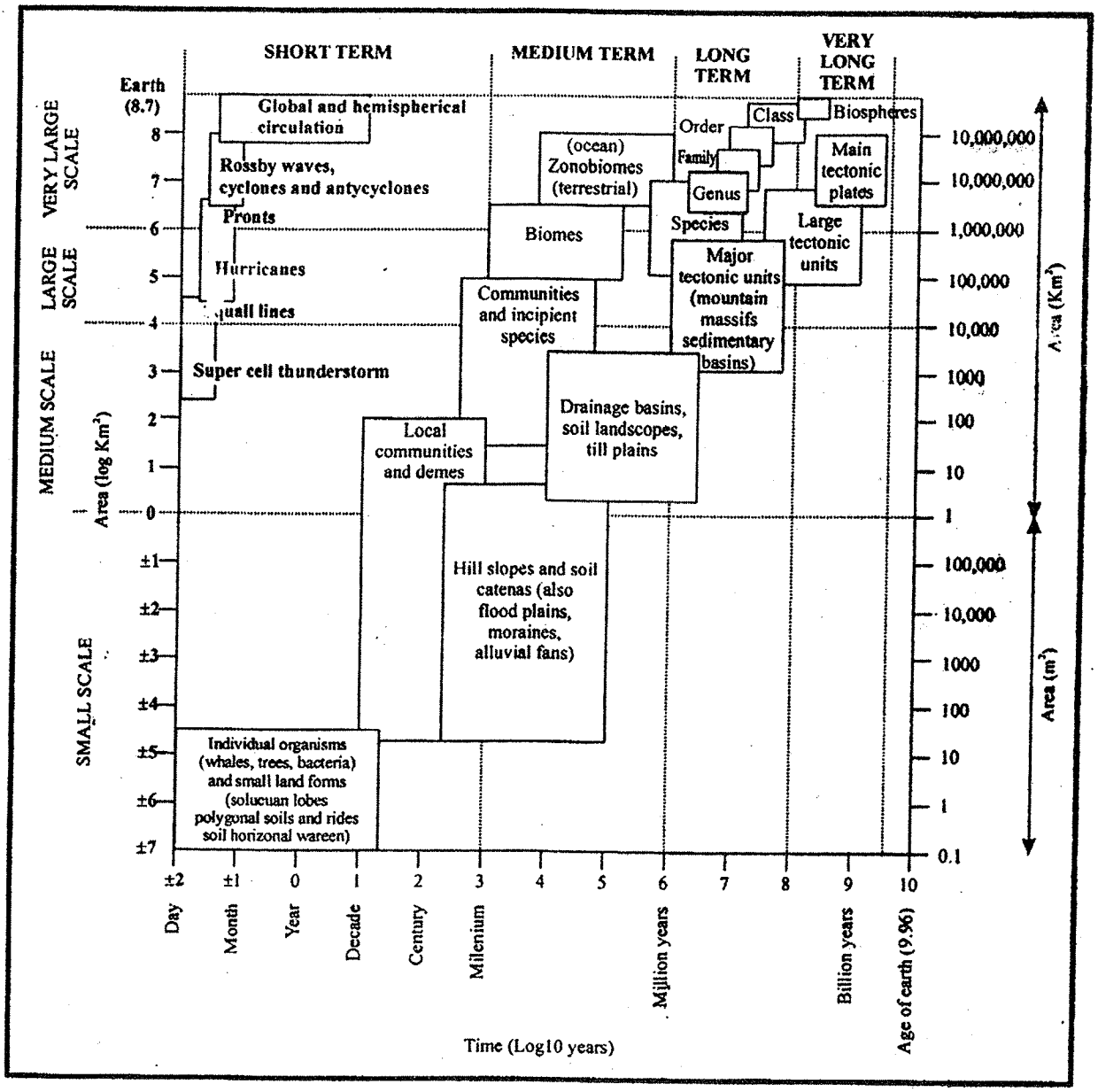


Fig. – 1 : Spatial and temporal scales of environmental change. source: Haggett, 1997

Any system goes towards equilibrium state, likewise environmental system also, Escalating human population on limited land causes increasing pressure on land resources. Millions of people are without the basic human needs of food, shelter, cloth, health, education and employment. Over population is not the only cause behind this situation but it is also due to environmental consequences. Loss of forest, loss

of fertility of soil, agricultural productivity and energy crisis have created many problems. Industrial pollution in form of wastes also caused environmental depletion. Man made environment have also effected natural environment. Thus with man nature relationship the facial impact has changed from time to time but every phase have some impact on environment be it positive or negative. The given diagram (fig. –1) is a self explained diagram which focuses that spatial impact of any environmental change affects on space in short term or long term period and the degree of impact increased with increasing time.

■ 4.2.1.4 Environmental degradation and causing pollutants

Depending on the nature of pollutants, environmental degradation varies. Environmental polluting materials are generally classified into solid wastes, liquid waste, gaseous waste, and wastes without weights. These pollutants may affect different environmental components and caused degradation of environment. Examples of environmental degradation are degradation of soil, land, water and air.

a. Solid waste: solid wastes are mainly coming from domestic and industrial sources. Garbage(from kitchen, slaughter house, canning and freezing industries), rubbish(leaves, grasses, plants, bottles, crockery and plastic materials), ashes, dead animals, sludge, sewage, industrial solid waste, agricultural waste, manure, crop residue, pesticides and insecticides are some of the examples of solid wastes. Solid waste may be biologically degradable or not.

b. Liquid waste: human beings have to depend on the tiny fresh water because the large percentage of oceanic water is saline in character. Amount of dissolved oxygen in fresh water keeps the life system of aquatic plants and animals. High concentration of BOD in water helps bacterial growth. It also changes the chemical characteristics of water. The important source of organic matter in water is sewage. It contains faecal matter urine and kitchen washing and soil washings. Sewage contains large number of bacteria. Excess concentration of nitrogen and phosphate from agricultural field causes eutrophication of stagnant water.

c. Gaseous waste: Most dangerous to people and animals are the carbon monoxides, SO_2, NO_2, O3 and smog gasses which are responsible for the formation of hydrocarbons. Hydrogen sulphide is another deadly gas when it occurs in large concentrations.

d. Waste without weight: Such kinds of wastes are also called the energy wastes. They include radioactive substances, heat and noise.

■ 4.2.1.5 Types of environmental degradation

Different kinds of pollution are found in different environmental systems. In this section we will discuss on-

■ 4.2.1.5.1 Air Pollution

Atmosphere is consisting of many gasses. Besides the gasses aerosols or solid and liquid particles are also present in the atmosphere which are also important in forming the structure of the atmosphere. The atmosphere is held to the planet by the force of gravity. A gravitational force also determines what gasses should be present. The earth's primitive atmosphere was much different from today. Four billion years ago it was consisted by ammonia, methane and trace amounts of carbon dioxide and water- vapor. There was little free oxygen present. Currently the atmosphere is understood to have consisted of nitrogen, carbon dioxide, carbon monoxide, water and hydrogen. Atmosphere is consisting of different gasses but the ratio of gasses of the atmosphere surrounding the earth surface more or less equal. In some cases it varies with place and time. Based on the composition and ratio of gasses it is mainly divided into two layers, *Homosphere* and *Heterosphere.* There are mainly five layers in the atmosphere. These are -

i. Troposphere
ii. Stratosphere
iii. Mesosphere or ozonosphere
iv. Thermosphere or ionosphere and
v. Exosphere or the outer layer

Troposphere is mainly composed of nitrogen (78%), oxygen (21%) and remaining 1% is composed of several other trace gases like argon, neon, helium, methane, krypton, xenon, hydrogen, nitrous oxide, carbon monoxide, ozone, ammonia, nitrogen oxide, sulfur oxide and radon.

Air pollution is the alteration of atmospheric quality by air pollutants from natural and man made sources. Air pollution is the accumulation in the atmosphere of substances that, in sufficient concentrations endanger human health or produce other measured effects on living matter and other materials. Among the major sources of pollution are power and heat generation, the burning of solid wastes, industrial processes, and especially transportation.

Types of air pollutants: The six major types of pollutants are carbon monoxide, hydrocarbons, nitrogen oxides, particulates, sulfur dioxide, and photochemical oxidants.

a. Primary air pollutants:

i. Carbon Dioxide

Carbon dioxide (CO_2) is one of the major pollutants in the atmosphere. Major sources of CO_2 are fossil fuel burning and deforestation. The concentrations of CO_2 in the air around 1860 before the effects of industrialization were felt, is assumed to have been about 290 parts per million (ppm). In the hundred years and more since then, the concentration has increased by about 30 to 35 ppm that is by 10 percent (Breuer). Industrial countries account for 65% of CO_2 emissions with the United States and Soviet Union responsible for 50%. Less developed countries (LDCs), with 80% of the world's people, are responsible

for 35% of CO_2 emissions but may contribute 50% by 2020. Carbon dioxide emissions are increasing by 4% a year (Miller).

The ocean waters contain about sixty times more CO_2 than the atmosphere. If the equilibrium is disturbed by externally increasing the concentration of CO_2 in the air, then the oceans would absorb more and more CO_2. If the oceans can no longer keep pace, then more CO_2 will remain into the atmosphere. As water warms, its ability to absorb CO_2 is reduced.

CO_2 is a good transmitter of sunlight, but partially restricts infrared radiation going back from the earth into space. This produces the so-called greenhouse effect that prevents a drastic cooling of the Earth during the night. Increasing the amount of CO_2 in the atmosphere reinforces this effect and is expected to result in a warming of the Earth's surface. Currently carbon dioxide is responsible for 57% of the global warming trend. Nitrogen oxides contribute most of the atmospheric contaminants.

ii. NO_X - nitric oxide (NO) and nitrogen dioxide (NO_2)

NO_X is a natural component of the Earth's atmosphere. It is important in the formation of both acid precipitation and photochemical smog (ozone), and causes nitrogen loading. It comes from the burning of biomass and fossil fuels. A major quantity of NO_X (30 to 50 million tons per year) is coming from human activities, and natural 10 to 20 million tons per year. It has a role in reducing stratospheric ozone.

iii. N_2O - nitrous oxide

It is also a natural component of the Earth's atmosphere. It is important in the greenhouse effect and causes nitrogen loading. Human inputs are one of the important sources (6 million tons per year), and natural source is also not negligible (19 million tons per year by nature). It can reside in the atmosphere for about 170 years. It comes from nitrogen based fertilizers, deforestation, and biomass burning.

iv. Sulfur and chlorofluorocarbons (CFCs)

Sulfur dioxide is produced by combustion of sulfur-containing fuels, such as coal and fossil fuels. It may also be generated during the process of producing sulfuric acid and in metallurgical process involving ores that contain sulfur. Sulfur oxides can injure man, plants and materials. At sufficiently high concentrations, sulfur dioxide irritates the upper respiratory tract of human beings because potential effect of sulfur dioxide is to make breathing more difficult by causing the finer air tubes of the lung to constrict. Power plants and factories emit 90% to 95% of the sulfur dioxide and 57% of the nitrogen oxides in the United States. Almost 60% of the SO_2 emissions are released by tall smoke stakes, enabling the emissions to travel long distances (Miller). As emissions of sulfur dioxide and nitric oxide from stationary sources are transported long distances by winds, they form secondary pollutants such as nitrogen dioxide, nitric acid vapor, and droplets containing solutions of sulfuric acid, sulfate, and nitrate salts. These chemicals descend to the earth's surface in wet form as rain or snow and in dry form as a gases fog, dew, or solid particles. This is known as acid deposition or acid rain.

v. Chlorofluorocarbons (CFCs)

CFCs are lowering the average concentration of ozone in the stratosphere. Since 1978 the use of CFCs in aerosol cans has been banned in the United States, Canada, and most Scandinavian countries. Aerosols are still the largest use, accounting for 25% of global CFC use (Miller) Spray cans, discarded or leaking refrigeration and air conditioning equipment, and the burning plastic foam products release the CFCs into the atmosphere. Depending on the type, CFCs stay in the atmosphere from 22 to 111 years. Chlorofluorocarbons move up to the stratosphere gradually over several decades. Under high energy ultra violet (UV) radiation, they break down and release chlorine atoms, which speed up the breakdown of ozone (O_3) into oxygen gas (O_2).

Chlorofluorocarbons, also known as Freon, are greenhouse gases that contribute to global warming. Photochemical air pollution is commonly referred to as "smog". Smog, a contraction of the words smoke and fog, has been caused throughout recorded history by water condensing on smoke particles, usually from burning coal. With the introduction of petroleum to replace coal economies in countries, photochemical smog has become predominant in many cities, which are located in sunny, warm, and dry climates with many motor vehicles. The worst episodes of photochemical smog tend to occur in summer.

vi. Particulates: particulate matters constitute about 5% of the weight of air pollutants. The size of the particulate matter ranges from 0.005 to 100 μm.in diameter. The term particulate is implied to a single type of entity. Particulate matter includes sulphate salts, sulphuric acid droplets, particles of lead, iron, carbon or silica, liquid spray and mists. Soil particles and dusts during land clearing and construction of buildings and highways also give rise to particulate matters. Grinding, emission of shoots and ash from power plants may also produce particulate matters.

b.Secondary sources of air pollution:

vii. Smog

Photochemical smog is also appearing in regions of the tropics and subtropics where savanna grasses are periodically burned. Smog's unpleasant properties result from the irradiation by sunlight of hydrocarbons caused primarily by unburned gasoline emitted by automobiles and other combustion sources. The products of photochemical reactions include organic particles, ozone, aldehydes, ketones, peroxyacetyl nitrate, organic acids, and other oxidants. Ozone is a gas created by nitrogen dioxide or nitric oxide when exposed to sunlight. Ozone causes eye irritation, impaired lung function, and damage to trees and crops. Another form of smog is called industrial smog.

This smog is created by burning coal and heavy oil that contain sulfur impurities in power plants, industrial plants, etc... The smog consists mostly of a mixture of sulfur dioxide and fog. Suspended droplets of sulfuric acid are formed from some of the sulfur dioxide, and a variety of suspended solid particles. This smog is common during the winter in cities such as London, Chicago, Pittsburgh. When

these cities burned large amounts of coal and heavy oil without control of the output, large-scale problems were witnessed. In 1952 London, England, 4,000 people died as a result of this form of fog. Today coal and heavy oil are burned only in large boilers and with reasonably good control or tall smokestacks so that industrial smog is less of a problem. However, some countries such as China, Poland, Czechoslovakia, and some other eastern European countries, still burn large quantities of coal without using adequate controls.

viii. Acid deposition: Acid deposition is a serious problem of temperate countries like, North America, Canada, Central Europe and Russia. With increasing industrial activity it becomes a problem to the developing countries like India. Acid deposition in two forms Dry and Wet fall out from the atmosphere and causing pollution.

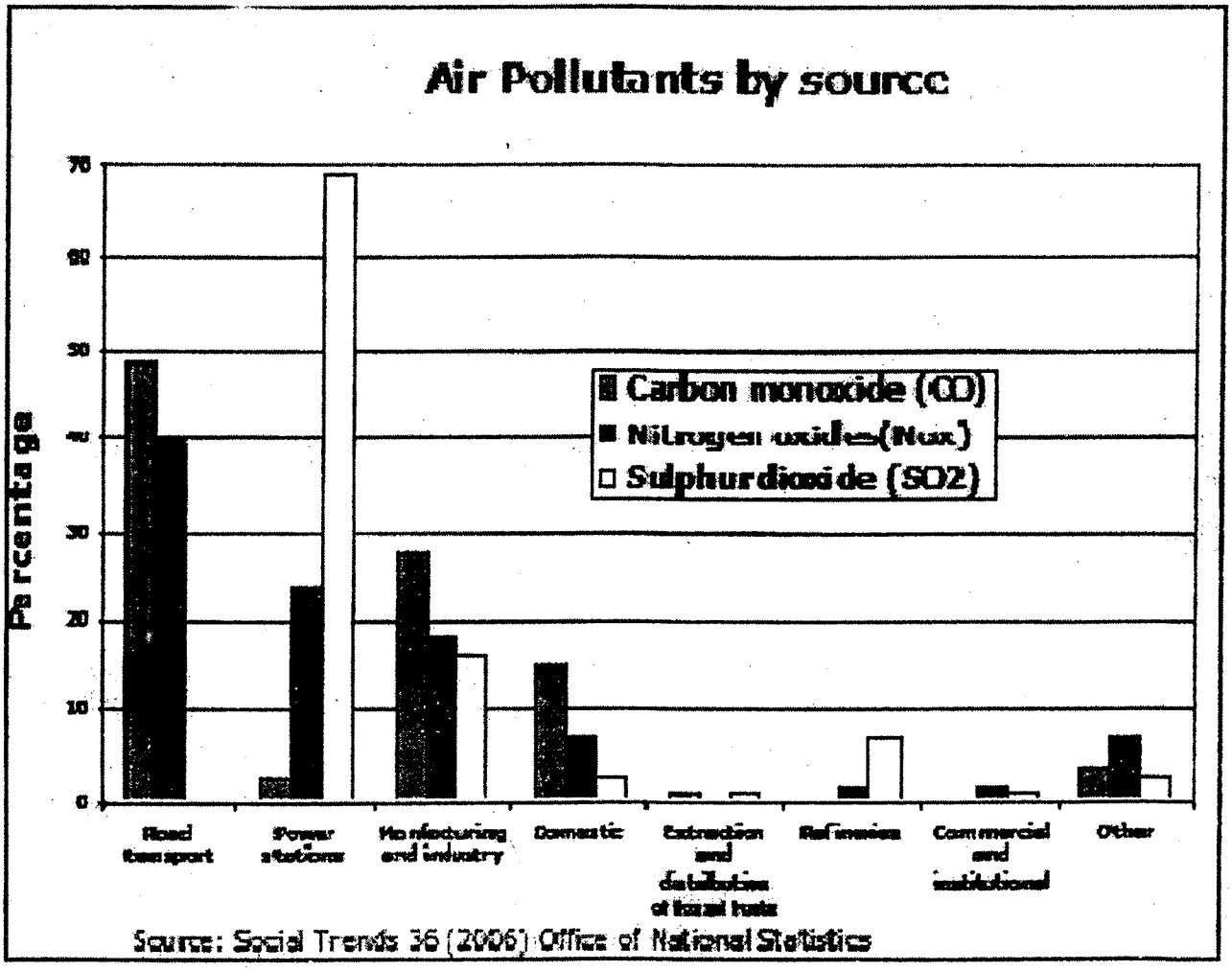


Fig. - 2

Sources/ causes of air pollution: The emission of sulfur dioxide from volcanoes, O_3 from lightning, and particulates and CO_2 naturally occurring fires etc. are natural sources of air pollution. The two main sources of air pollution are found. These are **stationary** sources and the **mobile** sources of pollutants. In

urban areas the transportation (predominantly automobiles) sector of mobile sector and fuel combustion in stationary sources, including residential, commercial, and industrial heating and cooling and coal-burning power plants are the main sources of air pollution. Motor vehicles produce high levels of carbon monoxides and a major source of hydrocarbons (HC) and nitrogen oxides (NOx). On the other hand fuel combustion in stationary sources is the dominant source of sulfur dioxide (SO_2).

Examples of Air Pollution

a. NoisePollution: Noise pollution or unwanted sounds that are carried by the air have an irritating and detrimental effect on human and other animals. Careful planning of streets and buildings in towns and better control over noisy vehicles can control the problem of noise pollution.

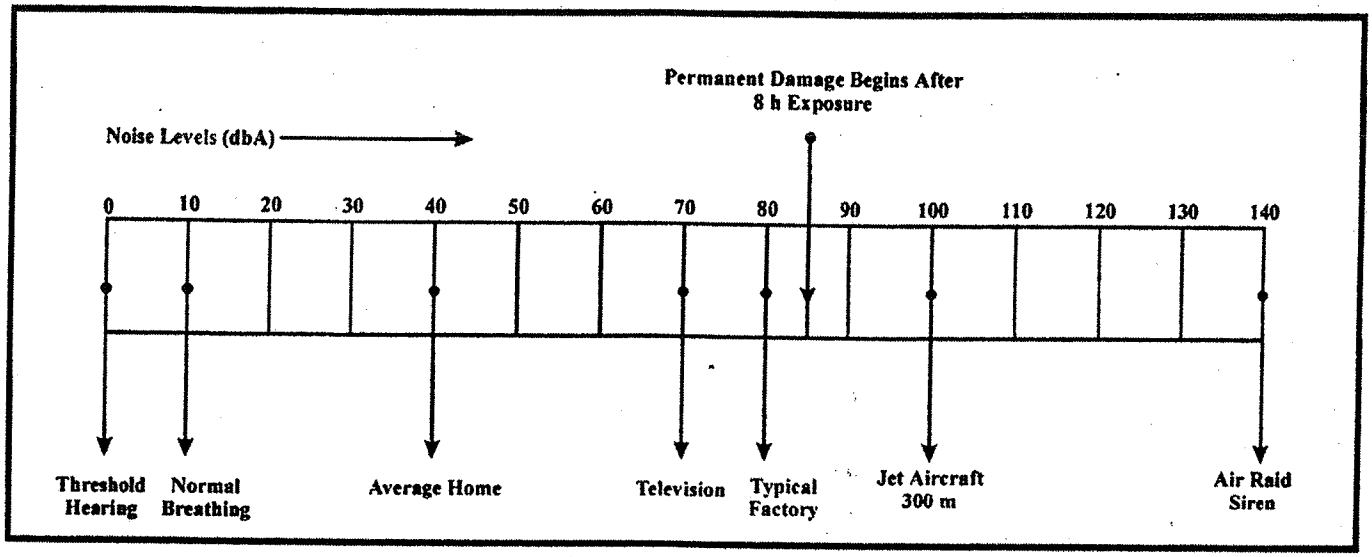


Fig.3 Noise level of some common sounds(based on Miller Jr,1988).

b.TobaccoSmoke: Tobacco smoke is one of the major forms of pollution in buildings. It is not only the smoker who is infected, but everyone who inhales are passively affected by the polluted air. There is a very strong connection between smoking and lung cancer. Bronchitis is common among smokers and unborn babies of mothers who smoke also suffer from the harmful effects of smoking.

c. Exhaust Gases of Vehicles: Pollution from exhaust gases of vehicles is responsible for 60% of all air pollution and in cities up to 80%. There is a large variety of harmful chemicals present in these gases, with lead being one of the most dangerous pollutants.

d. Combustion of Coal: The combustion of coal without special precautions can have serious consequences. If winds do not blow away the poisonous gases, they can have fatal effects and may lead to death.

e. Acid rain: Acid rain is the term for pollution caused when sulfur and nitrogen dioxides combine with atmospheric moisture to produce highly acidic rain, snow, hail, or fog. The acid eats into the stone, brick

and metal articles and pollutes water sources. There are six basic steps that are involved in the formation of acid rain.

i. The atmosphere receives oxides of Sulfur and nitrogen from man made sources.

ii. Some of this oxides fall back directly to the ground as dry deposition, either in the place of origin or in distant places.

iii. Sunlight stimulates the formation of photo oxidants (such as Ozone) in the atmosphere.

iv. These photo oxidants are interacting with the oxides of nitrogen and sulfur to produce H_2SO_4 and HNO_3 by oxidation.

v dissolve of these oxides with the droplets of clouds and rain to produce acidic cations (H^+ and NH_4^+), Sulphates (SO_4^{2-}) and nitrates(NO_3^-)

vi. Acid rain contains ions of Sulphate, nitrate, ammonium and hydrogen falls as wet deposition.

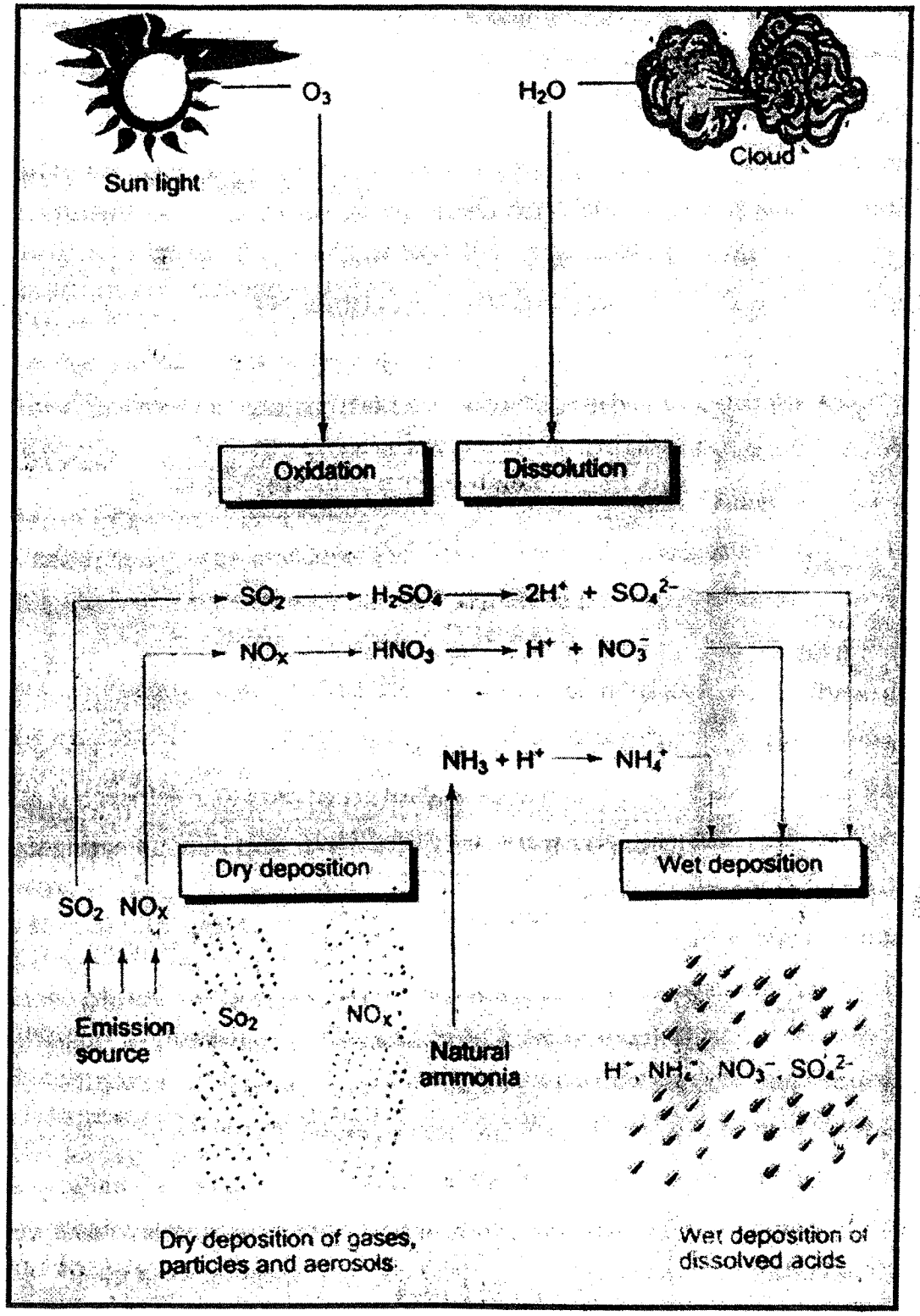


Fig. 4 -Chemistry of acid rain

● **Impact of air pollution:** Deterioration of environmental quality is causing different types of negative

impact on the physical environment. These negative consequences on environment further affected flora and fauna community.

● **Impact of air pollution on health:** Air pollution can affect our health in many ways with both *short-term* and *long-term* effects. Different groups of individuals are affected by air pollution in different ways. Some individuals are much more sensitive to pollutants than are others. Young children and elderly people often suffer more from the effects of air pollution. People with health problems such as asthma, heart and lung disease may also suffer more when the air is polluted. The extent to which an individual is harmed by air pollution usually depends on the **total exposure** to the damaging chemicals, i.e., the *duration of exposure* and the *concentration of the chemicals* must be taken into account.

▲ **Short-term effects** include irritation to the eyes, nose and throat, and upper respiratory infections such as bronchitis and pneumonia. Other symptoms can include headaches, nausea, and allergic reactions. Short-term air pollution can aggravate the medical conditions of individuals with asthma and emphysema. In the great "Smog Disaster" in London in 1952, four thousand people died in a few days due to the high concentration of pollution.

▲ **Long-term health effects** can include chronic respiratory disease, lung cancer, heart disease, and even damage to the brain, nerves, liver, or kidneys. Continual exposure to air pollution affects the lungs of growing children and may aggravate or complicate medical conditions in the elderly. It is estimated that half a million people die prematurely every year in the United States as a result of smoking cigarettes.

● **Pollution Damage to Plants**

With the destruction and burning of the rain forests more and more CO2 is being released into the atmosphere. Trees play an important role in producing oxygen from carbon dioxide. "A 115 year old Beech tree exposes about 200,000 leaves with a total surface to 1200 square meters. During the course of one sunny day such a tree inhales 9,400 liters of carbon dioxide to produce 12 kilograms of carbohydrate, thus liberating 9,400 liters of oxygen. Through this mechanism about 45,000 liters of air are regenerated which is sufficient for the respiration of 2 to 3 people" (Breuer 1). This process is called photosynthesis which all plants go though but some yield more and some less oxygen. As long as no more wood is burnt than is reproduced by the forests, no change in atmospheric CO2 concentration will result.

Pollutants such as sulfur dioxide, nitrogen oxides, ozone and peroxyacl nitrates (PANs), caused direct damage to leaves of crop plants and trees when they enter leaf pores (stomata). Chronic exposure of leaves and needles to air pollutants can also break down the waxy coating that helps prevent excessive

water loss and damage from diseases, pests, drought and frost. "In the Midwestern United States crop losses of wheat, corn, soybeans, and peanuts from damage by ozone and acid deposition amount to about $5 billion a year" (Miller 498).

▲ **Control Measures:** Although individual people can help to combat air pollution in their own immediate environment, efficient control can be best achieved by legislation. Some commonly enforced control measures include the establishment of more smokeless zones; control over the kinds of fuel used in cars, airplanes, power stations, etc. Alternative techniques to reduce air pollution should be adopted. Changing lifestyle by adaptation of low pollutant producing goods should be emphasized. Air pollution may also be reduced by removal of pollutant generating stuff from energy sources. For example removal of sulfur from coal before burning can prevent air pollution. Road side plantation and plantation around the pollutant emitting industries can control air pollution. Vehicular pollution can be controlled by both improvement of fuel and engine quality. Above all implementation of legislation by National Ambient Air Quality Standards (NAAQs), Central Air Pollution Control Board (CPCB) and ministry of Environment and Forests (MoEF) under the Environmental Protection Act., have empowered the Government to combat with the problem of air pollution.

■ 4.2.1.5.2 Water Pollution:

Introduction

Fresh water, an essential element for all forms of life, is a critical resource for the life world. Per capita availability of renewable water resources is the lowest in the region for China, India and Pakistan. Annual water resources per capita in the Pacific are the highest in the world. The sources of fresh water, including river basins, groundwater reserves, lakes, and man-made reservoirs, are increasingly under pressure to meet the heightening demand for agriculture, industry and domestic consumption. There is a general trend of water scarcity, deteriorating quality and sectoral conflicts in water allocation in the region. The Indian continent of South Asia and countries of East Asia had the highest level of water withdrawals for agriculture accounting for 92 and 77per cent of total consumption respectively. Several areas in the region, including northern China and the Aral Sea Basin in Central Asia, are water-scarce and already experiencing an acute shortage of fresh water. Some island countries in the Pacific and the Indian Ocean also experience critical water shortages. In many areas of the region, the misuse of water reserves has already resulted in depleted aquifers, falling water tables, and shrinking of inland lakes and stream flows to ecologically unsafe levels. The development of multipurpose dams for irrigation and hydroelectric

power generation and flood control have also created environmental problems which include the involuntary resettlement of displaced people, inundation of valuable lands, spread of waterborne diseases and land subsidence. Salinization and water logging leading to the degradation of agricultural land and depletion of flora and fauna and fishery reserves have also been observed. The quality of the water is becoming degraded because of domestic sewage effluents in water bodies, industrial effluents and non-point sources of pollution through agricultural run-off. The eutrophication problem is more serious in Asia and the Pacific as compared to Europe and America. Organic matters, pathogens, heavy metals, toxic chemicals, silt and salt and radioactive contamination pollute many rivers, particularly in South Asia and South-East Asia. The pollution of fresh water has compounded the problems of the existing water stress in the region. In many towns and cities, there is considerable a stage of water, up to 40 to 60 per cent of all the water supplied by the water company.

Defining water pollution

The quality of water from different sources varies widely. Precipitation absorbs gases from the atmosphere and removed particles from the air. When the precipitation strikes the ground it becomes surface water runoff or enters in to the ground. The surface water flows into larger and larger channels, ponds, lakes and rivers until some of it reaches the sea. Along its course, surface water picks up both organic and mineral particles, bacteria and other organisms as well as salts and other soluble substances. The water in lakes and swamps sometimes acquires odors, tastes and colors from algae and other organisms and from decaying vegetation.

Since ancient times, heavy metals from mining and pathogens from cities have caused serious, although localized, contamination. Since the industrial revolution, water pollution problems have become first regional, then continental and now global in nature. Much water is polluted when it is used in industry and agriculture or for domestic purposes. Mining is the major cause of metal contamination, whereas other industries contribute to acidification. The intensification of agricultural activities has led to the contamination of groundwater by fertilizers and other chemicals. Moreover, irrigation projects often cause a rapid rise in the level of groundwater, which leads to water logging and soil salinity.

Present status of water resource

In recent years, water issues have been the focus of increasing international concern and debate. From 26 to 31 January 1992, the UN system sponsored the International Conference on Water and the Environment (ICWE) in Dublin, Ireland. The ICWE called for innovative approaches to the assessment, development and management of freshwater resources. In addition, the ICWE provided policy guidance

for the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro in June 1992. UNCED highlighted the need for water sector reforms throughout the world.

In 1993, the World Bank issued a comprehensive policy paper defining its new objectives for the water sector. FAO recently established an International Action Program on Water and Sustainable Agricultural Development (IAP-WASAD). Likewise, the UNDP, WHO, UNICEF, WMO, Unesco and UNEP are all coordinating or participating in special programmes related to water resources.

Other international, national and local organizations are becoming more active in water issues. The 1990 Montreal meeting, "NGOs Working Together", focused attention on drinking-water supply and sanitation. The Canadian International Development Agency, the French Ministry of Cooperation and Development, the German Agency for Technical Cooperation (GTZ), the United Kingdom's Overseas Development Administration and the United States Agency for International Development (USAID) have recently developed water resource strategies for foreign assistance.

The message highlighted by all these efforts is that water is an increasingly scarce and valuable resource. Of principal concern is our failure to recognize and accept that there is a finite supply of water. The consensus is that the growing water scarcity and misuse of freshwater pose serious threats to sustainable development.

Importance of water/Uses

In today's world, agriculture still accounts for the majority of human water use. Globally, around 70 percent of water withdrawals are for agriculture. Domestic and industrial uses consume the remaining 30 percent. Domestic uses include drinking-water supplies, private homes, commercial establishments, public services and municipal supplies. Water uses differ greatly depending on access, quantity, quality and socio-economic conditions.

■ 4.4.2.4 Water pollutants

Depending on the source of origin of the pollutants they are classified categorically into

i. **Organic matter who consumes oxygen in the process of decomposition within water or Biological Oxygen Demand (BOD)**: BOD is expressed in usually mg. of dissolved oxygen content per liter of water at a particular temperature. It is one of the indicator of quality of water and the kind of life it can support. Water with 8mg/l oxygen content supports both fish and other aquatic lifebut with 2mg/l O can only supports worms, bacteria and other decomposers. Excessive accumulation of organic matter in the water increases oxygen demand and the decomposers also require oxygen as an energy source. thus excessive oxygen demand of the organisms and decomposers decreases the dissolved the oxygen content

of water.

ii. **Biological agents, causing water borne diseases like *Vibrio Cholerae* responsible for Cholera:** Different types of bacteria, viruses, protozoa, parasitic worms and other infection agents are coming into the water body with domestic wastes, sewerages, municipal waste waters and wastes from slaughter house which contaminated water and humans and animals when they are coming into contact to such contaminated water are directly or indirectly affected .

iii. **Nutrient enrichment responsible for eutrophication in water**: Eutrophication is the enrichment of waters with nutrients, especially phosphorus and nitrogen. It can lead to enhance plant's growth and depleted oxygen levels as these plant material decays. It is not always a human-induced problem, but is often linked to organic waste and agricultural runoff. Today 30 to 40 percent of the world's lakes and reservoirs are eutrophic. Toxic chemicals released from industries, insecticides, oil and petroleum products and plastic industries etc.

iv. **Heat released during cooling purposes in industries and suspended particles from the industries change the quality of water:** A maximum portion of water used in industrial sector is for cooling purposes. For this reason most of the industries are developed on the vicinity of water sources. As water absorbs the heat emitted from different industrial processes it increased the temperature of water which further effects on the physical quality of water and aquatic life forms.

v. **Radioactive wastes from power plants and radioactive mines also polluted water:** water from nuclear power plants, nuclear power testing centers, radioactive mining centers, waste from research laboratory and hospitals are some of the sources from where water is contaminated.

vi. **Different types of salts e.g. calcium salt changes the water quality:** Salinity is a significant and widespread form of freshwater pollution, particularly in arid, semi-arid and some coastal regions. The primary cause of salinization is a combination of poor drainage and high evaporation rates which concentrate salts on irrigated land. Salinity can adversely affect the productivity of irrigated crops and is also detrimental to industrial and household water users. It is not a new phenomenon; salinization of soil and water in the flood plain of the Tigris and Euphrates Rivers contributed to the decline of the Mesopotamian civilization some 6 000 years ago. The estimated global gross area of irrigated land is 270 million ha. About 20 to 30 million ha are severely affected by salinity while an additional 60 to 80 million ha are affected to some degree. Waterlogged soil, which aggravates the problem of salinity, is usually caused by overwatering and a lack of proper drainage systems. Runoff from agricultural areas fertilized with manure and chemicals pollutes watercourses and groundwater by increasing levels of nutrients

vii. **Toxic chemicals:** Toxic chemicals like arsenic, cadmium, chromate, lead, mercury, selenium, cyanide, Cromium, zinc, copper and nickel from varied sources become dangerous when they interfere with the action of engymes and other biochemicals and affects both aquatic life forms and human beings.

Causes behind water pollution

a. Deforestation: The clearing of land for agriculture and urban development, often leads to water contamination. When the soil is stripped of its protective vegetative covering, it becomes prone to erosion. This in turn leads to higher water turbidity, because of the increased amounts of suspended matter, to nutrient leaching and to a decreased water-retention capacity of the soil. There is also concern about the destruction of wetlands, which destroys the habitat of many species and removes natural filter mechanisms, permitting many common pollutants to reach water supplies.

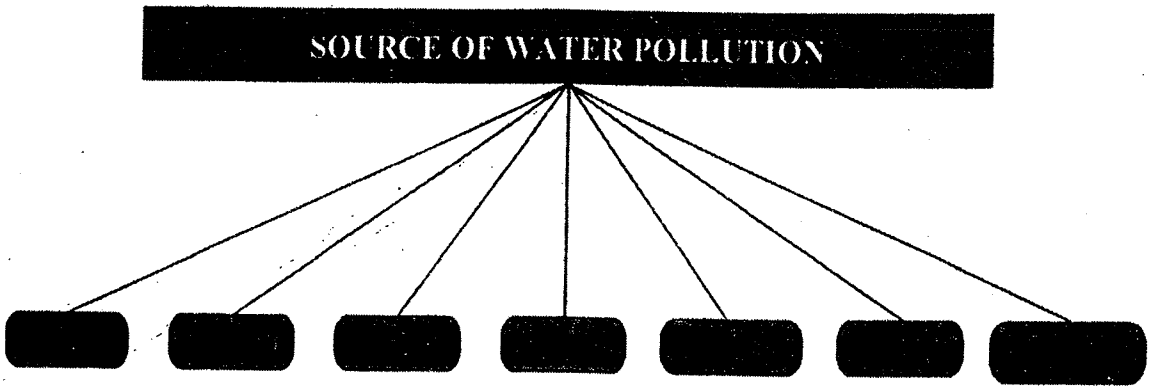


Fig. 5 Sources of water pollution

b. Industrial affluent: Water discharged from industries after having been used in production processes. This waste water may contain acids, alkalis, salts, poisons, oils and in some cases harmful bacteria.

c.Mining and Agricultural Wastes: Mines, especially gold and coal mines are responsible for large quantities of acid water. Agricultural pesticides, fertilizers and herbicides may wash into rivers and stagnant water bodies.

d. Municipal Sewage Disposal and Domestic Wastes: Municipal Sewage as well as domestic and farm wastes were often allowed to pollute rivers and dams.

e. Groundwater: Groundwater is polluted from surface sources and irreversibly damaged by the intrusion of salt water. Overexploited aquifers are losing their capacity to hold water and lands are subsiding. Cities are unable to provide adequate drinking-water and sanitation facilities.

f. Water logging and salinization: They are diminishing the productivity of irrigated lands. Decreasing water flows are reducing hydroelectric power generation, pollution assimilation and fish and other aquatic

life forms.

g. Oil production, oil spill and transport use: Nearly 6.1 million tons of oil enters into the ocean annually from various sources. Accidents during transportation created the problem of oil spill. It drastically affects the ecological balance of the ocean water. Besides these sources natural seepage, war, atmospheric fall out, off shore petroleum production also polluted water in various manners.

Impact of water pollution on Health

Two of the most troubling domestic water supply issues for policy-makers are access and health. Nearly one billion people in the world are without clean drinking-water. Providing easier access to safe drinking-water significantly improves health conditions. Personal hygiene increases when water availability rises above 50 liters per day (which generally means that it must be delivered to the house or yard). An estimated 1.7 billion persons contend with inadequate sanitation facilities. The lack of sewage collection and treatment is a major source of surface and groundwater pollution.

Health officials identify five categories of disease related to water: *i)* water-borne diseases (typhoid, cholera, dysentery, gastroenteritis and infectious hepatitis); *ii)* water-washed infections of the skin and eyes (trachoma, scabies, yaws, leprosy, conjunctivitis and ulcers); *iii)* water-based diseases (schistosomiasis and guinea-worm); *iv)* diseases from water-related insect vectors such as mosquitoes and black flies; and *v)* infections caused by defective sanitation (hookworm).

Potential Waterborne Disease Causing Organisms and their source

Organism	Major disease	Primary source
	Bacteria	
Salmonella typhi	Typhoid fever	Human feces
Salmonella paratyphi	Paratyphoid fever	Human feces
Other *Salmonella* sp.	Gastroenteritis (salmonellosis)	Human/animal feces
Shigella	Bacillary dysentery	Human feces
Vibrio cholerae	Cholera	Human feces, coastal water
Pathogenic *Escherichia coli*	Gastroenteritis	Human/animal feces
Yersinia enterocolitica	Gastroenteritis	Human/animal feces
Campylobacter jejuni	Gastroenteritis	Human/animal feces
Legionella pneumophila	Legionnaires' disease, Pontiac fever	Warm water
Mycobacterium avium intracellulare	Pulmonary disease	Human/animal feces, soil, water
Pseudomonas aeruginosa	Dermatitis	Natural waters
Aeromonas hydrophila	Gastroenteritis	Natural waters
Helicobacter pylori	Peptic ulcers	Saliva, human feces?

Enteric viruses		
Poliovirus	Poliomyelitis	Human feces
Coxsackievirus	Upper respiratory disease	Human feces
Echovirus	Upper respiratory disease	Human feces
Rotavirus	Gastroenteritis	Human feces
Norwalk virus and other caliciviruses	Gastroenteritis	Human feces
Hepatitis A virus	Infectious hepatitis	Human feces
Hepatitis E virus	Hepatitis	Human feces
Astrovirus	Gastroenteritis	Human feces
Enteric adenoviruses	Gastroenteritis	Human feces
Protozoa and other organisms		
Giardia lamblia	Giardiasis (gastroenteritis)	Human and animal feces
Cryptosporidium parv	Cryptosporidiosis (gastroenteritis)	Human and animal feces
Entamoeba histolytica	Amoebic dysentery	Human feces
Cyclospora cayetanensis	Gastroenteritis	Human feces
Microspora	Gastroenteritis	Human feces
Acanthamoeba	Eye infection	Soil and water
Toxoplasma gondii	Flu-like symptoms	Cats
Naegleria fowleri	Primary amoebic meningoencephalitis	Soil and water
Blue-green algae	Gastroenteritis, liver damage, nervous system damage	Natural waters
Fungi	Respiratory allergies	Air, water?

Fig. - 6

The World Bank's *World Development Report 1992* estimates that providing access to safe water and adequate sanitation could result in two million fewer deaths from diarrhea among young children and 200 million fewer episodes of diarrhoea illnesses each year.

Water conflict: Now a day, it becomes a strategic resource and centering water many political conflicts are increasing. UNESCO's World Water Development Report(WWDR,2003)from its World Water Assessment Program indicates that , in the next 20 years , the quantity of water available to everyone is predicted to decrease by 30%.At present some of the countries have insufficient water supply. All over the world there are millions of examples about water conflict. Control of Jordan River by Israel creates conflict between Jordon and Israel. Conflict between Iraq and Syria about Ataturk dam is another example. The Nile is shared by nine countries. Creation of 3 Gorges dam on Yangtze River creates social and environmental problem. Dispute between India and Bangladesh about river Ganges is another political issue. Though these two countries sign an agreement but till issues going on for the quality of water. Another inter state conflict is between Karnataka and Tamilnadu about Kaveri water. Conflict for water among four countries of South America (Argentine, Brazil, Bolivia and Paraguay) is seen for the Guarani aquifer.

Water, even when plentiful, is frequently drawn into the realm of politics. Domestic laws and well-

established customs can help resolve water-related disputes at national and village levels but international law has not developed fast enough to deal with the growing number of water-related conflicts between many countries and regions. At present implementation of

Control Measures: The following measures can be used to stop water pollution-every intelligent people should be wise enough not to pollute water in any way; by research and legislation the pollution of water bodies, even though not entirely prevented, must be effectively controlled. Since 1977, the UNEP/ WHO Global Environment Monitoring System (GEMS) has been working with UNESCO and WMO to develop a global water quality monitoring network. More than 50 water variables are monitored to provide information on the suitability of water for human consumption and for agricultural, commercial and industrial use. Recent assessments have found that the main water pollutants are: sewage, nutrients, toxic metals and industrial as well as agricultural chemicals.

The International Conference on Water and the Environment (ICWE) was held in Dublin, Ireland, from 26 to 31 January 1992. The conference provided the major input on freshwater problems for UNCED, convened in Rio de Janeiro, Brazil, June 1992. The ICWE was attended by 500 participants from 114 countries, 38 NGOs, 14 intergovernmental organizations and 28 UN bodies and agencies.

The major work of the ICWE was undertaken by six working groups which addressed:

- Integrated water resources development and management;
- Water resources assessment and impacts of climate change on water resources;
- Protection of water resources, water quality and aquatic ecosystems;
- Water and sustainable urban development and drinking-water supply and sanitation;
- Water for sustainable food production and rural development and drinking-water supply and sanitation;
- Mechanisms for implementation and coordination at global, national, regional and local levels.

■ 4.2.1.5.3 Land Pollution

Land pollution is the addition of undesirable matter to the land that damage the terrestrial organisms, reduce the uses of the land .Land pollution is the degradation of the Earth's land surface through misuse of the soil by poor agricultural practices, mineral exploitation, industrial waste dumping, and indiscriminate disposal of urban wastes. It includes visible waste and litter as well as pollution of the soil itself.

Mechanism of land pollution:

Land pollution involves the following mechanism:

- Deposition of solid waste

- Accumulation of non-biodegradable materials
- Toxification of chemicals into poisons
- Alteration of soil chemical composition (imbalance of chemical equilibrium to soil medium)

By as much, land pollution of this has a mass globally, everyday threatening the very foundation and mechanical support of every matter on earth. Statistically, it has been shown that:

- loss of 6 million hectares of land per year
- loss of 24 billion tons of topsoil per year
- loss of minimum 15 million acres prime agricultural land to overuse and mismanagement
- desertification of land results in the lost of 16 million per square miles of world's land surface

Causes of land pollution: there are mainly two forms of malpractices that cause land pollution. These are -

a.Unhealthy soil management methods;

- improper tillage of soil in which excessive tillage result in the deterioration of soil structure
- non-maintenance of a proper supply of organic matter in the soil from the balance composition of the reserves of organic matter especially nitrogen, phosphorus and sulfur supply after cultivation of vegetation, living the soil prone to oil infertility, unable to stabilize the soil physicality which ultimately let to desertification
- irregular maintenance of a proper nutrient supply of trace elements gives rise to the use of excessive synthetic fertilizers, which are non biodegradable and accumulate in the soil system which eventually destroys useful organisms such as bacteria, fungi and other organisms
- Improper maintenance of the correct soil acidity which ultimately disrupted the adaptation of various crops and native vegetation of different soils as the solubility of minerals present will be affected. In a more acidic soil, minerals tend to be more soluble and washed away during rainfall while alkaline soil, minerals are more insoluble which form complex minerals unable to be absorbed into the flora system physiological usage.

b. Improper irrigation practices;

- poorly drained soil result in salt deposits leading to high soil salinity that inhibit plant growth and may lead to crop failure
- non irrigated land giving rise to stagnation of agriculture waste products which accumulates and increases land toxicity and also decreasing
- irregular irrigation leads to decreasing moisture of land for soil medium and replenishment of

solvents for minerals

Sources of land pollution

We can classify major sources that lead to land pollution to the following categories:

- agriculture
- mining and quarrying
- sewage sludge
- dredged spoils
- household
- demolitions and constructions industrial constructions.

Sources of Land Pollution through different methods

Sources	Methods
Agriculture	accumulation of animal manures excessive input of chemical fertilizer sillicit dumping of tainted crops on land
Mining and Quarrying	using of explosives to blow up mines using of machineries which emits toxic byproducts and leaks to the ground
Sewage sludge	improper sanitation system causes sludge to leak at surrounding soil
Dredged spoils	improper method of dredging at fertile land causes soil infertility, leaving the soil more prone to external pollution
Household	improper waste disposal system causes waste accumulation improper sanitation system

Demolition and construction	non biodegradable rubbles or debris which are not cleared settled in the soil undergo chemical reactions and increase soil toxicity
Industrial	poisonous/toxic emissions of gases which are not filtered or neutralized

Fig. - 7

Examples of Land Pollution

i. Soil Pollution and erosion: Soil Erosion is a major and serious aspect of man's role in changing his own environment. Although there are many techniques available for attempting to reduce the intensity of the problem, it still appears to remains intractable. Soil pollution is mainly due to chemicals in herbicides (weed killers) and pesticides (poisons which kill insects and other invertebrate pests). Litter is waste material dumped in public places such as streets, parks, picnic areas, at bus stops and near shops. Construction, urbanization, war, mining and other such activities are often significant in accelerating the erosion of the soil, but the prime cases are agriculture and deforestation. It is estimated that soil erosion on agricultural land operates at a rate of about 30t ha-1 per year, which is approximately eight times quicker than topsoil is formed

Forest protect the underlying soil from the direct effects of rainfall, runoff is generally reduced. Tree roots bind the soil, and the litter layer protects the ground from rain splash. It is thus to be anticipated that with the removal of forest for agriculture or for other reasons rates of soil loss will increase and the mass movements will increase in magnitude and frequency. The rates of erosion that results will be particularly high if the ground is left bare, though under crops the increase will be less marked. Furthermore, the method of ploughing, the time of planting, the nature of the crop, and the size of fields will all have an influence on the severity of erosion. In some cases the erosion produced by forest removal will be in the form of widespread surface stripping. In other cases the erosion will occur as more spectacular forms of mass movement, such as highest rates of erosion are produced in the construction phase when there is much bare ground and much disturbance produced by vehicle movements and excavations Because of the adverse effects of accelerated erosion a whole array of techniques has now been widely adopted to conserve soil

ii. Deforestation and Erosion

After the removal of vegetation of a rain forest, an area rarely recovers. This deforested area is eroding away because there is no longer a good root system to anchor the topsoil or decaying plant matter to replenish its nutrients. If the cycle continues, the area may eventually resemble a desert.

iii. Waste Disposal: Disposal of normally solid or semisolid materials, resulting from human and animal activities. The accumulation of waste threatens the health of people in residential areas. Waste decays, encourages household pests and turns urban areas into unsightly, dirty and unhealthy places to live in. Solid wastes are useless, unwanted, or hazardous. Solid wastes typically may be classified as follows:

a. Garbage: decomposable wastes from food

b. Rubbish: non-decomposable wastes, either combustible (such as paper, wood, and cloth) or noncombustible (such as metal, glass, and ceramics)

c. Ashes: residues of the combustion of solid fuels

d. Large wastes: demolition and construction debris and trees,Dead animals

e. Sewage-treatment solids: mat. .l retained on sewage-treatment screens, settled solids, and biomass sludge

f. Industrial wastes: such materials as chemicals, paints, and sand

g. Mining wastes: slag heaps and coal refuses piles

h. Agricultural wastes: farm animal manure and crop residues.

Disposal of solid wastes through different methods and different times can cause land and soil pollution like

i) Landfill

Sanitary landfill is the cheapest satisfactory means of disposal, but only if suitable land is within economic range of the source of the wastes; typically, collection and transportation account for 75 percent of the total cost of solid waste management. In a modern landfill, refuse is spread in thin layers, each of which is compacted by a bulldozer before the next is spread. About 3 m (about 10 ft) of refuse has been laid down; a thin layer of clean earth, which also is compacted, covers it.

Pollution of surface and groundwater is minimized by lining and contouring the fill, compacting and planting the cover, selecting proper soil, diverting upland drainage, and placing wastes in sites not subject to flooding or high groundwater levels. An average city dweller may produce a ton of refuse in a year, a volume that rapidly overflows local dumps. Cities running out of space for landfill often turn to incinerating their waste or transporting it to other areas, although up 90 percent of the material might have been recycled.

Gases are generated in landfills through anaerobic decomposition of organic solid waste. If a significant amount of methane is present, it may be explosive; proper venting eliminates this problem.

ii) Incinerators

In incinerators of conventional design, refuse is burned on moving grates in refractory-lined chambers; combustible gases and the solids they carry are burned in secondary chambers. Combustion is 85 to 90 percent complete for the combustible materials. In addition to heat, the products of incineration include the normal primary products of combustion is carbon dioxide and water as well as oxides of sulfur and nitrogen and other gaseous pollutants; nongaseous products are fly ash and unburned solid residue. Emission of fly ash and other particles are often controlled by wet scrubbers, electrostatic precipitators, and bag filters.

iii) Composting

Composting operations of solid wastes include preparing refuse and degrading organic matter by aerobic microorganisms. Refuse is presorted, to remove materials that might have salvage value or cannot be composted, and is ground up to improve the efficiency of the decomposition process. The refuse is placed in long piles on the ground or deposited in mechanical systems, where it is degraded biologically to humus with a total nitrogen, phosphorus, and potassium content of 1 to 3 percent, depending on the material being composted. After about three weeks, the product is

Effects of land pollution

The effects of land pollution are far ranging in the industrial age. The nature of the industrial revolution and the lack of a sustainable development for industrial progress have allowed the creation reckless input of chemicals and products which may serve as toxic to life forms.

The effects of pollution on the land are not limited to the terrestrial ecosystem, because the synthetic chemicals are not degraded by the normal processes of life. From there, the pollution can travel through the roots of plants into any herbivore which consumes the plant and on and on and on until it reaches the highest organisms in the food web, humans.

Nowadays, there is an excess of waste being dumped. The long term effects of this could be the pollution of new building grounds. People live or work in nearby areas, could suffer from health problems. The health problems that could occur from land pollution, are not very well known at this time. But the problems the amount of toxic chemicals, coming from this waste, are going to cause, are health issues such as deformities or cancers. This is the worrying issue and it is not quite clear yet about the way in which to prevent health problems from land pollution

Control Measures to land pollution

The solution to land pollution is to reduce, re-use and recycle. We can try to prevent land pollution by disposing of some waste correctly. Appliances such as refrigerators should be care fully used.

By throughing out the garbage to dustbins with a little thought and effort will help to control the

unwanted spreading of domestic wastes. We can separate household waste at home for recycling. More than half of our domestic waste could be recycled or re-used but once it is mixed up, it becomes more difficult to separate different components for recycling. The organic component of waste can also be separated and recycled by composting. It would make recycling easier, if waste collection authorities set up a system for householders to separate their rubbish into paper, glass and metal. Separate collections would be more expensive in the short term, but save resources, disposal costs and immeasurable environmental damage.

The following measures can be used to control land pollution:

a. Anti-litter campaigns can educate people against littering;

b. Organic waste can be dumped in places far from residential areas;

c. Inorganic materials such as metals, glass and plastic, but also paper, can be reclaimed and recycled.

■ **4.2.2 Natural and managed ecosystem:** The term "ecosystem" was first proposed by Tansley (1935) as a name for the interaction system comprising living things together with their nonliving habitat. He regarded the ecosystem as not only the organism complex, but also the whole complex of physical factors forming what we call the environment. It was first applied to levels of biological organization represented by unites such as community and the biome. Odom (1952) and Evans (1956) expanded the extent of the concept to include other levels of organization. Where as managed ecosystem is an ecosystem which is controlled by human induced forces.

Examples of managed ecosystem :

■ **4.2.2.1Agricultural ecosystem**: Agricultural ecosystems or agro ecosystems are specialized controlled systems designed and managed by humans for the production of food and fiber. It is a complex system of teracting biotic and abiotic elements performing certain functions and processes such as primary production, consumption, and decomposition resulting in energy flow and nutrient cycling. The agro ecosystem is further characterized by a hierarchy of integrated systems (e.g. farms within communities, within watersheds, within regions and so forth) composed of interconnected and interrelated biophysical elements (soil, water, air and climatic resources, plants and animals), and socioeconomic elements (social, cultural, economic, institutional and political concerns). The interactions among these elements determine the properties of the agro ecosystem.

Agro ecosystem Characteristics

Agricultural ecosystems (referred to as agroecosystems) have been described by Odum (1984) as domesticated ecosystems. He states that they are in many ways intermediate between natural ecosystems (such as grasslands and forests) and fabricated ecosystems (cities).

Agro ecosystems are solar powered (as are natural systems) but differ from natural systems in that:

1. there are auxiliary energy sources that are used to enhance productivity; these sources are processed fuels along with animal and human labor;
2. species diversity is reduced by human management in order to maximize yield of specific foodstuffs (plant or animal);
3. dominant plant and animal species are under artificial rather than natural selection; and,
4. control is external and goal-oriented rather than internal via subsystem feedback as in natural ecosystems.

Agro ecosystems do not happen without human intervention in the landscape. Therefore, creation of these ecosystems (and maintenance of them as well) is necessarily concerned with the (human) economic goals of production, productivity, and conservation. Agroecosystems are controlled, by definition, by management of ecological processes. Crossley, et al, (1984) addressed the possible use of agro ecosystem as a unifying and in many ways clarifying concept for proper management of managed landscape units. All ecosystems are open, that is, they exchange biotic and abiotic elements with other ecosystems. Agro ecosystems are extremely open — with major exports of primary and secondary production (plant and animal production) as well as increased opportunity for loss of nutrient elements. Because modern agro ecosystems are entirely dependent on human intervention, they would not persist but for that intervention. It is for this reason that they are sometimes referred to as artificial systems as opposed to natural systems that do not require intervention to persist through space and time.

Definitions of agro ecosystems often include the entire support base of energy and material subsidies, seeds, and chemicals, and even a sociopolitical-economic matrix in which management decisions are made. Crossley (1984) stated that while this is logical, he preferred to designate the individual field as the agro ecosystem because it is consistent with designating an individual forest catchments or lake as an ecosystem. He envisions the **farm system** as consisting of a set of agroecosystems — field with similar or different crops — together with support mechanisms and socioeconomic factors contributing to their management.

Ecosystem Pattern and Process

As previously stated that managed ecosystem is controlled by human beings. Till such kind of ecosystems is following a procedure and they have a particular pattern as below-

- enhanced productivity of producers through fertilization
- improved productivity through selective breeding
- management of pests with various control methods
- management of various aspects of the hydrologic cycle
- land forming

■ 4.2.2.2 Urban Ecology

Ecology is the complex process by which all active organic matter relates. The term "urban ecosystem" is defined in different ways by different people. The definition depends on the perspective. For the ecologist, the urban ecosystem is an ecological conceptualization of the urban area: a conglomeration of interconnected systems and processes at work in the area, such as energy cycling, consumption of resources, and nutrient cycling. Local residents concerned with the preservation or restoration of a fragmented natural space might adopt the "urban wild lands" as definition of urban ecosystem. In a nut shell we can say that *urban* ecology is the study of how these dense concentrations relate to active organic matter. According to Michael *R. Allen (2002)* urban ecology is then at least a doubling of living complexities.

Urban ecologists have explored the city as a natural environment (Hough 1990; Beatley 2000). Urban ecology includes the study of the interaction between living things and their environment in the city, a profoundly altered ecosystem (Gilbert, 1989; Douglas1981). This contrasts with the Chicago School's sociological approach to study the social and spatial organization of the city. This perspective offers ecologists the opportunity to address the practical problems related to the anthropogenic impact on ecological systems, and also provides opportunities to examine fundamental ecological questions concerning the structure, function, and organization of ecosystems in general (McDonnell and Pickett 1991).

City as an Ecosystem: Understanding the city as an ecosystem began with two different, but related, types of studies. Urban metabolism research generated a holistic view of the city as a consumer and digester of resources and a creator of waste products. This perspective started as viewing the city as an organism with its own metabolic processes. Abe Wolman (1965) suggested that in order to overcome shortages of water and pollution of water and air, the city should be viewed as an organic body with metabolic processes. As such, inputs and out puts could be measured, and this information could help to form public economic policies. The UNESCO/MAB programme began their extensiveeffort to understand urban metabolism and cities with a seminal study of Hong Kong (Boyden andCelecia 1981; Boyden, et al, 1981). Their approach was to examine the complex interactions that take place within cities, rather than studying specific problems in isolation. This technique is illustrated by the flow of important materials through Hong Kong. Studies along these lines include those that explore the energy, water, and nutrient balances of cities, along with the flows of waste materials, among others (Douglas 1983).

Urban Ecology Approach

The urban ecology approach was and remains largely within the realm of biology. In this understanding, ecologists have looked upon cities as unique types of natural ecosystems. Cities are therefore not unlike natural landscapes (coastal scrub, grassland, oak wood lands, marshes, and stream–sides), holding a wide

range of species. Many of these types of studies have applications to urban planning (see for example, Hough, 1990).Urban ecology keeps humans and human activities separate from the ecological world. Those working within this approach are largely interested in the concepts and processes of the stresses, disturbances, structures, and functions of urban ecological systems, and how urban ecosystems relate more generally to larger ecosystems (excluding people). These types of studies have also been called the 'bio–ecological approach' (Grove and William R Burch, 1997).Despite the separation of human and natural processes, there are interesting results and new techniques that have emerged from these studies, which have the potential to provide understanding of the relationships between human density and various ecological activities. One is the examination of changes in natural processes and conditions that occur along the rural–urban gradient. Another is how natural processes can be restored within areas disturbed by humans (Givoni, 1991). These studies provide details of how to reverse and deal with human–induced hazards and adverse health effects and how urban ecosystem processes can be use to mitigate problems. Whire these and similar studies provide insight into the biology of systems within cities, they remain only marginally useful in providing a policy framework for dealing with the complexities of cities, as they do not focus on the role and influence of social structures and activities in ecosystems processes.

■ Summary

Environmental degradation is deterioration from normal condition. It may caused by both internal and external influences. There are so many fields where such kind of deterioration is seen. Example of such kind are water pollution, soil pollution, land pollution and air pollution etc. environmental degradation and pollution have impact on both plant and animal kingdom.

The concept of ecosystem has developed as both as a discipline and an approach. Its primary focus on interactions between living things and their non–living environments has provided a pivot for cooperation among a host of discipline spanning the natural, social, and human sciences. Thus there is simultaneous coexistence of natural and man made ecosystem are common.

■ Keywords

Environmental degradation, pollution, solid waste, liquid waste, gaseous waste, water pollution, soil pollution, air pollution, environmental impact, natural ecosystem, managed ecosystem, agro-ecosystem, urban ecosystem and urban ecology etc.

Self Assessment Questions

1. **Define environment. Differentiate environmental degradation from environmental pollution. What are the causes of environmental degradation?**
2. **What do you mean by pollutants? Write about the pollutants that are causing different types of pollution? Write briefly about their sources.**
3. **Write briefly about the sources of pollutants those are responsible for air pollution. What are the impacts of air pollution on plants?**
4. **What do you mean by point and non point sources of air pollution? How do they deteriorate the quality of air in an industrial area?**
5. **What are the sources of water pollution? How does polluted water impacts on human health?**
6. **Discuss the short term and long term effects of land pollution on agriculture and ecosystem.**
7. **Define man made ecosystem. What are the basic characteristics of managed ecosystem?**
8. **Briefly discuss about the agricultural ecosystem as a managed ecosystem. What are the negative consequences of such ecosystem?**
9. **Define urban ecology. Delineate the role of city as an ecosystem.**
10. **What do you mean by urban ecosystem? In what ways it is different from natural ecosystem**

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M.A./M.Sc. PART – I
Paper - II : Module - IV
Unit - 03

Module Structure

- 4.3.0 INTRODUCTION
- 4.3.1 COMPONENTS OF SOCIO-CULTURAL ENVIRONMENTS
- 4.3.2 IMPORTANCE OF SOCIO-CULTURAL ENVIRONMENT FOR HUMAN WELFARE
- 4.3.3 RELATIONSHIP BETWEEN PHYSICAL AND SOCIO-CULTURAL PROBLEMS
- 4.3.4 SELF ASSESSMENT QUESTIONS
- 4.3.5 SELECTED REFERENCES

■ 4.3.0 INTRODUCTION

Culture is the learned behaviours and beliefs of distinctive groups of people. Culture traits, the smallest differentiating items of culture, are the building blocks of integrated culture complexes. Together, traits and complexes in their spatial patterns create human-'cultural'-landscapes, define culture regions, and distinguish culture groups. Those landscapes, regions, and group characteristics change through time as human societies interact with their environments, develop new solutions to collective needs, or are altered through innovations adopted from outside the group.

The detailed complexities of culture can be simplified by recognition of its component subsystems.

■ 4.3.1 COMPONENTS OF SOCIO-CULTURAL ENVIRONMENTS :

To some writers in newspapers and the popular press, "culture" means the arts (literature, painting, music, etc.). To a social scientist, **culture** is the specialized behavioral patterns, understandings and adaptations that summarize the way of life of a group of people. In this broader sense, culture is as much a part of the regional differentiation of the earth as are topography, climate and other aspects of the physical environment. The visible and invisible evidences of culture-buildings and farming patterns, language and political organization – are elements in the spatial diversity that invites and is subject to geographic inquiry. Cultural differences in area result in human landscapes with variations as subtle as the differing "feel" of urban Paris, Moscow and New York or as obvious as the sharp contrast of rural Zimbabwe and the Prairie Provinces of Canada.

Components of Culture :

Culture is transmitted within a society to succeeding generations by imitation, instruction and example. It is learned not biological and has nothing to do with instinct or with genes. As members of a social group, individuals acquire integrated sets of behavioral patterns, environmental and social perceptions, and knowledge of existing technologies. Of necessity we learn the culture in which we are born and reared. But we need not – indeed, cannot – learn its totality. Age, sex, status or occupation dictate the aspects of the cultural whole in which we become fully indoctrinated.

A culture, that is, despite overall generalized and identifying characteristics and even on outward appearance of uniformity, displays a social structure – a framework of roles and interrelationships of individuals and established groups. Each individual learns and adheres to the rules and conventions not only of the culture as a whole but, importantly, of those specific to the subgroup to which he or she belongs. And that subgroup may have its own recognized social structure.

Culture is a complexly interlocked web of behaviors and attitudes. Realistically, its full and diverse content can not be appreciated, and in fact may be wholly misunderstood, if we concentrate our attention only on limited, obvious traits. Distinctive eating utensils, the use of gestures, or the ritual of religious ceremony may summarize and characterize a culture for the casual observer. These are, however, individually insignificant parts of a much more complex structure that can be appreciated only when the whole is experienced.

Culture traits are units of learned behavior ranging from the language spoken to the tools used or to the games played. A trait may be an object (a fishhook, for example), a technique (weaving and knotting of a fish net), a belief (in the spirits resident in water bodies), or an attitude (a conviction that fish is superior to other animal flesh). Such traits are the most elementary expressions of culture, the building blocks of the complex behavioral patterns of distinctive groups of peoples.

Individual culture traits that are functionally interrelated comprise a **culture complex.** The existence of such complexes is universal. Keeping cattle was a *culture trait* of the Maasai of Kenya and Tanzania. Related traits included the measurement of personal wealth by the number of cattle owned; a diet containing the milk and blood of cattle; and disdain for labor unrelated to herding. The assemblage of these and other related traits yielded a *culture complex* descriptive of one aspect of Maasai society. In exactly the same way, religious complexes, business behavior complexes, sports complexes and others can easily be recognized in American or any other society.

Culture traits and complexes have spatial extent. When they are plotted on maps, the regional character of the components of culture is revealed. Geographers are interested in the spatial distribution of these individual elements, but their usual concern is with the **culture region**, a portion of the earth's surface occupied by people sharing recognizable and distinctive cultural characteristics that summarize their collective attributes or activities. Examples include the political organizations societies devise, their religions, their form of economy, and even their clothing, eating utensils or housing. There are as may such culture regions as there are separate culture traits and complexes of population groups.

Finally, a set of culture regions showing related culture complexes and landscapes may be grouped to form a culture realm. The term recognizes a large segment of the earth's surface having fundamental uniformity in its cultural characteristics and showing a significant difference in them from adjacent realms. Culture realms are, in a sense, culture regions at the broadest scale of generalization. In fact, the scale is so broad and the diversity within the recognized realms so great that the very concept of realm may mislead more than it informs.

■ 4.3.2 IMPORTANCE OF SOCIO-CULTURAL ENVIRONMENT FOR HUMAN WELFARE :

On the whole, while cultures are essentially conservative, they are always in a state of flux.

Many individual changes, of course, are so slight that they initially will be almost unnoticed, though collectively they may substantially alter the affected culture. Think of how the culture of the United States differs today from what it was in 1940 – not in essentials, perhaps, but in the innumerable electric, electronic and transportational devices that have been introduced and in the recreational, social, and heavioral adjustments they and other technological changes have wrought. Among these latter have been shifts in employment patterns to include greater participation by women in the waged workforce and associated changes in attitudes toward the role of women in the society at large. Such cumulative changes occur because the cultural traits of any group are not independent; they are clustered in a coherent and integrated pattern. Change on a small scale will have wide repercussions as associated traits also changes to accommodate the adopted adjustment. Change, both major and minor, within cultures is induced by *innovation, spatial diffusion* and *acculturation.*

Innovation :

Innovation implies changes to a culture that result from ideas created within the social group itself and adopted by the culture. The novelty may be an invented improvement in material technology, like the bow and arrow or the jet engine. It may involve the development of nonmaterial forms of social structure and interaction : feudalism, for example or Christianity.

Primitive and traditional societies characteristically are not innovative. In societies at equilibrium with their environment and with no unmet needs, change has no adaptive value and has no reason to occur. Indeed, all societies have an innate resistance to change. Complaints about youthful fads or the glorification of times past are familiar cases in point. However, when a social group is inappropriately unresponsive – mentally, psychologically, or economically – to changing circumstances and innovation, it is said to exhibit *cultural lag.*

Innovation – invention – frequently under stress, has marked the history of humankind. Domestication of plants and animals appears to have occurred independently in several

recognizable areas of "invention" of agriculture. From them, presumably, came a rapid diffusion of food types, production techniques, and new modes of economic and social organization as the majority of humankind changed from hunting-gathering to sedentary farming by no later than 2000 years ago. All innovation has a radiating impact upon the web of culture; the more basic the innovation, themore pervasive its consequences.

Few innovations in human history have been more basic than the Agricultural Revolution. It affected every aspect of society. Culture altered at an accelerating pace, and change itself became a way of life. Humans learned the arts of spinning and weaving plant and animal fibers. They learned to use the potter's wheel, to fire clay and make utensils. They developed techniques of brick making, mortaring, and building construction. They discovered the skills of mining, smelting, and casting metals. Special local advantages in resources or products promoted the development of long-distance trading connections. On the foundation of such technical advancements a more complex exploitative culture appeared, including a stratified society to replace the rough equality of hunting and gathering economies.

The source regions of such social and technical revolutions were initially spatially confined. The term **culture hearth** is used to described those restricted areas of innovation from which key culture elements diffused to exert an influence on surrounding regions. The hearth may be viewed as the "cradle" of a culture group whose developed systems of livelihood and life created distinctive cultural landscapes. All hearth areas produced the trappings of *civilization,* which are usually assumed to include writing (or other forms of record keeping), metallurgy, long-distance trade connections, astronomy and mathematics, social stratification and labor specialization, formalized governmental systems, and a structured urban society. Several major culture hearths emerged, some as early as 7000 to 8000 years ago, following the initial revolution in food production. Prominent centers of early creativity were located in Egypt, Mesopotamia, the Indus Valley of the Indian subcontinent, northern China, southeastern Asia, and in several locations in Africa, the Americas, and elsewhere.

In most modern societies, innovative change has become common, expected, and inevitable, though it may be rejected by some of their separate culture groups. The rate of invention, at least as measured by the number of patents granted, has steadily increased, and the period between idea conception and product availability has been decreasing. A general axiom is that the more ideas available and the more minds able to exploit and combine them, the greater the rate of innovation. The spatial implication is that larger urban centers of advanced economies tend to be centers of innovation, not just because of their size but because of the number of ideas interchanged. Indeed, ideas not only stimulate new ideas, but

also create circumstances in which new solutions must be developed to maintain the forward momentum of the society.

Diffusion :

Spatial diffusion is the process by which a concept, practice, innovation, or substance spreads from its point of origin to new territories. Diffusion may assume a variety of forms, but basically two processes are involved. Either people move to a new area and take their culture with them (as the immigrants to the American colonies did), or information about an innovation (like barbed wire or hybrid com) may spread throughout a culture. In either case, new ideas are transferred from their source region to new areas and to different culture groups.

It is not always possible to determine whether the existence of a culture trait in two different areas is the result of diffusion or of independent (or parallel) innovation. Cultural similarities do not necessarily prove that spatial diffusion has occurred. The pyramids of Egypt and of Central America most likely were separately conceived and are not evidence, influenced by them. Both their language and culture complex govern French Canadian selective acceptance of Anglo influences. Traditional groups, perhaps controlled by firm religious conviction – such as the Hasidic Jewish community of New York City – may very largely reject culture traits and technologies of the larger society in whose midst they live.

Adopting cultures do not usually accept intact items originating from the outside. Diffused ideas and artifacts commonly undergo some alteration of meaning or form that makes them acceptable to a borrowing group. The process of the fusion of the old and new, called **syncretism**, is a major feature of culture change. It can be seen in alterations to religious ritual and dogma made by convert societies seeking acceptable conformity between old and new beliefs; the mixture of Catholic rites and voodooism in Haiti is an example. On a more familiar level, syncretism is reflected in subtle or blatant alterations of important cuisines to make them conform to the demands of America's fast food franchises.

Acculturation :

Acculturation is the process by which one culture group undergoes a major modification by adopting many of the characteristics of another, usually dominant, culture group. In practice, acculturation may involve changes in the original culture patterns of either or both of two groups involved in prolonged firsthand contact. Such contact and subsequent cultural alteration may occur in a conquered or colonized region. Very often the subordinate or subject population is forced to acculturate or does so voluntarily, overwhelmed by the superiority in numbers or the technical level of the conqueror.

The tribal Europeans in areas of Roman conquest, native populations in the wake of Slavic occupation of Siberia, and Native Americans following European settlement of North America experienced this kind of acculturation. In a different fashion, it is evident in the changes in Japanese political organization and philosophy imposed by occupying Americans after World War II or in the Japanese adoption of some more frivolous aspects of American life. In turn, American life was enriched by awareness of Japanese food, architecture and philosophy, demonstrating the two-way nature of acculturation.

In the modern period the population relocations and immigration impacts discussed have resulted in unprecedented cultural mixings throughout the world. The traditional "melting pot" – more formally, **amalgamation theory** – view of immigrant integration into for example, United States or Canadian Society suggests that the receiving society and the varied arriving newcomer groups eventually merge into a composite mainstream culture incorporating the many traits of its collective components. More realistically, in order to be accepted, newcomer groups must learn the accustomed patterns of behaviour and response and the dominating language of the workplace and government of the culture they have entered. Acculturation for them involves the adoption of the values, attitudes, ways of behavior, and speech of the receiving society. In that process, the immigrant group loses its separate cultural identity to the extent that it accepts over time the culture of the larger host community.

When that integration process is completed, **assimilation** has occurred. But assimilation does not necessarily mean that consciousness of original cultural identity is reduced or lost. Competition theory, in fact, suggests that as cultural minorities begin to achieve success and enter into mainstream social and economic life, awareness of cultural differences may be heightened, transforming the strengthening immigrant group into a self-assertive minority pursuing goals and interests that defend and protest its position within the larger society. Carried to extremes, militant minority self-assertion may result in the loss of the larger social and cultural integration the acculturation process seeks to assure – a circumstance of increasing concern in Western European and Anglo American destination countries.

Language, religion, ethnicity, and gender meet out criteria and are among the most prominent of the differentiating cultural traits of societies and regions. Language and religion are basic components of culture, helping to identify who and what we are as individuals and clearly placing us within larger communities of persons with similar characteristics. In our earlier terminology, they are mentifacts, components of the ideological subsystem of culture that help shape the belief system of a society and transmit it to succeeding generations.

Ethnicity is a cultural summary rather than a single trait. It is based on the firm understanding by members of a group that they are in some fundamental ways different from

others who do not share their distinguishing composite characteristics, which may include language, religion, national origin, unique customs, or other identifiers. Like language and religion, ethnicity has spatial identification. Like them, too, it may serve as an element of diversity and division within culturally complex societies and states.

Language, religion, and ethnicity treat all members (for all adult members) of a society uniformly. Yet among the most prominent strands in the fabric of culture are the social structures (sociofacts) and relationships that establish distinctions between males and females in the duties assigned and the rewards afforded to each. Gender is the reference term recognizing those socially created distinctions. It conditions the way people use space and

ronment that, in its ways, contributes to differences among people. In primitive societies, the acquisition of food, shelter and clothing – all parts of culture – depends on the utilization of the natural resources at hand. The interrelations of people with the environment of a given area, their perceptions and utilization of it, and their impact on it are consistent and interwoven themes of geography. They are the special concerns of those geographers and anthropologists exploring *cultural ecology*, the study of the relationship between a culture group and the natural environment it occupies.

Cultural ecologists see evidence that subsistence pastoralists, hunter-gatherers, and gardeners adapted their productive activities – and by extension, their social organizations and relationships – to the specific physical limitations of their different local habitats. Presumably, similar natural environmental conditions influenced the development of similar adaptive responses and cultural outcomes in separate, unconnected locales. The stimulation of initial subsistence tendencies, however, is not identical to preordaining complex cultural results.

Environments as Controls :

Geographers have long dismissed as invalid and intellectually limiting the ideas of environmental determinism – the belief that the physical environment by itself shapes humans, their actions, and their thoughts. Environmental conditions alone cannot account for the cultural variations that occur around the world. Levels of technology, systems of social organization, and ideas about what is true and right have no obvious relationship to environmental circumstances.

The environment does place certain limitations on the human use of territory. However, such limitations must be seen not as absolute, enduring restrictions, but as relative to technologies, cost considerations, national aspirations and linkages with the larger world. Human choices in the use of landscapes are affected by group perception of the possibility and

desirability of their settlement and exploitation. These are not circumstances inherent in the land.

Possibilism is the viewpoint that people, not environments, are the dynamic forces of cultural development. The needs, traditions, and technological level of a culture affect how that culture both assesses the possibilities of an area and shapes the choices that it makes regarding them. Each society uses natural resources in accordance with its culture. Changes in a group's technical abilities or objectives bring about changes in its perceptions of the usefulness of the land. Of course, there are some environmental limitations on use of area. For example, if resources for feeding, clothing, or housing ourselves within an area are lacking, or if we do not recognize them there, there is no inducement for people to occupy that territory. Environments that do contain such resources provide the framework within which a culture operates.

Human Impacts :

People are also able to modify their environment, and this is the other half of the human – environment relationship of geographic concern. Geography, including cultural geography, examines both the reactions of people to the physical environment and their impact on that environment. By using it we modify our environment – in part, through the material objects we place on the landscape : cities, farms, roads and so on. The form these take is the product of the kind of culture group in which we live. The **cultural landscape**, the earth's surface as modified by human action, is the tangible, physical record of a given culture. House types, transportation networks, parks and cemeteries and the size and distribution of settlements are among the indicators of the use that human have made of the land.

As a rule, the more technologically advanced and complex the culture, the greater its impact on the environment, although preindustrial societies can and frequently do exert destructive pressures on the lands they occupy. In sprawling urban industrial societies, the cultural landscape has come to outweigh the natural physical environment in its impact on people's daily lives. It interposes itself between "nature" and humans. Residents of the cities of such societies – living and working in climate-controlled buildings, driving to enclosed shopping malls – can go through life with very little contact with or concern about the physical environment.

■ 4.3.4 SELF ASSESSMENT QUESTIONS

1. **What is included in the concept of culture? How is culture transmitted?**
2. **Differentiate between culture traits and culture complexes. Between environmental delterminism and possibilism.**
3. **What are the components of subsystems of the three part system of culture? What characteristics-aspects of culture— are included in each of the subsystems?**

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M.A. / M. Sc. PART - I
Paper - II :: Module - IV :: Unit - 04

Module Structure

- 4.4.1 Introduction (Environment & Development Debate)
- 4.4.2 Objective
- 4.4.3 Environmental Movement
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  - Ecological foundation of the Chipko Movement
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  - Dams and Civilization
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  - Benefits from Dams
  - Problems with Dams
  - Socio-economic impacts of Dams
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  - Displacement due to Dams
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- 4.4.6 Silent Valley Project
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- 4.4.8 Narmada Bachao Andolan (NBA)
- 4.4.9 Sustainable Development
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- 4.4.11 References

4.4.1 Introduction

In the mid 1970s, environmentalism as an organised movement emerged in India. Now, environmental advocacy matured from protest against environmental damage to question about the character and course of development.

'Environment' and 'Development' Debate :

> The term *'development'* has many different connotations. *Development is about people, about enhancing their ability and power to direct their own lives, in the context of their environment, history and aspirations for the future.*
>
> Development encompasses better nutrition, health, education and freedom from oppression and poverty.
>
> The process of development involves structural transformation in the organisation of society and the economy. Such a process can not take place without altering relationships of dominance and subordination or affecting the interests of different groups within society.

The relationship between development and environment is the crux of the environmental debate in India. *People are a part of the environment,* intimately linked to the air, water, soil, flora and fauna. This complex web of living and non-living systems is in perpetual flux, and sustains the process of life. *The environment provides the resource base for development.*

'Environmentalism' has finally become part of the dominant discourse. 'Development' has given way to *'sustainable development'* and 'growth' has given way to *'green growth'*. Even now there exists a number of misconceptions about environmental issues in the Third World.

First misconception is that Third World countries need 'development' and can not afford the luxury of protecting nature's ecological processes.

Second misconception is closely related to the first, is that poor people can not be a source of ecological solutions, they are merely a source of environmental problems.

Development is not universally benign. Development for some, means underdevelopment and dispossession of many.

Development interventions aimed at commercialisation of natural resources involve a major shift in the manner in which rights to resources are perceived and exercised. It transforms commons into commodities, and deprives the politically weak communities of access to resources, and robs resources from nature, to generate growth on the market for more privileged groups in society. This transformation in the Third World is often state mediated, though the final outcome is privatisation.

For example, dams are constructed using state funds to provide energy and water for private industry and cash crop cultivation.

Most critical ecology movements are based on the need to protect nature and need to strengthen people's collective rights to common resources. The emergence of social movements around ecological issues related to forests and water systems, indicates that it is the marginal communities in the Third World for whom the protection of nature is essential for survival. From their perspective, it is destructive development which is a luxury that the Third World can not afford. Also, ecology and economics are not opposed, but coverage in the survival economics of the Third World.

Nature and people are never taken into account in development – plans which emerge from the North, in terms of their intellectual and political genesis. Through international aid, control over resources has shifted from local communities to national and international financial institutions. Through internationally financed development projects, conflicts over natural resources pit tribal and peasant communities against international institutions, with the state acting as an agent of dispossession of local communities, to clear the way for global plans and ideologies of development. Actually there should be a wider concept of economy which is based on the maintenance of life and livelihood, not merely on the accumulation of profits.

Whether we consider population growth, technological choices, or specific sectors of the economy like agriculture, irrigation and power generation, the conflict between development and environmental conservation remains unresolved. *In the early years, environment and development were seen as two sides of the same coin, but in practice this meant that environment was the limiting factor.* Subsequently the concept of ecological development arose, which emphasised equitable development in harmony with the ecology. This has been replaced by the concept of *sustainable development, "meeting the needs of the present without compromising the ability of future generations to meet their own needs."* The concept has been projected as a new developmental paradigm that bridges the conflict between environmental concerns and conventional economics

In an era of rising *'green capitalism'* where justice has become absolete and has been separated from issues sustainability, people's ecology movements in the Third World highlight the way in which issues of ecology and equity, sustainability and justice are inermately linked to one another. They provide an alternative perception of ecology as the politics of survival, based on the production and maintenance of life, not profits. It is this alternative form of Third World perspective that this chapter deals with the current environmental issues in India.

■ 4.4.2 Objectives

After going through this unit we shall be able to know the following topics :

- Characteristics of different kinds of Movements
- Environment and Development Debate
- Chipko Movement in India

- Dams and related merits and conflicts
- Silent Valley Project and its analysis
- Narmada Dam Project
- Concept of Sustaiable Development

4.4.3 Environmental Movement (Andolan)

The English word *'movement'* derives from the old French verb *'movoir'*, meaning 'to move, stir or impel', and the mediaeval *'movimentum'*. In the general English usage, the movement is meant to be *'a series of actions and endeavours of a body of persons for a social object'* (Oxford Dictionary). From the perspective of social sciences, there is no precise definition of *social movement*. The essential features of social movement are :

i) A social movement is a deliberate collective endeavour to promote change in any direction and by any means.

ii) A social movement must evince a minimal degree of organisation.

iii) A social movement's commitment to change and the *raisen d'etre* of its organisation are founded upon the conscious volition, normative commitment to the movement's aims or beliefs and active participation on the part of the followers or members.

Since the late 1960s, there has been a radical change in the old concept of social movement. Now the movements which emerge in the society are commonly designated as *'New Social Movements (NSM)'*. The common features are :

i) It is a non-violence type of movement.

ii) There is no direct conventional political participation.

iii) Direct actions through civil disobediences are generally made.

iv) The supporters of NSM are drawn predominantly from 'a new middle class'.

v) NSM are mostly spearheaded not by political parties, but by non-party organisations.

Considering the nature, features and methodologies *Environmental Movements may be regarded as under the category of New Social Movement (NSM).*

Other examples of New Social Movement are :

Women's movement, peace movement, anti-nuclear movement etc. which have been prepared to use unconventional forms of political participation, including civil disobedience and direct action, to achieve their aims. This may also be termed as *'new politics'*. A new politics account would interpret environmentalism as simply one element of a wider structural and cultural transformation of contemporary politics. In all sorts of environmental movements the linkage between technology and ecology, and politics and culture undergo significant changes and new concept emerges in the

field of social science.

The growing evidences of environmental decline and the role of unsustainable development in it have given rise to an unprecedented level of environmental activism all over the world. India has witnessed quite a long drawn environmental struggles. The *Chipko Movement, the Narmada Bachao Andolan, the anti-dam movement at Tehri, the fishermen's movement in Kerala and Chilka, the anti-missile-range movement at Baliapal are some of the better known Environmental Movements.*

- **Features of Environmental Movements :**

(i) *Many environmental issues are potentially capable of uniting the entire society.*

Example : When water becomes contaminated or air gets polluted, none (irrespective of rich & poor; caste & creed) in the society is really spared. This generalised nature of environmental issues is one reason why environmental movements have become so prominent in a rather short time all over the world.

(ii) *Environment movements may be sectional/class movements.*

Example : Narmada Bachao Andolan seeks to resist construction of big dams on the Narmada river in order to, mainly, prevent evictions of thousands of rural, predominantly tribal families from their habitat and destruction of ecological balance. But the movement is opposed by those who believe that the dam will extend the process of development in Maharashtra, Gujrat and Madhya Pradesh. Those who support the construction of dams include mainly the rich peasants cultivating cash crops who are expected to derive maximum benefit from better irrigation and power facilities after the completion of the dam. This movement thus brings the conflict between development of the rich and the middle class on one hand and the simultaneous decline of environment and underdevelopment of the poor and the tribals, on the other.

(iii) There are two types of environmentalism :

(a) *Western environmentalism :* It is primarily concerned with aesthetic and health issues like maintaining greeneries, preserving wildlife and obviously, pollution free atmosphere.

(b) *Indian or third world environmentalism :* Here common environmental issues are confined mainly among the urbanelite and the middle class. On the other hand, most of the mass-based environmental movements in the third world are intertwind with movements for socio-economic rights of the rural poor and marginal people.

(iv) *Sometimes middle class environmentalism contradicts the interest of the poor.*

Example : When polluting factories in the urban areas are closed or relocated to prevent pollution, the workers suffer most. Though they are prime victims of such pollution, loss of employment threatens their immediate survival.

(v) *Environmental movements are mostly spearheaded not by political parties, but by some non-party organisations.*

In some countries in the West, such organisations have in course of time transformed into political parties with environment as their major or even sole concern. The *Green Party* in Germany in a prime example. In some other cases, established parties have been forced to accommodate some environmental issues in their programme or have allowed environmental lobbies to operate within the organisation. In India none of these features have become prominent as yet. On the contrary, since there is virtually a consensus among the major parties regarding the dominant development paradigm, environmental issues are normally not taken up by the political parties with any seriousness. In fact, they are often viewed, if not overtly expressed as new obstacles to development.

(vi) *The voluntary groups leading the environmental movements are generally quite small and localized.*

Being at the grassroots, they can interact with the people easily, identify their problems and potentials better, are less bureaucratic and have more flexibility.

On the other side, they lack resources and a vision of totality. Mostly built around one or two individuals, they are sometimes victims of personal caprices and vulnerable to threats or lures from above and often quite short-lived. As a result, while some of them have made significant contribution in addressing some local problems, their influence on macro-level issues has so far been at best marginal, if at all.

■ 4.4.4 Chipko Movement

"Embrace the trees and
Save them from being felled;
The property of our hills,
Save them from being looted."

— Ghanshyam Raturi (1972), Poem of Protest used as slogan in Chipko movement.

Literally *'Chipko'* means hugging or ebrassing. The movement derives its name from the efforts of the villagers to save trees from felling by embracing them. Chipko movement developed in the Garhwal region of the Himalayas. The extremely rich forests in this part had begun to be excessively exploited during British rule to support increasing commercial activities. The process went on unhindered even after independence. *The cumulative adverse effects it had for the economy of hill people and ecology of the region gave rise to the Chipko Movement.* Gopeswar, Tehri, Chamoli and Narendranagar are some of its most famous sites. The movement attained its peak in the 1970s and could force the Government to concede one of its major ecological demands.

● Dynamics of Chipko Movement

The Chipko Movement is historically, philosophically and organisationally an extension of the traditional *Gandhian satyagraha*. Some writer thinks that Chipko has its origins in an incident which

occurred in Rajasthan in 1763, when members of the *Bishnroi* sect laid down their lives to protect trees being felled under orders from the Maharaja of Jodhpur. Different Chipko agitations have invoked the spirit and memory of past upsurges against the cuttlement of customary rights. Its special significance lies in the fact that it took place in post-independent India. The continuity between the pre-independence and post-independence forms of this stayagraha has been provided by Gandhians, including *Sri Dev Suman, Mira Behn and Sarala Behn.* Sri Dev Suman was initiated into Gandhian satyagraha at the time of the Salt Satyagraha. He died as a martyr for the cause of the Garhwali people's right to survive with dignity and freedom. Both Mira Behn and Sarala Behn were close associates of Gandhiji. They settled in the interior of the Himalayas and established ashrams. Sarala Behn settled in Kumaon, and Mira Behn lived in Garhwal till the time she left for Vienna due to ill health. Equipped with the Gandhian world view of development based on justice and ecological stability, they contributed silently to the growth of women power and ecological consciousness in the hill areas of Uttar Pradesh. The influence of these two European disciples of Gandhiji on the heritage of struggle for social justice and ecological stability in the hills of Uttar Pradesh has been immense and they generated a new brand of Gandhian activists who provided the foundation for the Chipko Movement. *Sundarlal Bahuguna* is prominent among the new generation of workers deeply inspired by these Gandhians. Influenced by Sri Dev Suman, he joined the independence movement at the age of 13. Later, he worked with Mira Behn in Bhilangana Valley and was trained in her ecological vision. In an article written in 1952, Mira Behn had stated that there was *'Something Wrong in the Himalaya'*.

"Year after year the floods in the North of India seem to be getting worse, and this year they have been absolutely devastating. This means that there is something radically wrong in the Himalayas, and that 'something' is, without doubt, connected with the forests. It is not, I believe, just a matter of deforestation as some people think, but largely a matter of change of species.

Living in the Himalayas as I have been continuously now for several years, I have become painfully aware of a vital change in species of trees which is creeping up and up the southern slopes –those very slopes which let down the flood waters on to the plains below. This deadly change over is from Banj tree (Himalayan Oak) to Chir pine. It is going on at an alarming speed, and because it is not a matter of deforestation, but of change from one kind of forest to another, it is not taken sufficiently seriously. In fact the quasi-commercial Forest Department is inclined to shut its eyes to the phenomenon, because the Banj brings them in no cash for the coffers, whereas the chir pine is very profitable, yielding as it does both timber and resin."

Mira Behn had thus identified not merely deforestation but change in species suitable to commercial forestry as the reason for ecological degradation in the Himalayas. She recognised that the leaf litter of oak forests was the primary mechanism for water conservation in the Himalayan mountain watersheds.

The Banj leaves, falling as they do, year by year, create a rich black mould in which develops a thick tangled mass of undergrowth (bushes; creepers, and grasses), which in their turn add to the leaf-

mould deposit and the final result is a forest in which almost all the rain water becomes absorbed. Some of it evaporates back into the air and the rest percolates slowly down to the lower altitudes, giving out here and there beautiful sweet and cool springs. It would be difficult to imagine a more ideal shock-absorber for the monsoon rains than a Banj forest.

The chir pine produces just the opposite effect. It creates with its pine needles a smooth, dry carpet, which absorbs nothing and which at the same time prevents the development of any undergrowth worth the name. In fact, often the ground in a chir pine forest is as bare as a desert. When the torrential rains of the monsoon beat down on these southern slopes of the Himalayas, much of the pine-needle carpet gets washed away with the water and erosion invariably takes place, because these needles, being non-absorbent, create no leaf-mould, but only a little very inferior soil, which is easily washed out from the rocks and stones.

Inheriting these early lessons in ecology, Bahuguna was later able to transfer this ecological perspective to Chipko. The rapid spread of resistance in the hills of Uttar Pradesh and its success in enforcing changes in forest management was also largely due to the awareness created by folk poets like *Ghanshyam Raturi,* grassroots organisational efforts of a number of people including *Man Singh Rawat, Chandi Prasad Bhatt and Dhoom Sing Negi. Bhatt,* who later became well known for his work, became an activist at the behest of Bahuguna in 1959 when they met at a bus station in Gopeshwar where Bhatt was working as a booking clerk and Bahuguna, along with Rawat and Raturi, was waiting for a bus during an organisational trip through Gopeshwar. Having found Bhatt a promising activist, Bahuguna invited him to join them.

The Chipko movement is the contemporary expression of a continuing heritage of peaceful resistance by the people of Uttarakhand. In the post-independence period, under the coordination of Sarala Behn, the Gandhians organised themselves into the *Uttarakhand Sarvodaya Mandal* in 1961. The Sarvodaya movement in the sixties was organised around four major issues.

(i) The organisation of women.

(ii) Fight against alcohol consumption.

(iii) Fight for forest rights.

(iv) The establishment of local, forest based small industries.

While the fight against alcohol consumption provided the platform for the organisation of women, the increasing conflict over forest produce between the local and non-local industries provided the rallying point for popular protest during the sixties. In 1968 the people of Garhwal renewed their resolve to fight for their forests in a memorial meeting held at Tilari on 30 May.

The platform for the organisation of women was thus ready by the seventies and this decade saw the beginning of more frequent and more vocal popular protests on the rights of the people to protect and utilise local forests. In 1971 *Swami Chidanandji* of Rishikesh undertook a month-long march to bless the people in their struggle. The year 1972 witnessed the most widespread organised protests

against commercial exploitation of Himalayan forests by outside contractors in Uttarkashi on 12 December, and in Gopeshwar on 15 December. It was during these two protest meetings that Raturi composed the famous poem describing the method of embracing the trees to save them from felling.

While the concept of saving trees from felling by embracing them is old in Indian culture, as was the case of Bishnois, in the context of the current phase of the movement for forest rights in Uttarakhand this popular poem written in 1972 is the earliest source of the now famous name *'Chipko'*. In 1973 the tempo of the movement in the two centres— Uttarkashi and Gopeshwar— reached new heights. Raturi and Bhatt were the main organisers in these two places. While a meeting of the Sarvodaya Mandal was in progress in Gopeshwar in April 1973, the first popular action to chase contractors away erupted spontaneously in the region, when the villagers demonstrated against the felling of ash trees in Mandal forest. Bahuguna immediately asked his colleagues to proceed on a foot march in Chamoli district following the axemen and encouraging people to oppose them whereever they went. Later in December 1973, there was a militant non-violent demonstration in Uttarkashi in which thousands of people participated. In March 1974, twenty-seven women under the leadership of *Goura Devi* saved a large number of trees from a contractor's axe in Renj. Following this, the government was forced to abolish the private contract system of felling and in 1975 the Uttar Pradesh Forest Corporation was set up to perform this function. *This was the first major achievement of the movement and marks the end of a phase in itself.*

Bureaucratisation, however, cannot replace a civilisational response to the forest crisis. The ecological limits to forest extraction was hardly recognised and estimated. Ecological problems were accentuated leading to increased suffering of women who were responsible for bringing water, collecting fodder, etc. During the next five years Chipko resistance for forest protection spread to various parts of the Garhwal Himalayas. It is important to note that it was no longer the old demand for a supply of forest products for local small industries but the new demand for ecological control on forest resource extraction to ensure a supply of water and fodder that was being aired. In May 1977 Chipko activists in Henwal Valley organised themselves for future actions. In June of the same year, *Sarala Behn* organised a meeting of all the activists in the hill areas of Uttar Pradesh which further strengthened the movement and consolidated the *resistance to commercial felling as well as excessive tapping of resin from the Chir pine trees.* In Gotars forests in the Tehri range the forest ranger was transferred because of his inability to curb illegal over-tapping of resin. Consciousness was so high that in the Jogidanda area of the Saklana range, the public sector corporation, Garhwal Mandal Vikas Nigam, was asked to regulate its resin-tapping activity.

Among the numerous instances of Chipko's successes throughout the Garhwal Himalayas in the years to follow, are those in Adwani, Amarsar and Badiyargarh. The auction of Adwani forests took place in October 1977 in Narendernagar, the district headquarters. *Bahuguna* undertook a fast against the auction and appealed to the forest contractors as well as the district authorities to refrain from auctioning the forests. The auction was undertaken despite the expression of popular discontent. In the first week of December 1977, the Adwani forsts were scheduled to be felled. Large groups of

women led by *Bachhni Devi* came forward to save the forests. Interestingly, Bachhni Devi was the wife of the local village head, who was himself a contractor. Chipko activist *Dhoom Singh Negi* supported the women's struggle by undertaking a fast in the forest itself. Women tied sacred threats to the trees as a symbol of a vow of protection. Between 13 and 20 December a large number of women from fifteen villages guarded the forests while discourses on the role of forests in Indian life from ancient texts continued non-stop. It was here in Adwani that the ecological slogan : *'What do the forests bear? Soil, water and pure air'* was born.

The axemen withdrew only to return on 1 February 1978 with two truckloads of armed police. The plan was to encircle the forests with the help of the police in order to keep the people away during the felling operation. Even before the police could reach the area volunteers of the movement entered the forests and explained their case to the forest labourers who had been brought in from distant places. By the time the contractors arrived with the police each tree was being guarded by three volunteers who embraced the trees. The police, having been defeated in their own plan and seeing the level of awareness among the people, hastily withdrew before nightfall.

In March 1978 a new auction was planned in Narendranagar. A large popular demonstration was organised against it and the police arrested twenty-three Chipko volunteers, including women. In December 1978 a massive felling programme was planned by the public sector Uttar Pradesh Forest Development Corporation in the Badiyargarh region. The local people instantly informed *Bahuguna* who started a fast unto death at the felling site, on 9 January 1979. On the eleventh day of his fast Bahuguna was arrested in the middle of the night. This act only served to further strengthen the comitment of the people. Folk poet *Ghanashyam Raturi* and priest *Khima Shastri* led the movement as thousands of men and women from the neighbouring villages joined them in the Badiyargarh forests. The people remained in the forests and guarded the trees for eleven days, when the contractors finally withdrew. Bahuguna was released from jail on 31 January 1979.

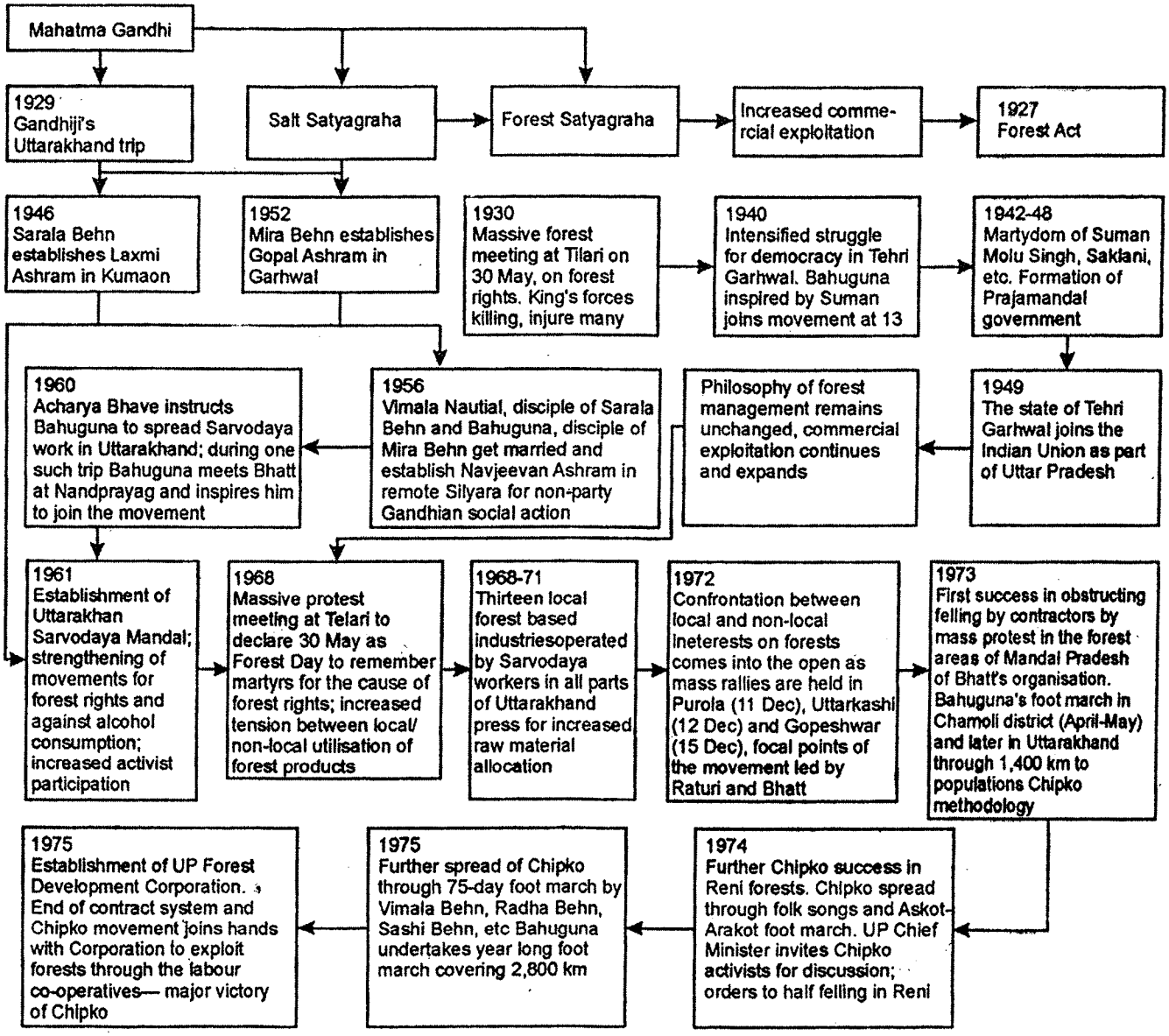
The cumulative impact of the sustained grassroots struggles to protect forests was a re-thinking of the forest management strategy in the hill areas. The Chipko demand for the declaration of the Himalayan forests as protection forests instead of production forests for commercial exploitation was recoghised at the highest policy making level. The late Prime Minister, *Mrs. Indira Gandhi*, after a meeting with Bahuguna, recommended a fifteen year ban on commercial green felling in the Himalayan forests of Uttar Pradesh.

The moratorium on green felling gave the Chipko movement breathing time to expand the base of the movement and *Bahuguna* undertook a 4,780 km long arduous Chipko foot march from Kashmir to Kohima to contact villagers in the long Himalayan range and to spread the message of Chipko. At the same time, activists found it opportune to spread the movement to other mountain regions of the country. *Chipko* became a message, a vision and a symbol so much so that other forest movements like the *Appiko Movement in Karnataka*, was consciously built on the *Chipko* model. Environmental movements like the Narmada Bachao Andolan and the anti-dam movement at Tehri could attract popular

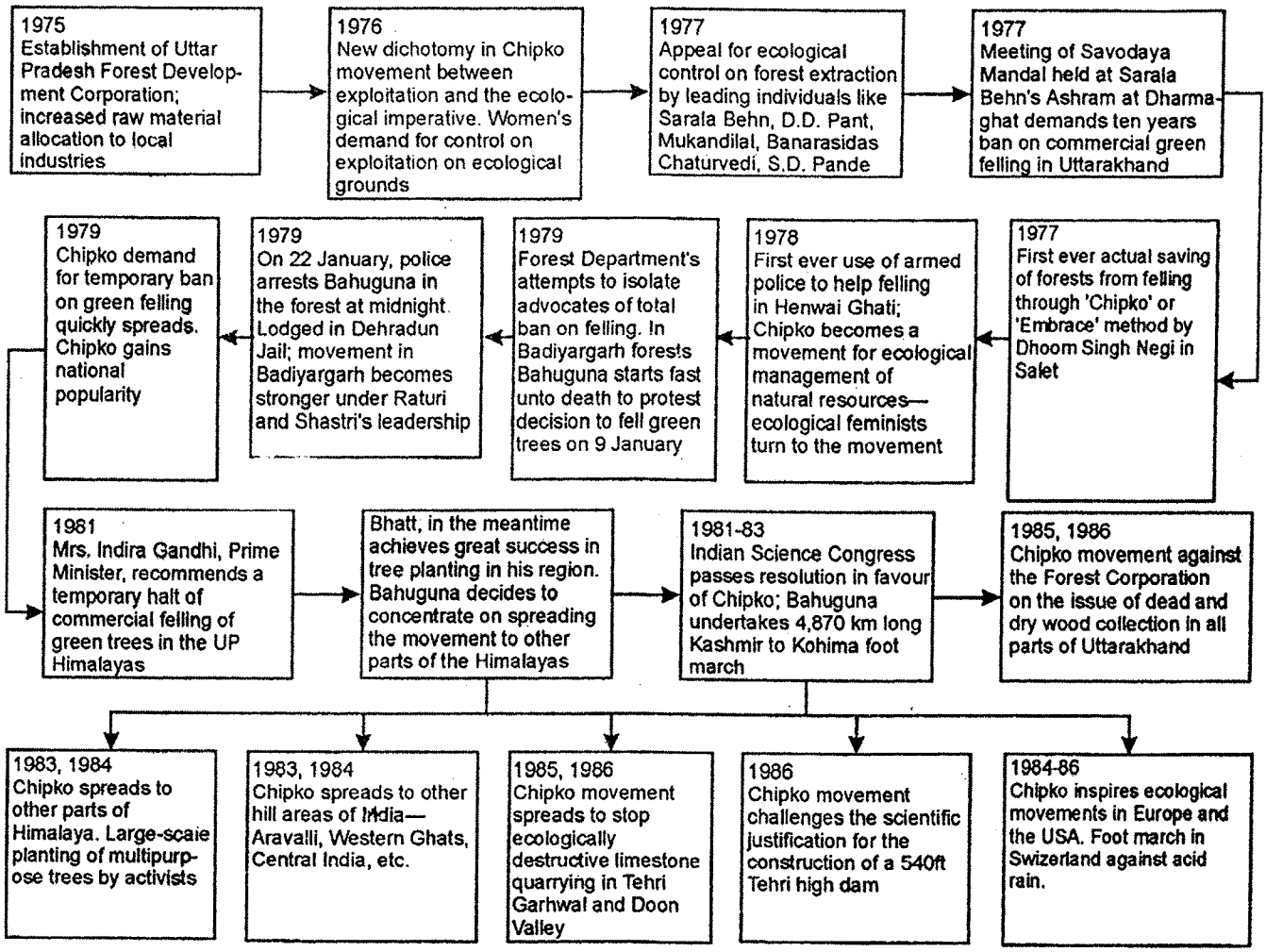
attention partly due to milieu Chipko so vitally helped to create.

■ Schematic Diagram of the Dynamics of Chipko Movement in India ■

The evolution of the chipko Movement (Ist. phase up to 1974)



The Evolution of the Chipko Movement (2nd. Phase upto 1986)



■ Ecological Foundation of the Chipko Movement

Both the earlier forest satyagrahas and their contemporary form the Chipko movement, are rooted in conflicts over forest resources and are similar cultural responses to forest destruction. What differentiates Chipko from the earlier struggles is its ecological basis. The new concern to save and protect forests through Chipko satyagraha did not arise from a resentment against further encroachment on people's access to forest resources. It was a response to the alarming signals of rapid ecological destalisation in the hills. Villages that were once self-sufficient in food were forced to import food as a result of declining food productivity. This, in turn, was related to the decrease in soil fertility in the forests. Water sources began to dry up as forests disappeared. The so-called 'natural disasters', such as floods and landslides, began to occur in river systems which had hitherto been stable. The Alaknanda disaster of July 1970 inundated 1,000 km of land in the hills and washed away many bridges and roads. In 1977 the Tawaghat tragedy took an even heavier toll. In 1978 the Bhagirathi blockade resulting from a big landslide above Uttarkashi led to massive floods across the entire Gangetic plains.

The over-exploitation of forest resources and the resulting threat to communities living in the forests have evolved from concerns for distribution of material benefits to concerns for distribution of ecologically generated material costs. During the first stage, the growth of commercial interests resulted in efforts to exclude competing demands. The beginning of large-scale commercial exploitation of India's forest resources led to the need for a forest legislation which denied village communities' access to forest resources. The forest satyagrahas of the thirties were an outcome of the Forest Act of 1927 which denied people access to biomass for survival while increasing biomass production for industrial and commercial growth. The growth imperative, however, drove production for commercial purposes into the second stage of conflict which is at the ecological level. Scientific and technical knowledge of forestry included in the existing model of forest management, is limited to viewing forests only as sources of commercial timber. This gives rise to prescriptions for forest management which are basically manipulations *to maximise immediate growth of commercial wood.* This is achieved initially by the destruction of other biomass forms that have lower commercial value but may be very important to the people, or have tremendous ecological significance. The silvicultural system of modern forestry includes prescriptions for the destruction of non-commercial biomass forms to ensure the increased production of commercial biomass forms. The encouragement to substitute ecologically valuable oak forests by commercially valuable conifers is an example of this shift. Ultimately, this increase in production may be described as mining of the ecological capital of forest ecosystems which have evolved over thousands of years.

The contemporary *Chipko movement, which has become a national campaign, is the result of these multidimensional conflicts over forest resources at the scientific, technical, economic and ecological levels.* It is not merely a conflict confined to local or non-local distribution of forest resources, such as timber and resin. The Chipko demand, at one stage was for a larger share for the local people in the immediate commercial benefits of an ecologically destructive pattern of forest resource exploitation. It has now evolved to the demand for ecological rehabilitation. Since the *Chipko movement is based upon the perception of forests in their ecological context, it exposes the social and ecological costs of short-term growth-oriented forest management.* This is clearly seen in the slogan of the Chipko movement which claims that the *main products of the forests are not timber or resin, but soil, water and oxygen.* With proper social control the basic biomass needs of food, fuel, fodder, small timber, and fertiliser can, in the Chipko vision and the Garhwal practice, be satisfied as positive externalities of biomass production primarily aimed at soil and water conservation to stabilise the local agro-pastoral economy.

The Chipko movement has been successful in forcing a fifteen year ban on commercial green felling in the hills of Uttar Pradesh, in stopping clear felling in the Western Ghats and the Vindhyas, and in generating pressure for a national forest policy which is more sensitive of people's needs and to the ecological development of the country. Unfortunately, the Chipko movement has often been presented by vested interests as a reflection of a conflict between 'development' and ecological concern', implying that 'development' relates to material and objective bases of life whereas 'ecology'

is concerned with non-material and subjective factors, such as scenic beauty. The deliberate introduction of this false and dangerous dichotomy between 'development' and 'ecology' disguises the real dichotomy between ecologically sound development and unsustainable and ecologically destructive economic growth. The latter is always achieved through the destruction of life-support systems and material deprivation of marginal communities. Genuine development can only be based on ecological stability which ensures sustainable supplies of vital resources. Gandhi and later his disciples, Mira Behn and Sarala Behn, clearly described how and why development is not necessarily contradictory to ecological stability. *The conflict between exploitative economic growth and ecological development implies that, by questioning the destructive process of growth, ecological movements like Chipko are not an obstacle to the process of providing material welfare. On the contrary, by constantly keeping ecological stability in focus, they provide the best guarantee for ensuring a stable material basis for life.*

- **Important Features of the Chipko Movement :**

Some important features of the Chipko Movement are—

i) The village women were mainly in the forefront of the agitation in many areas.

ii) Chipko movement was not an isolated movement. It may be viewed as eloquent phase in the long chain of peasant resistance in the Garhwal region of the Himalayas.

iii) It was a reactive movement in the sense that the Government's apathy to the development activities undertaken by the *'Dashauli Gram Swaraj Sangh'*, led the latter to take to more action oriented programmes which culminated into Chipko Movement.

iv) Chipko activists did not remained confined only to agitational politics. While opposing the destructive development strategy promoted by the state, they also took up constructive programmes like plantation of those trees which are suitable for local ecology. Their focus on ecology as permanent economy transformed the movement to a paradigmatic conflict.

v) Sundarlal Bahuguna had undertaken a long trans-Himalayan (Kashmir to Kohima) foot-march to make people aware of the importance of Himalayan forests and sustainable economy. Thus Chipko became a message, a vision and a symbol so much so that other forest movements like the *Appiko movement* in Karnataka, were consciously built on the Chipko model.

vi) The general political situation obtaining in the hills of UP also contributed to whatever success Chipko could achieve. Lack of economic development and political marginalisation had generated considerable grievances among the local people leading to a number of movements culminating in the now-famous *Uttarakhand Movement.* Chipko developed in this already prevailing environment of economic deprivation and political discontent.

vii) Mobilizing capacity of the movement was that many of its leaders could successfully utilize *traditional* cultural idioms. Gandhian leaders took to *Satyagraha, long marches* and *fast-unto-death* which resembled the struggle against British rule. Similarly, recitations from the Gita, offering pujas and tieing *rakhis*— all these traditional Hindu practices resorted to during

movements could give solemnity to the cause. It was widely perceived as a fight against the evil forces represented, in this case, by the Government-bania nexum.

viii) Chipko reflects ideological plurality in Indian environmentalism. Personality as well ideological differences have been expressed between two of its prominant leaders— *Sundarlal Bahuguna and Chandi Prasad Bhatt.* Ideologically, Bahuguna is overtly and completely a follower of Gandhi and Vinobha Bhave. In Bhatt, however, one can find a synthesis of Gandhian and Western socialism-ideologically closure to J. P. Narayan and R. M. Lohia. Bahuguna seems to prefer a return to the pre-industrial economy. Bhatt, on the other hand, is more interested in alternative path to industrialization with political and economic decentralisation.

- **Chipko (Locally known as - Appiko Chaluvali) Movement in South India :**

Chipko (Locally known as - Appiko Chaluvali) Movement in South India is a struggle against commercial forest policy. The destruction of tropical natural forests and the raising of monoculture plantations of teak and Eucalyptus caused irreversible changes in the forest ecosystem. The destruction of mixed species denied people access to biomass for fodder, fertiliser, etc. The clear felling of natural forests has led to severe soil erosion and drying up of perennial water resources. Moved by the destruction of essential ecological processes, *the youth of Salkani village in Sirsi launched a Chipko movement which was locally known as 'Appiko Chaluvali'.* They embraced the trees to be felled by contractors of the forest department. The protest within the forest continued for thirty-eight days and finally the felling orders were withdrawn. The success of this agitation spread to other places and the movement has now been launched in eight areas covering the entire *Sirsi forest division in Uttara Khanda and Shimoga districts.* These areas included Mathghatta, Salkani, Balegadde, Husei, Nedgod, Kelgin Jaddi, Vanalli and Andagi. The rapid spread of the movement was based on evidence provided by villagers that the forest department was over-exploiting the forests. Villagers' complaints were later confirmed by official visits by scientists and politicians. In the forest of Kalase, with an area of 151.75 hectares earmarked for selection-cum-improvement felling for the year 1983-84, a total of 590 trees above the girth limit of 2 metres was earmarked for felling. The Indian Plywood Mills had extracted a total of 125 trees belonging to eight species in the 1982-83 season. Thus a total of 715 trees spread over 151.75 hectares, or 4.05 trees per hectare were to be extracted. With an additional 5 per cent added for damage, the total number expected to be felled was 4.25 trees per hectare.

Representative of the *Lakshminarasimha Yuvak Mandali* who launched the Appiko movement in September 1983 maintained that (a) there was an exessive concentration of trees earmarked for felling in easily accessible areas, and (b) there was excessive damage to trees during the course of felling. In 1 hectare plot sampled it was found that eleven trees had been marked for cutting, out of which eight had been felled. In the process of felling these eight trees, as many as five trees had been damaged. This rapacious destruction of forest resources was undermining the ecological survival of local communities, who finally stopped felling through non-violent direct action as seen in the case of Chipko.

▲ **Objective of the Appiko movement :**

i) To protect the existing forest cover,

ii) To regenerate trees in denuded lands and,

iii) To utilise forest wealth with due consideration to conservation.

All these objectives are implementated through locally established Parisara Samrakshna Kendras (environmental conservation centres).

The Appiko movement has created awareness among villagers throughout the Western Ghats about the ecological destruction of their forest wealth. People now closely monitor the exploitation of forests by the forest department, and have been able to show the discrepancy between professed and actual practice of forest management. In December 1984, villagers of Gerasoppo range of Honavar forest division were able to record the felling practices and damage to forests due to timber exploitation. Their observations were as follows :

Forest Rule	***Actual Practice***
1. No tree will be felled on slopes and catchment areas of rivers (protection forests).	Trees are felled in catchment areas of Sharavati river (Honavar forest division on steep slopes).
2. In evergreen forest areas only two trees per acre will be felled.	In evergreen forest areas seven trees were felled in one acre (Marked).
3. Minimum girth of trees felled should be 2.5 metres.	Two marked trees (Nos. 542 and 111) felled had a girth of 1.80 metres and 1.50 metres, respectively. Thirty-seven trees, with a girth of over 50 cms, and thirty-two trees, with a girth of over 10 cms were damaged.
4. The distance to be maintained from one tree to another tree to be felled should be 50 metres.	The distance from tree No. 75 to tree No. 90 which had to be felled was only 4.60 metres.
5. Trees to be felled shall be lopped of their branches to reduce damage.	No lopping was done while felling trees.
6. No tree either dead, diseased or green should be felled near streams or the water line.	Eight trees felled on an 80 degree slope, seven trees felled on a 75 degree slope, and ten trees were felled on the water line.
7. Dragging of logs is not allowed.	Dragging of logs was done extensively all over the place.

The top soil up to six inches was ripped off totally by dragging logs. This soil will be carried to the Sharavati river, raise its bed and the water level, and cause floods in an area which receives 250 inches of rainfall every year. Besides destabilising the catchment area, commercial exploitation has

also deprived people of their use of forest biomass for basic needs. An 80-year old man, *Rama Naik* of Mattingadde village, narrated his experience.

> "We had enough of medicinal trees. There was enough bamboo and cane for us. But after independence the felling of trees began and now everything is gone. There was no cane left. People's greed to make fast money has ruined us."

In the context of this conflict between commercial demands and the demands for ecological stability and survival, the *Appiko activists believe in the Chipko philosophy that 'the basic products of the forests in the Western Ghats are soil, water and pure air'* which form the basis of life in the Deccan Plateau. They are not fuelwood and timber which are regarded as ultimate products from these forests in the market economy.

- So, the slogan of nature exploitater (Western Philosophy) :

  What do the forest bear?
  Profit on resin and Timber.

- But, Chipko's (Indian Philosophy) lesson :

  What do the forest bear?
  Soil, water and pure air.

- Bahuguna's slogan : **'Ecology is permanent economy.'**

▲ ***History of Chipko (Appiko Chaluvali) Movement in South India (In Tabular Form)*** ▲

Date	*Details*	*Purpose of Felling*	*Local Problems*	*Type of Forest*	*Distance from Salkani(km)*	*Remarks*
8 September 1983 I	150 women and 30 women from Salkani, Balegadde, Monondoor, etc. walked five miles to Kalase-Kudergod forest. They hugged trees and stopped the axemen, who were felling trees under the orders of the forest department.	For commercial purpose, to obtain timber.	The only patch of forest left near these villages to obtain fuelwood and fodder, honey, etc.,— forest invaded by epitorium weed.	Mixed tropical semi-evergreen Forest growth in midst of big boulders.	8	Chipko spreads to South India. Demand of people total ban on felling of green trees. People ready to sacrifice their lives for this cause
22 September	Forest officials and experts visit the area and spot. Promise of people's involvement in felling decisions.		People's sentiments ignored completely.	Forest growth in midst of big boulders.		
29 September	Felling starts again in this forest. The people launch the movement and hug trees.		People's support (total)	Laterite soil.		
14 October	The labourers of forest contractors leave the felling sites.					

Date	*Details*	*Purpose of Felling*	*Local Problems*	*Type of Forest*	*Distance from Salkani(km)*	*Remarks*
16 October II	Movement started by people in Bengaon forest. It was launched by the people spontaneously! Sixty people most of them tribals hugged the trees to save them.	For timber	People are tribals dependent on the forest for survival: disappearance of bamboo. Wild pigs destroy the crop. Drying up of water resources.	Mixed tropical semi-evergreen Hilly slopes. Canopy opened.	40	Movement in second place began on its own!
18 October	The movement in Bengaon gains momentum. 150 people gather to support the movement.					Very sparse habitat and gathering of 150 people is a great achievement.
23 October III	The movement begins in Husri forest. 100 men and women join hands and stop felling through Chipko.	For timber. For fuelwood needs of Sirsi town. Clear felling to plant commercial species.	Deciduous forest. Village Monoculture of teak and eucalyptus has affected agricultural yield. Wild pigs have increased in number. Fuelwood shortage. Wood for agricultural impliments not available. People are mostly labourers.	Deciduous forest. Mixed varieties. Useful to farmers.	36 From Sirsi 6 km.	Appiko initiates people to launch the movement.

■ Ecological Marxist :

Ecological Marxists are activists considered to be intectually broad and believers in Marxism with environmental concern. They have unflinching loyality to socialism and modern science. Unlike the Gandhians, they fight against tradition by spreading scientific spirit among the people. Unlike the alternative technologists they give precedence to political actions for systemic change rather than local, disparate constructive efforts.

■ Chipko as an Environmental Movement :

Chipko lies in a path of continuity with earlier peasant struggles in Uttarakhand; at the same time, as an organised and sustained *New Social Movement* (NSM). Private face of Chipko is a quintessential peasant movement; and its public profile is a celebrated environmental movement in the world. Thus,

while the last Chipko agitation in Uttarakhand occurred in 1980, the movement's activists have since been tirelessly propagating its message concerned about environment. Within the Himalaya, foot-marches and environmental camps are organised at regular intervals. There has also been a significant attempt to contribute to the environment debate in India and abroad.

- **Six-Point charter (Spelt out by Sarvoday workers of Uttarakhand, 1973)**

1. Abolition of the auction/contractor system and the formation of forest labour cooperative.
2. People's participation in forest management and protection to be institutionalise through the gram sabha, the area samiti, district councils and forest panchayats.
3. Establishment of local, small-scale forest based industries to generate employment.
4. A new forest settlement to determine the people's rights to forest produce, such as fuel wood and fodder.
5. Assistance to village efforts to afforestation.
6. Ban on felling green trees in areas critical for the protection of water sources and the prevention of landslides.

- **Chipko Charter (by Sarvoday leader, Chandi Prasad Bhatt, 1986; presented at a meeting of environmental activist)**

1. To understand what the forest itself wants and to analyse the socioeconomic conditions of the people in order to establish the type of forestry required.
2. To identify and reserve areas affected by landslides and erosion, or crucial for the conservation of water resources.
3. To establish minimum needs of people living next to forests and an administration such that these rights may be easily exercised.
4. Complete stoppage of the contractor system, and instead the people to be organised to undertake conservation, development and exploitation work in forests.
5. Trees of use to villagers to be planted near the village so that people do not need to enter the reserved forests.
6. Village industries based on minor forest products to be set up to prevent migration.

- **Lessons from Chipko Movement**

(i) It has given a lesson that dichotomy between *'development'* and *'environment'* can be reduced to what is 'development and how scientific knowledge is generated and used to achieve it. Only 'development' slogan was—

"What do the forest bear?
Profit on resin and timber."

on the other hand ecological science was captured in the slogan :

"What do the forest bear?
Soil, water and pure air."

(ii) The movement underwent a qualitative transformation from being based merely on conflicts over resources to conflicts over scientific perceptions and philosophical approaches to nature.

(iii) The movement has laid the foundation of an alternative forestry science which is ecological in nature and oriented towards public interest.

Forests are not only commercial interest; they are not only timber mines of commercially valuable species. *Scientific forestry* does not ignore the complex relationship within the forest community and between the plant life and other resources like soil and water. The destruction of the forest ecosystem adversely affects the economic interests of those groups of society which depend on the diverse resource functions of forests for their survival. Chipko movement gave an alternative *scientific forestry* which save guard public interest also. For tribals and other forest communities a complex forest-ecosystem is productive interms of herbs, tubers, fibres, the gene pool etc.

(iv) Chipko's demand is conservation of not merely local forest resources but the entire life-support system, and with it the option for human survival. So, it has global implications.

■ 4.4.5 DAMS (General Feature)

Dams have made significant contributions to human development and, benefits derived from them have been considerable. Several major dams in peninsular India were built, or planned, before independence. The *Periyardam* (Kerala) came up in the late nineteenth century; the uncut tree stumps submerged by its reservoir are now a valuable refuge for wildlife. Other early dams were the *Krishnarajasagar* (now a popular tourist site in Mysore), *Mettur* (Tamil Nadu), *Nizamsagar* (Hyderabad), *Tungabadhra* (Andhra Pradesh), *Bhakra* (Himachal Pradesh) and *Hirakud* (Orissa). All were made of masonry, except Bhakra which is a gigantic concrete dam. Many small masonry structures built in ancient India are still in use, the most famous of them is said to be a 5.5 m high second-century *Chola dam* across the mouth of the Cauvery.

After independence, the need for hastening economic growth, increasing food production and establishing core industries, required a tremendous spurt in irrigation and power generation. *The harnessing of river waters for irrigation, flood control and the generation of hydroelectric power became a central feature of development policy.* India's monsoon climate provides a seasonal abundance of rainfall, and the ensuing problem of flooding rivers, Storage reservoirs seemed the best solution to prevent floods, and to conserve the water for the dry season. This could be released when required, and could also be used to generate power. India's topography provided some suitable sites where the river valleys narrowed sufficiently to be blocked by a dam, as at *Hirkud* (Orissa), *Bhakra*

(Himachal Pradesh) or *Nagarjunasagar* (Andhra Pradesh). For the young nation each of these multipurpose river valley projects was an enormous technical challenge. Their successful completion inspired tremendous nationalistic pride.

The debate on big dams in India emerged only in the late 1970s, after the controversy over a proposed hydroelectric project in *Silent Valley*— an uninhabited, biologically-rich tropical rain forest, one of the last remnants of its kind in the country. Despite the persistence of the pro-dam Left Front Government in Kerala, envirnmentalists suceeded in pressuring the Central Government to abandan the project. The Kerala Sastra Sahitya Parishad (KSSP) which led the campaign, was able to mobilise journalists and other professionals and had the critical support of senior scientist administrators like M. S. Swaminathan and M. G. K. Menon. Since then there have been several agitations against big dams— *Bedthi* (Karnataka), *Bhopalpatnam* (Madhya Pradesh-Maharashtra), *Tehri* (Uttar Pradesh), *Suvarnarekha* (Bihar). *Inchampalli* (Madhya Pradesh-Andhra Pradesh), and the current movement against the *Narmada aams*.

Most of the India's river valleys are highly populated and rivers have provided the primary life support systems for our riparian settlements. Large dams, intensive irrigation and large diversions have been ordinarily associated with three types of conflicts :

(i) *First Type* of conflict is related to large-scale displacement and uprooting of people from their ancestral home-lands leading to *ecological refugees*. Here human rights issues are intimately linked with ecological issues.

(ii) *Second Type* of conflict arises from the ecological impact of impounding large quantities of water, transporting it across drainage boundaries and using it for intensive irrigation. Displaced people are, of course, in direct conflict with those who benefit from large dams and massive irrigation systems. However, when dams and canals cause water logging, even the beneficiaries fight against state planned water projects.

(iii) *Third Type* of conflict which is an outcome of large river diversions is regional conflict (or interstate conflicts) over water rights.

■ Dams and Civilization (Global Scenario)

About eight thousand years ago, the Sumerians built an irrigation-based civilization between the Tigris and Euphrates rivers. By the first century B.C, low dams had been built in the Mediterranean, the Middle East, Central America, and China. Limited technology kept their height down : a fifth-century Sri Lankan dam, 34 m high, was the worlds highest for a millennium. The age of the hydropower and large dams emerged following the *development of the turbine in 1832.* In the beginning of the century, hydro electric plants were operating in the United States, Italy and Norway. Improvements in turbine design ushered in the mega-dam boom in the 1930s. During the last century, much of the world turned to dams to help meet escalating demands for water. Indeed, *from the 1930s to the 1970s the construction of large dams became synonyms with development and economic progress.* Viewed

as symbols of modernization and humanity's ability to control and use nature's resources, dam construction saw a dramatic increase. This trend reached *a peak in the 1970s, when on average two or three new large dams were commissioned each day somewhere in the world.* The decline in dam building since then has been equally dramatic, especially in North America and Europe, where most technically attractive sites are already developed. Today, most of the world's large rivers are dammed. Worldwide, some 45000 "large" dams *(over 15 m high, according to the International Commission on Large Dams)* and about 800000 smaller ones have been constructed. Men have built dams for thousands of years for the following purposes :

(i) Conversion of available water to usable water. 1.4 billion-km^3 of water is available in the world in form of liquid water, ice and water vapour, 97% is sea water.

(ii) Reducing variability in seasons of low flow in rivers.

(iii) Water storage to provide insurance against uncertainty in natural water availability due to climatic variability.

(iv) Regulating release of water for various uses such as drinking and irrigation.

(v) Safety from social and economic tragedies due to flood and drought conditions.

(vi) Sustainable energy generation.

- **Characterwise Dam-Distribution in the world :**
  - Most of the single purpose dams around the world (48% approx.) are for irrigation and therefore it contributes greatly to food production and a considerable proportion (15%) of those dams serve for domestic and industrial water supply.
  - For the world as a whole, nearly 20% of dams generate electricity. However, in Europe alone, about 40% are hydro power dams.
  - Other purposes include flood control (8%), recreation (4%) and to a lesser degree, inland navigation and fish farming.
  - Multi-purpose dams account for a large proportion. Irrigation comes first in this category also, followed by flood control, hydro power, domestic and industrial water supply and recreation, with fish farming and navigation.
  - In India, more than 80% of the rain occur during monsoon (100 days span— 45 rainy days) and 60-80% precipitation occur in just 6-8 intense rainfall spells. Harness it where and when we can— in situ; by extending residence time to encourage infiltration/groundwater recharge; by digging, repairing, replenishing tanks, ponds wetlands; watershed management, building little check dams, small and medium irrigation works. Even if we do all that, we still need large dams to store the excess water.

- **Benefits from Dams :**

At present, out of the 45000 large dams in the world, two-thirds are in the Peoples Republic of China. Asia, North America and Europe account for more than 95% of dams built. Africa is marginal in these statistics with hardly more than a few hundred. Dams have made a major contribution to the progress of human societies, enabling them to control their water resources for human needs :

(i) 40% of world food production comes from irrigated farming, with a direct 16% contribution from land irrigated from dam reservoirs. 30-40% of the 268 million hectares of irrigated land is watered from dams.

(ii) Hydro-electric power produces 19% of world energy and is used in more than 150 countries. It accounts for more than 90% of all energy in 24 countries and more than 50% in 63 countries.

(iii) 12% of large dams supply towns and cities with water (60% in North America).

(iv) 13% of the world's dams help control river floods and flooding in nearly 75 countries.

(v) Some dams have helped improve ecosystems by creating new wetlands and new opportunities for fishing and recreation in the reservoirs.

(vi) Dams have made an important and significant contribution to human development, and the benefits derived from them have been considerable.

- **Problem with Dams :**

Some of the problems which are commonly associated with dams are —

(i) Most of the world's large dams have been unable to achieve the technical, economic and social objectives for which they were designed. Many of them have typically fallen short of physical targets, did not recover their costs and have been less profitable in economic terms than expected. Large dams built for municipal and industrial water supply have generally fallen short of intended targets for timing and delivery of bulk water supply and have exhibited poor financial cost recovery and economic performance.

(ii) The impacts of large dams on ecosystems are more negative than positive and in many cases, this has led to serious irrecoverable loss of species and ecosystems. It is impossible to mitigate many of the effects of new reservoirs on ecosystems and terrestrial biodiversity, and efforts to 'save' wild species have not been affective in the long term.

(iii) Large dams have serious consequences on the living conditions and culture of populations, especially indigenous people. They have displaced large numbers of people, who, when resettled, have been unable to recover acceptable conditions of existence. People affected by the negative impacts have not always enjoyed the benefits from the dam.

(iv) The loss of forest and wildlife habitat and the degradation of upstream catchment areas due

to inundation of the reservoir area.

(v) The loss of aquatic biodiversity, of upstream and downstream fisheries, and of the services of downstream floodplains, wetlands, and riverine, estuarine and adjacent marine ecosystems.

(vi) Cumulative impacts on water quality, natural flooding and species composition where a number of dams are sited on the same river.

(vii) Sedimentation and the consequent long-term loss of storage is a serious concern globally, and the effects will be particularly felt by basins with high geological or human-induced erosion rates, dams in the lower reaches of rivers and dams with smaller storage volumes.

(viii) Waterlogging and salinity affect one-fifth of irrigated land globally (including land irrigated by large dams) and have serve, long-term and often permanent impacts on land, agriculture and livelihoods where rehabilation is not undertaken.

(ix) In too many cases an unacceptable and often unnecessary price has been paid to secure the benefits, especially in social and environmental terms, by people displaced, by communities downstream, by taxpayers and by the natural environment.

(x) Lack of equity in the distribution of benefits has called into question the value of many dams in meeting water and energy development needs when compared with the alternatives.

(xi) By bringing to the table all those whose rights are involved and who bear the risks associated with different options for water and energy resources development, the conditions for a positive resolution of competing interests and conflicts can be created.

Socioeconomic Impacts of Dams :

(i) Poorly managed involuntary displacement and loss of livelihood.

(ii) Many of the displaced people were not recognized and therefore were not resettled or compensated.

(iii) Depriving the indigenous people of the means to support traditional ways of life, particularly in case of culturally vulnerable indigenous/ethnic minority groups which are largely dependent on locally available natural resources.

(iv) Higher incidences of waterborne diseases particularly among vulnerable communities.

(v) Low Regional economic development reforms and inadequate distribution of project benefits to affected communities.

(vi) It is not possible to mitigate many of the impacts of reservoir creation on terrestrial ecosystems and biodiversity, and efforts to 'rescue' wildlife have met with little long-term success.

(vii) The use of fish passes to mitigate the blockage of migratory fish has had little success, as the technology has often not been tailored to specific sites and species.

(viii) Some 40-80 million people have been physically displaced by dam worldwide.

(ix) Millions of people living downstream from dams (particularly those depending on natural flood plain function and fisheries) have also suffered serious harm to their livelihoods and the future productivity of their resources has been put at risk.

(x) Where compensation was provided it was often inadequate, and where the physically displaced were enumerated, many were not included in resettlement programmes.

(xi) Those who were resettled rarely had their livelihoods restored, as resettlement programmes have focused on physical relocation rather than the economic and social development of the displaced.

(xii) The larger the magnitude of displacement, the less likely it is that the livelihoods of affected communities can be restored.

- **Ethical Dilemma with Dams :**

The following is a list of issues leading to an ethical dilemma for decision makers :

(i) Rights of a small numbers of locally affected population versus flights of large number of potential beneficiaries.

(ii) Conservation of natural resources in the context of satisfaction of essential human needs by exploiting those natural resources.

(iii) Increased production of wealth to support growing needs versus fair distribution of accumulated wealth.

(iv) Standards of international donors and lending agencies versus standards of less developed beneficiary countries.

(v) If we are going to have sustainable development, we can't leave the environment totally pristine. This is a trade-off that we must accept, though impacts on the environment can and should be minimized.

(vi) There are more good dams that bad ones. The bad dams are the shallow ones that flood large areas on land, or that produce relatively little power. In the tropics these dams are associated with diseases like schistosomiasis and malaria but these are not a problem in temperate areas.

- **Displacement due to dams :**

Displacement is often regarded as a one time phenomenon by which a person is forced to leave his/her original location and go elsewhere. Displacement by definition in involuntary

Displacement needs to be viewed as a process rather than an event which starts much before the actual physical displacement and continues for a long time after uprootment has taken place. Displacement is not a single event, but a series of happenings, affecting human lives in many ways. In most cases, there is a gap of not just years but decades between the first announcement of the

dam and its completion. As a consequence, areas likely to be submerged stop getting funds for building or maintaining infrastructure. Government itself encourages deforestation in the catchment areas, as in the case of *Sardar Sarovar dam in Gujrat*. This period is likely to be marked with uncertainty and fear as systematic information about the date and extent of submergence is almost never imparted. Indigenous and tribal people and vulnerable ethnic minorities have suffered disproportionate levels of displacement and negative impacts on livelihood, culture and spiritual existence. Affected populations living near reservoirs as well as displaced people and downstream communities have often faced adverse health and livelihood outcomes from environmental change and social disruption. Among affected communities, gender gaps have widened and women have frequently borne a disproportionate share of the social costs and were often determinated against in the sharing of benefits.

- **Possible Solutions to minimise problems with Dams :**

Public acceptance of key decisions is essential and sustainable water and energy resources development. Acceptance emerges from recognizing rights, addressing risks, and safeguarding the entitlements of all groups of affected people, particularly indigenous and tribal peoples, women and other vulnerable groups. The following actions could improve the acceptability and minimise the problems of a dam project.

(i) Avoid and minimize ecosystem impacts.

(ii) Engage in participatory, multi-criteria analysis of development needs and options.

(iii) Ensure that displaced and project-affected peoples' livelihoods are improved.

(iv) Resolve past inequities and injustices, and transform project-affected people into beneficiaries.

(v) Conduct regular monitoring and periodic review.

(vi) Develop, apply and enforce incentives, sanctions and corrections mechanisms— especially in the area of environmental and social performance.

(vii) Recognition of rights and assessment of risks should be the basis for the identification and inclusion of stakeholders in decision making on energy and water resources development.

(viii) Access to information, legal and other support should be made available to all stakeholders, particularly indigenous and tribal peoples, women and other vulnerable groups, to enable their informed participation in decision making processes.

(ix) Demonstrable public acceptance of all key decisions should be achieved through agreements negotiated in an open and transparent process conducted in good faith and with the informed participation of all stakeholders.

(x) Decisions on projects affecting indigenous and tribal peoples should be guided by their free, prior and informed consent, achieved through formal and informal representative bodies.

(xi) Corrupt practices should be avoided through enforcement of legislation, voluntary integrity pacts, debarment and other instruments.

(xii) National water policies should make specific provision for basin agreements in shared river basins. Agreements may be negotiated on the basis of good faith among riparian States. They should be based on principles of equitable and reasonable utilization, no significant harm, prior information and the Commission's strategic priorities.

(xiii) Riparian states may go beyond looking at water as a finite commodity to be divided and embrace an approach that equitably allocates not the water, but the benefits that can be derived from it. Where appropriate, negotiations include benefits outside the river basin and other aspects of mutual interest.

(xiv) Dams on shared rivers may not be built in cases where riparian states raise an objection that is upheld by an independent panel. Disputes between countries can be resolved through various means of dispute resolution including, in the last instance, the International Court of Justice.

[N.B. : Now-a-days, in the United States and France, large dams are being decommissioned as their high maintenance costs and damage to fisheries have become intolerable. Mega-dams may be a symbol of development in India, but they are beginning to seem an obsolete technology elsewhere in the world.]

■ 4.4.6 Silent Valley Project

Silent valley is situated in Kerala. It is a secluded forest tucked away in the Ghats, not far from Ooty.

Why is the name "Silent Valley"?

Many conflicting explanations have been given for the name Silent Valley. The version now accepted is that an Englishman Wandering through the forest christened it 'Silent Valley' because of the silence that descends on it at night fall. The silence is due mainly to the absence of the insect *cicada*, whose comforting call resounds in most other forests at night.

● **About the Valley :** Because Silent Valley has always been difficult to reach, even on foot, it has remained a well preserved forest. The total area of the valley is 9,000 ha; and it is surrounded by high ridges (long narrow top). It is one of the few places in India with no human habitation— not even a tribal village.

Silent Valley is a *'shola forest'* (*Shola* is thick vegetation found at the base of the valleys in the Western hills of South India). It is a store house of rare and valuable plants and animals. Scientists have found several varieties of wild pepper. Cardamom grows wild as do black gram, rice bean and *urad dal*. Several plants are the source of important drugs. The evergreen forest trees *'Hydnocarpus'*, whose seeds contain the oil used to treat leprosy; and the herb-like shrub *'Reuvolfia Surpentina'*

used for treating high blood pressure, are two examples. Rare fauna include the *'Lion Tail Macaque', Great Indian Harnbill'* and *'Nilgiri Tahr.* Silent valley is one of World's richest biological and genetic heritages.

● **Lion-Tailed Macaque (*Macaca Silenus*) :**



Lion-Tailed Macaque is an endanged primate. It is restricted to the Western Ghats of South India where it is found only in the wet evergreen forests and some shoals.

These gregarious monkeys live in troops consisting between 12 to 20 individuals. They almost exclusively live on the canopy of the evergreen forests where they move with at a leisurely pace searching for food. They seldom descent to the ground. Being omnivores, they feed on fruits., leaves, insects and other small animals.

The Lion tailed Macaque is the only Indian macaque with a black colored coat. It measures 50-60 cm including head and body with the tail measuring another 30-40 cm. The females are slightly smaller. An interesting feature is the short tail that ends in a tassel of hairs, very similar to that of the lion, earning it the name.

Their dark colour, their habit of living in dimly lit forests and their shy nature make spotting this macaque difficult. However, their occasional call to communicate with members of the troop can give away their presence. Their call resembles the loud cough of a man. Lion-Tailed Macaques of Silent valley in Kerala would have been a thing of the past, but for the public protest against the proposed dam across the *Kunthipuzha River.*

● **Starting Point of Environmental Dispute :**

In the middle 1970s, *Kerala state Electricity Board* (KSEB) prepared the proposal to build a dam across the *Kuntipuzha river* and create a reservoir in silent valley, in Kerala's Palghat district. As it flows through the valley, the Kuntipuzha drops 857 m, making the valley an attractive site for generating hydroelectricity. The proposal claimed that, (i) 24 MW power will be generated, (ii) 10,000 ha of land can be irrigated; (iii) 2000 jobs may be provided. The dam, which could be 130m high, would be built between two hillocks in a gorge through which the river runs.

If was almost by accident that the proposal came to the attention of an official in the central Government. Concerned about the protection of India's environment he asked for the project to be reconsidered. The issue came up before prime Minister Indira Gandhi, She appointed a committee in 1980 to look into the matter and to give a report. The committee pointed out that Silent Valley was the last remaining example of flora and fauna that had evolved to the fullest possible extent in a *tropical rain forest* and was an ecosystem undisturbed by human interference. Were that dam to be built, the unique ecosystem might be irretrievably lost.

The committee suggested that the dam either be dropped or if it had to be constructed, it be completed with certain safeguards. KSEB was eager to build the dam, so agreed to the committee's conditions. ***Silent Valley Project was one of the rare occasions where other than money or material benefits environmental matter was taken into consideration***

A non-govt organisation (NGO), Known as *Kerala Sastra Sahithya Parishad (KSSP)* got interested in Silent Valley. KSSP's own members were teachers of physics, Chemistry and biology. Initially they gave scientific arguments for protection of environment instead of development (i.e. production of electricity). The idea of conserving a virgin forest for its flora and fauna seemed irrelevant to the people living near the proposed dam and the inhabitants of the northern districts of Kerala who were suffering from acute shortage of electricity and unemployment. *The silent valley struggle needed to consider not only the ecological and aesthetic value of the valley but also the socio economic implications of the submergence of several thousand trees in the hills.* With these needs in view KSSP conducted its own studies to show why the valley should not be destroyed and how the same amount of electricity could be obtained in other ways.

● **Output of KSSP's studies**

i) Benefits of producing electricity would go only to a few people as two thirds of Kerala's electricity was consumed by industries which employed only a few thousand people.

ii) The submergence of vast areas of forest would destroy the source of energy as district from electricity of a large number of people who depend on firewood to cook.

Scientific bodies of botanists, zoologists and geologists, set up by the central Government, lent support to KSSP's findings. They backed KSSP's contention that rather than an overall decline in rainfall, deforestation (due to construction of dam) in evergreen forests such as Silent Valley results in an increase in the number of dry days in the monsoon season. This means fewer rainy days but heavier rainfall. In the absence of tree cover, the run off of soil increases, thereby degrading the land in the area.

● **Features of the Protest**

KSSP was able to rouse public opinion on the need to save Silent Valley.

i) KSSP had many science groups in villages, brought out journal and newsletters, and had an impressive membership of 7,000 thinking people.

ii) KSSP collected signatures of around 600 teachers, prominent citizens and students and sent a memorandum to the Kerala Government.

iii) KSSP organised street plays, exhibitions, public debates, and a unique '*jatha*' (a marathon march) covering 300 to 400 villages along its 6,000 km route.

iv) Some leading intellectuals of Kerala wrote letters and articles in the press and participated in the public debates.

v) Students (School, College & University) across Kerala carried slogan and placards proclaiming their opposition to the project.

This was the first time in India that teenagers came out on the streets of protest against the destruction of the environment.

vi) Eminent persons like Dr. Salem Ali, K.P.S. Menon and different academic organisation supported the KSSP's movement on Silent Valley Project.

vii) Kerala State Electricity Board (KESB) was supported by the local people near the dam who were convinced that they would find jobs either directly during construction or later from industries which would come up subsequently in the area. KSSP worked hard to convince the people that the promised benefits were only illusory and were not going to be sustained.

viii) **Lion-tailed Macaque,** an inhabitant of Silent Valley forest is one of the most threatened species of monkey in the world. The survival of this monkey became an issue contested by the pro and anti-Silent Valley dam campaigners. Questions were raised about the importance and priority given to the monkey over the benefits that would accrue to humans by building the dam. The debate attracted wide attention, and ultimately a resolution was passed by IUCN (the World Conservation Union) asking the Indian government to conserve more effectively the forest areas of the Western Ghats, including the undisturbed forests of Silent Valley in Kerala.

● **Effect of the Movement**

On the basis of an examination of the costs and benefits as well as the pressure put on the Kerala government by Indira Gandhi who returned to power in 1980, the scales tilted against the project. Silent Valley was declared a *National Park* in 1985 by Prime Minister Rajib Gandhi, Which meant that *No project could come up in the area.* Silent Valley Project was abandoned.

In case of failure of the movement the adverse effects that the state would face are :

- *The deforestation (must for construction of dam) was bound to affect the climatic conditions in the state and even outside, by depriving the state of its legitimate share of rain during the monsoon;*
- *The preservation of forests was needed for conducting research in medicine, pest control, breeding of economic plants and a variety of biological purposes. If silent valley forest was not preserved, such type of activities could not be implemented.*
- *The deforestation was bound to interfere with the balance of nature, as between the forest land on one side and arable & others types of lands on the other.*

Silent Valley Project is regarded as the India's first major '*environment versus development*' controversy.

■ 4.4.7 Narmada River Dams

The *Narmada River springs from a holy pool amidst Hindu temples on the Amarkantak plateau* in the forested Shahdol district of Madhya Pradesh, and then winds westwards along a 1,300 kilometer course to drain into the Arabian sea. The Narmada is one of the India's most sacred rivers. A verse in the ancient *Matsya Purana* commands those who wish to wash away their sins to bathe three times in the *Saraswati River,* seven times in the *Yamuna* or once in the *Ganga,* but if it is the *Narmada* that one visits mere sight of the river is cleansing enough.

The Narmada basin drains an area of 98, 796 square kilometers and is home to 21 million people, nearly 80 percent of whom live in villages. About a quarter basin is covered in moist and dry deciduous forests and about 60 percent of black soils composed of silty clay with low permeability.

Although the *Narmada Valley Project* was conceived in 1946, final planning and work on it commenced only after the *Narmada Water Disputes Tribunal* passed its final orders in 1978. This tribunal was established in 1969 under *India's Interstate Water Disputes Act* of 1956 to resolve the dispute on river-water sharing among the riparian states of *Madhya Pradesh, Gujarat and Maharashtra.* The tribunal also laid down conditions regarding resettlement and rehabilitation of the people to be displaced by the submergence the 'oustees'.

The *Narmada Valley Project,* if and when completed, will rank as the largest irrigation project ever planned and implemented as a single unit anywhere in the world. By the year 2040, the project authorities hope to complete *31 major dams* (11 on the Narmada and 20 on its tributaries), *135 medium dams* and *3000 minor dams.* Out of the 31 major dams, the ones most controversial are the *Sardar Sarovar Project* (SSP) in *Gujrat* and the *Narmada (Indira) Sagar Project (NSP) in Mahyapradesh.* The NSP, which has the largest submergence zone and will create biggest artificial reservoir in India, is years behind the SSP in construction.

'*Narmada River Project*' is a multi crore project that will generate a big revenue for the Government. The Narmada Valley Development plan is the most promised and most challenging plan in the history of India. The proponents are of the view that it will produce 1450 MW of electricity and pure drinking water to 40 million people covering thousands of villages and towns. Some of the dams have already been completed such as *Tawa* and *Bargi Dams.*

The *Sardar Sarovar Project* (SSP) has gained international notoriety due to intense opposition by villagers. Led by the *'Narmada Bachao Andolan'* (Save the Narmada movement), activists and villagers forced the World Bank to withdraw from the project in the early 1990s. A case filed with the Indian Supreme Court stopped construction of the Dam for nearly six years. However, on October 18, 2000, the Indian Supreme Court issued a controversial final ruling allowing construction to proceed.

About 200,000 people would be displaced for the reservoir; hundreds of thousands more will

loose land or livelihood due to related developments. Thousands of people who have been resettled are struggling to survive on cramped plots with no arable land or source of livelihood. Faced with these future prospects, villagers have vowed to remain on their lands and face submergence behind the party built dam rather than face a life of certain destitution. People affected by the extensive canal system are not considered as project-affected people and are not entitled to the same resettlement and compensation packages as those living in the reservoir area Hundreds of thousands of people whose land or livelihoods are affected by either project-related developments or downstream impacts are not entitled to any compensation at all.

There are no credible environmental studies or rehabilitation plans. Although the legal framework requires that affected people be given land - for-land compensation, there is no land available for resettlement. Conditional environmental clearance was given to the project in June 1987, although basic environmental impact studies required under the Indian law were never completed and even today remain incomplete.

The benefits of SSP have been greatly exaggerated. The project is expected to generate only 50 MW (1450 MW planned) after seasonal water flow and power consumption for pumping water is accounted for. The project is supposed to irrigate 1.9 million hectares and provide drinking water to over 20 million people. However, these benefits are based on over estimates of annual flow in the river and assume extremely high irrigation efficiency. The costs for building drinking water distribution systems have not been considered into the project's cost. The arid Kutch region will not receive any water supply benefits until 2025, if ever. Still the Gujrat state Government continues to spend 80 percent of its irrigation budget on SSP at the cost of implementing viable alternatives.

According to *'Narmada Bachao Andolan'* :

i) The hydroproject will devastate human lives and biodiversity by destroying thousand of acres of forests and agricultural land.

ii) The project will deprive thousands of people of their livelihood.

iii) According to their demand, water and energy could be provided to the people through alternative technological means, that would be ecologically beneficial.

To day, the international movement against the Narmada dams has become the celebrated *symbol of the 'Green' cause.*

■ 4.4.8 Narmada Bachao Andolan (NBA)

'Narmada Bachao Andolan' is a non-governmental organisation (NGO) that mobilised tribal people, *adivasis,* farmers, environmentalists and human rights activists against the *Sardar Sarovar Dam* being built across the Narmada River, Gujrat, India. Medha Patkar established 'Normada Bachao Andolan in 1989.

It originally focussed on the environmental issues related to trees that would be submerged

under the dam water. In 1985, after hearing about the Sardar Sarovar Dam. *Medha Patkar* and her colleagues visited the project site and noticed the project work being shelved due to an order by the *Ministry of Environment and Forests,* Government of India. The reasons for this was cited as "non-fulfillment of basic environmental conditions and lack of completion of crucial studies and plans." What she noticed was that the people who were going to be affected were given no information, but for the offer for rehabilitation. Due to this, the villagers had many questions right from why their permission was not taken to whether a good assessment on the ensuing destruction was taken. Furthermore, the officials related to the project had no answers to their questions. Through Patkar's channel of communication between the government and the residents she provided critiques to the project authorities and governments involved. At the same time, her group realized that *all those displaced was given compensation for the immediate standing crop and not for displacement and rehabilitation.*

● ***Mode of campaign and feature of the movement :***

The mode of campaign includes hunger strikes, mass- media publicities etc.

As *Patkar* remained immersed in the Normada struggle, she chose to quit her Ph. D studies and focus entirely on the Normada activity. Thereafter, she organised a 36-*day long, solidarity march* among the neighbouring states of the Narmada valley from Madhya Pradesh to the Sardar Sarovar Dam site. *Medha Patkar* said that the march was "a path symbolizing a long path of struggle". This march was resisted by the police, who according to Patkar were "Caning the marchers and arresting them and tearing the clothes off women activists."

Patkar further undertook a fast in 1993 and resisted evacuation from the dam site. In 1994, The Narmada Bachao Andolan office was attacked reportedly by a couple of political parties, where Patkar and other activists were physically assaulted and verbally abused. In protest a few NBA activists and Patkar began a fast and 20 days later, they were arrested and forcibly fed intravenously. Due to the movement, the World Bank's participation in the projects was canceled in 1995.

Numerous local NGOs coalesced to form the Narmada Bachao Andolan (NBA) in response to the construction of the Sardar Sarovar Dam along the Narmada river in the Indian state of Gujarat. The local movement, with the help of the international coalition of NGOs, was able to spread information throughout the world with hearings, symposiums and tours. Hence, 'Narmada Bachao Andolan' became international in character.

The slogan (Mantra) of the Narmada Bachao Andolan which inspired the local people was : ***"Hamara gaon mein hamara raj' (our villages, our rule).***

Again, the internationalization of the local movements challenges the *state sovereignlty.* This becomes evident as one looks at the internalization of the Narmada Bachao Andolan. In this connection, it may be mentioned that *'State sovereignty'* is composed of borders, both geographical and national. When these borders dissolve and the state no longer has total supremacy over its

territory, its sovereignty declines. With increasing globalizations international actors are eroding state sovereignty. Transnational alliances between northern environmental NGOs and the local resistance movements allow for the transmission of money and information across the borders. New identities also form as a result of the connections, as happened in case of Narmada Bachao Andolan.

Many celebrities have shown their support for the 'Narmada Bachao Andolan' – as for example : Booker Prize winner *Arundhati Roy* and actor *Aamir Khan.* In 1996 veteran documentary film maker, *Anand Patwardhan* made an award-winning documentary on this issue, titled *'A Narmada Diary'*. For leading the environmental movement, *Medha Patkar* was awarded *'Right Livelihood Award'* in 1991. Press Information Bureau (PIB), after the supreme Court's verdict wrote :

"The Narmada Bachao Andolan has rendered a yeoman's service to the country by creating a high-level of awareness about the environmental and rehabilitation and relief aspects of Srdar Sarovar and other projects on the Narmada. But, after the court's verdict it is incumbent on it to adopt a new role. Instead of 'damning the dam' any longer, it could assume the role of vigilant observer to see that the resettlement work is as humane and painless as possible and that the environment aspects are taken due care of."

■ 4.4.9 Sustainable Development :

The term *'sustainable development' ordinarily is defined as the development, which satisfies the needs of the present without compromising the ability of future generation to satisfy their needs.* Thus it aims at balancing the needs of present and future generation and gives importance on *'eco-justice'* and *'eco-efficiency'*. While eco-justice ensures rights of all persons to environmental resources, eco-efficiency ensures conserving energy and input per unit of output.

The two buzz words of the new millennium lexicon are *'globalisation'* and *'sustainable development'*. In the initial stages we were concerned with economic growth or prosperity which was mainly the indicator of the national wealth a country was producing year after year. It was thus a narrowly defined 'income' or wealth and prosperity' based view and its only parameter was country's real income, i.e. Gross Domestic Product (GDP). It, however, did not take much long to realize that it is not the country's wealth alone but the welfare of its people that is most important. Economic growth must become inclusive, every person, a common man at large, should be its stake holder. He should enjoy the betterment of his living standard. It is not wealth generation alone, but wealth distribution that is important. Thus we moved ahead from growth to growth plus equity.

$$\boxed{\text{Growth} \Rightarrow \text{Growth} + \text{Equity}}$$

This was the concept of economic development. To-day we have moved beyond this. Equity as was conventionally understood was a static concept. It took into consideration the equality of opportunity to people at a given point of time. But what about equality of opportunity over a period of time? What if using the opportunity to improve the standard of living to-day reduces or destroys similar opportunities for generations to come? Are we using up the resources over which they also

have their rightful claims? In other words we need to look at the problem of equity not only among people at a given point of time, but among people across different generations over a period of time. That precisely is the concept of sustainability of development or *sustainable development.*

- According to Webster's, New International Dictionary, *"sustain* — to cause of continue (as in existence or a certain state, or in force or intensity); to keep up, especially *without interruption diminution,* flagging, etc; to prolong."
- Considering the globe as a whole 'sustainable development' means— improving the quality of human life while living within the carrying capacity of supporting ecosystems.
- Sustainability is the 'long-term, cultural, economic and environmental health and vitality with emphasis on long-term, together with the importance of linking our social, financial, and environmental well-being.'
- Sustainability is the simple principle of taking from the Earth only what it can provide indefinitely, thus leaving future generation no less than we have access to ourselves.

It may be stated that sustainable development is constrained by :

(i) what the nature/earth has to offer (*carrying capacity*)

(ii) what we can take from it while not undetermining the future generations.

(iii) improvements of standard of living for present generation within the above constraints.

Carrying capacity of an ecosystem means the size of the population that can be supported indefinitely on the available resources and services of that ecosystem. *Living within the limits of an ecosystem* depends on three factors :

(a) the amount of resources available in the ecosystem;

(b) the size of the population;

(c) the amount of resources each individual is consuming.

Illustration : Let us consider a case of survival in a lifeboat after a shipwreck. The survival of number of people in the lifeboat depends on how much food and water are reserved; how much each person eats and drinks each day; and how many days they are afloat. If the lifeboat is replaced by an island, how long the people survived would depend on the food and water supply on the island and how wisely they used it. A small desert island will support far fewer people than a large continent with abundant water and fertile soil for growing crops.

Here food and water are the *natural capital* of the island. *'Living within the carrying capacity'* means using those supplies no faster than they are replenished by the island's environment : using the 'interest' income of the natural capital. A community that is living off the interest of its community capital is living within the carrying capacity. A community that is degrading or destroying the ecosystem on which it depends is using up its community capital is living

unsustainability. In this respect it can be mentioned :

"Nature has enough to satisfy every person's need not any person's greed."

— Mahatma Gandhi

Community sustainability is living within the carrying capacity of the community's human, social and built capital. Carrying capacity is much harder to measure for these types of capital, but the basic concept is the same.

Some example are :

1. A community that allows its children to be poorly educated, undernourished, and poorly housed is eroding its *human capital.*
2. A community that allows the quality of its social interactions to decline through lack of trust, respect and tolerance is eroding its *social capital.*
3. A community that allows its buildings, roads, parks, power facilities, water facilities and waste processing capability to decay is eroding its *built capital.* Additionally, a community that is creating built capital without considering the future maintenance of that capital is setting itself up for eventual decay.

The population dynamics of the world is as follows :

Table

Time taken to add 1 billion population on the earth :

1st billion population	2 million years
2nd billion population	130 years
3rd billion population	30 years
4th billion population	15 years
5th billion population	12 years

The massive population size and its mind boggling speed of growth has created serious concerns as to how and whether the earth's resources will be enough to ensure the sustainance to this growing population.

Modern definition :

Sustainable development in the ability to make development- choice which respects the relationship between the three "Es"— Economy, Ecology and Equality.

- *Economy :* Economic activity should serve common good, be self renewing and should build local assets and self reliance.
- *Ecology :* It should involve the realization that humans are part of nature, nature has limits and communities are responsible for protecting and building natural assets.

- *Equality :* The opportunity for all for full participation in all activities, benefits and decision making of a society at a given point of time as well as protecting the rightful claims of future generations.

If these ingredients are incorporated in the national goals of all countries then it should be possible to develop *sustainable society*. Such a society would be characterized by an emphasis on preserving the environment, developing strong peaceful relationships between people and nations and an emphasis on equitable distribution of wealth.

If these three essential ingredients are treated separately, very often it presents dilemma like :

(i) *'if the environmentalist win the economy suffers';*

or, (ii) *'if business has its way the environment will be destroyed'.*

Actually *economy-environment linkage* is one area where we have to have *'win-win solution'* and not *'win-looser solution'*. No body can afford to be a loser, we all are on one side only, and there are no two sides to this coin of sustainable community development. There has to a holistic solution and not a piecemeal solution.

▲ Problems related to Piecemeal Solution

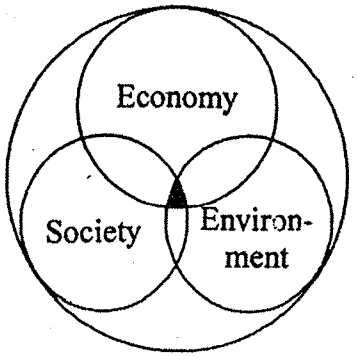
(a) Solution to one problem can make another problem worse.

Example : Creating affordable housing is a good thing, but when that housing is built in areas, it results increased traffic and the related pollution problems.

(b) Opposite groups are automatically created and they are always in a fighting mood.

(c) Short term benefits can not give long terms results.

Sustainability requires *integrated view* of the world— it requires multidimensional indicators that show the links among a community's economy, environment and society.



Integrated View of Sustainability

▲ Green Accounting :

Green accounting essentially concentrates on depletion of environmental capital. Conventionally the physical capital so much dominated the thinking, policy as well as practice that the natural capital

and its depreciation was overlooked. This is corrected through the system of *Green Accounting.*

● **SNNP (Sustainable Net National Product) :**

On the basis of 'Green Accounting' one indication is developed which is known as *'Sustainable Net National Product (SNNP)'*. SNNP is calculated as :

SNNP = GNNP (Gross National Product) – (deffensive expenditure + cost of unmitigated pollution + depreciation of man-made capital + depreciation of environmental capital).

The corporate units are persuaded by pollution control boards in different countries to take steps to comply with the prescribed standards. They are awarded special incentives if they change over to Green Technology or make efforts to reduce the amount of pollution they generate year on year basis. The credit is given in terms of *carbon points* or carbon credits.

Indicators of sustainability are different from traditional indicators of economic, social, and environmental progress.

Traditional indicators — such as stakeholder- profits, asthma rates and water quality — measure changes in one part of a community as if they were entirely independent of the other parts. *Sustainability indicators reflect the reality that the three different segments are very tightly interconnected.*

First and fore most, we all must realize that environment protection is not a charity. It can not be done through philanthropy alone. It has to be achieved through participation and empowerment.

Secondly, *not only is environment protection not charity, but also a business and must be treated like one.* Business is about optimization choices, so are the choices relating sustainable development. Environment is just like any other business and therefore should be dealt with like any other business applying business principles. It can be remembered that basis of any business is exchange and the purpose of any business is not maximize the outcome of business.

▲ **Some tools to assess the impact :**

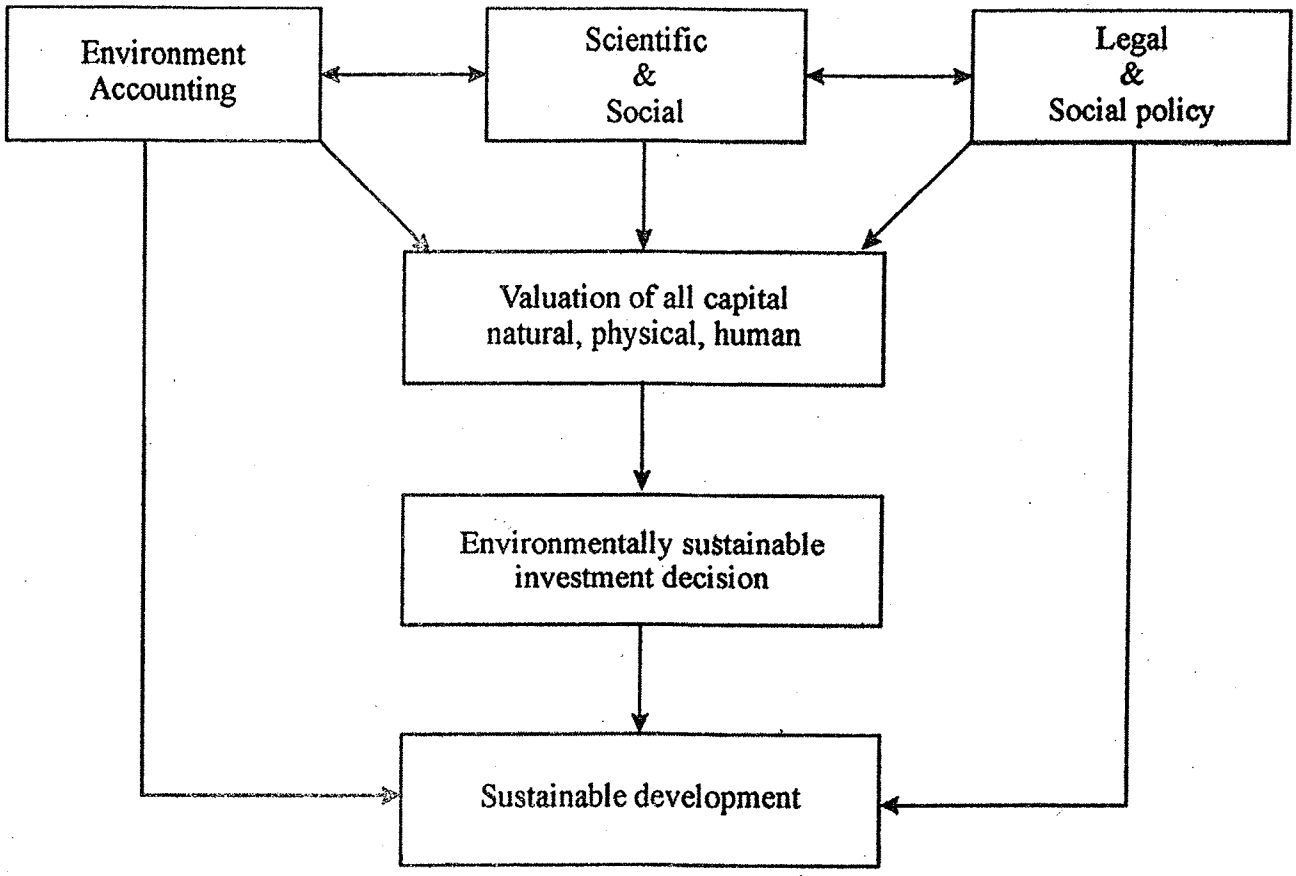
Efforts are being made to assess the impact of economy on environment by developing various tools. Some of them concentrate on the rate of use of earth's reproducible resources in different parts of the world to maintain their current standard of living. One such tool is *ecological foot print.*

● *Ecological foot print :*

Ecological foot print is defined as the hectors of gland required to sustain the present consumption levels considering the reproducible natural resources incorporated in it. Some rough estimates indicate that if the developed countries want to maintain their present rate of resource consumption we would need 10 to 12 Earths to sustain it. That essentially indicates that the world is moving at rate faster than the one that can be sustained in the long run.

▲ Sustainable development and civil society :

We must treat environmental issues by making them a part of larger economic issues and develops a holistic approach. One broad mechanism is given below :



The problem of sustainable development need not be very untractable. We have various solutions looming on the horizon. As for example, the use and varied applications of solar energy gives us a new hope as a substitute for fuel problem. The constant research pertaining to 'green technology and chemistry', bio-technology and nano-technology now offers us a series of solutions to overcome the serious problem of depletion of natural resources and environmental degradation.

■ 4.4.10 Self Assessment Questions

A. Short Answer Type Questions.

1. What do you mean by the term 'development' in the context of environment.
2. What are the common features of 'social movement'?
3. What is 'New Social Movement'?
4. What did give rise to 'Chipko Movement'?
5. What is the contribution of Mira Behn in Chipko Movement?
6. What was the ecological slogan in Chipko Movement?
7. What is 'Appiko Movement'?
8. What are the objectives of the Appiko Movement?
9. What do you mean by the term 'Ecological Marxist'?
10. What are the lessons of the Chipko Movement?
11. What are the common conflicts associated with large dams
12. What are the purposes of the dams?
13. What is the contribution of lion-tailed Macaque in silent Valley Project Movement?
14. Why the silent valley is designated as silent?
15. 'Silent Valley Project is regarded as the India's first major environment versus development controversy' – do you agree? Give arguments of your answer.
16. What would be the adverse effects in case of failure of the silent valley movement?
17. What is the main controversy with Sardar Sarovar Project?
18. Name two celebrities who give support to Narmada Bachao Andolan.
19. Define sustainable development.
20. What is 'ecological foot print'?

B. Essay Type Questions

1. Write a short note on 'Environment and Development Debate'.
2. Write the features of 'Environmental Movements'.
3. Give an account of the important features of Chipko Movement.
4. Write the benefits and problems with dams.
5. Write notes on : (a) Socioeconomic Impacts of Dams; (b) Ethical Dilemma with Dams; (c) Possible solutions to minimise problems with Dams.
6. What do you know about the movement on Silent Valley Project? Write the features of the protest.
7. Give a brief outline of Narmada River Dams and Narmada Bachao Andolan.
8. What is 'green accounting'? — Explain with example.
9. Write notes on 'sustainable development'.
10. Write the contribution of Medha Patkar in Narmada Bachao Andolan.

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"Learner's Feed-back"

After going through the Modules Units please answer the following questionnaire.
Cut he portion and send the same to the Directorate.

To
The Director
Directorate of Distance Education,
Vidyasagar University,
Midnapore - 721 101.

1. The modules are : (give √ in appropriate box)
   ☐ easily understandable : ☐ very hard : ☐ partially understandable.

2. Write the number of the Modules/Units which are very difficult to understand :
   .....
   .....
   .....

3. Write the number of the Moduels/ Units which according to you should be re-written.
   .....
   .....
   .....

4. Which portion/page is not understandable to you? (mention the page no. and portion)
   .....
   .....
   .....
   .....

5. Write a short comment about the study material as a learner.
   .....
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.....
(Full Signature of the Learner)

Date : .....

Enrolment No. .....

Phone /Mobile No. .....



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