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ENS 601

Atmosphere and Climate Change

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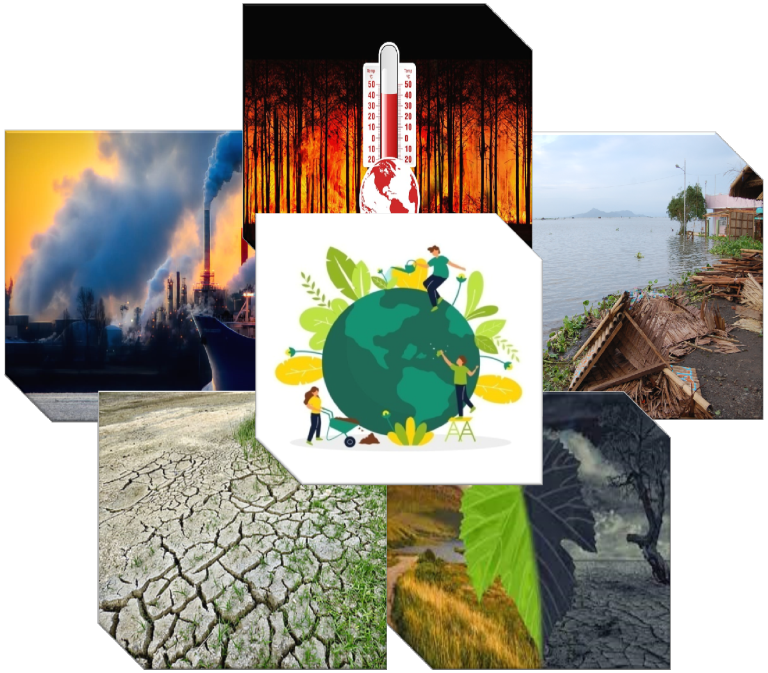

Department of Forestry and Environmental Science
School of Earth and Environmental Science

Uttarakhand Open University
Haldwani, Nainital (U.K.)

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Atmosphere and Climate Change

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Unit 1: The Earth

Unit Structure

1.0 Learning Objectives

After completion of this unit you will be able to:

- explain the formation of Solar system;
- describe the concept of inner and outer planets;
- explain the formation of Earth;
- discuss the internal structure of Earth; the atmosphere and hydrosphere of Earth;
- describe the gravitational, thermal and magnetic fields of Earth; and
- Outline the concept and significance of geological time scale

1.1 Introduction

The envelope of gas and or dust particles that surrounds the various celestial bodies of the universe, due to the force of gravity is called atmosphere. On the other hand, space is the void region that exists beyond celestial bodies. When we look at the scheme of things across scales we come across a very striking similarity. On the lower side, if we consider an atom as the most basic unit of our Universe, we will see that only a tiny fraction of it is occupied by matter i.e. the sub atomic particles like proton, neutrons and electrons and the rest are void space. Similar is true on the other side of the scale. It is the vast emptiness of the universe which is interspersed with various celestial entities like stars, planets, satellites and asteroids. These aforesaid entities are arranged in numerous local groups such as galaxies (kind of a mini universe), clusters, super clusters and filaments of galaxies. None of the above celestial units or groups are static, they are in continuous move and undergoing changes, whether small or big, by every passing moment of time. Further, evidences suggest that the universe is expanding, that is the volume of space inside it is increasing.

Scientific community agrees well to the fact that the same laws of nature govern the entire cosmos; however, we witness a variety of phenomena across space. Why it is so? Take for example, the atmosphere of our planet Earth which also encourages to flourish various life forms is significantly different than its known neighbours like Mercury, Venus, Sun or Moon. The properties of the atmosphere such as thickness, density, chemical or gaseous composition on different bodies of the universe and the weather phenomena unfolding there vary depending on many factors. These factors can be like the size and mass of the primordial matter from which an existing body has formed; mechanism of evolution; evolutionary phase (i.e. stage of formation or age); physical or chemical reactions that are taking place; location inside the universe/galaxy and distance from the neighbouring celestial bodies. An examination of facts about the phenomena happening in space and in the atmosphere of celestial bodies will help intimate ourselves with our own Universe and to dispel various myths.

1.2 Origin of the Universe and Origin of the Earth

Scientists have theorized that at the beginning, the entire universe (and for that matter its entire mass or energy and space) was confined within a very very tiny dot (call it, the ancient primordial matter) as happens when a dying star becomes a black hole. Enormous compression within such a tiny dimension due to the effects of gravity might have caused a condition that Einstein’s equation terms as “singularity” (a point where the laws of physics would simply break down). It is quite possible that all the matter was in the form of pure energy as compression of the massive mass of the universe in such small volume would result in unimaginable amount of heat. Then a destabilizing moment came with an explosion of the space, also termed as big bang (albeit without noise probably as propagation of sound waves requires a medium like air which was non-existent at that time) followed by formation of various types of entities (e.g. nebula, galaxy, protostar, star, binary stars, proplanetary disc or proplyd, planet, natural satellite or moon, asteroids) of the universe which is a continuous process. The astounding explosion that brought out our universe, although billions of years ago, has left its imprint all across the universe in the form of remnant energy, known as cosmic microwave background radiation (CMBR). Occasionally, gamma rays (the most energetic form of light in the universe) are produced in very intense bursts of jets so powerful that more energy is released in few seconds than the sun would produce during its entire lifespan of 10 billion years.

A star is born as a gigantic ball of very hot dense gas, not a solid. In course of time, most stars develop their own planetary systems (exception being the binary stars) where a central star is surrounded and orbited by a number of planets and some of the planets may again be orbited by one or many number of moons (natural satellites). Such an arrangement happens to conserve angular momentum (a measure of the consistency of angular motion) which is one of the many laws of nature. Another law of physics whose effect is omnipresent all across the universe is the law of gravity. Due to the immense mass of celestial bodies like many planets and moons, these attract the gases and space dust in their neighbourhood and keep them attach while rotating themselves. This envelope is what we know as atmosphere.

The primordial atomic elements of the Universe were hydrogen (H2) and helium (He). Inside the core of first generation stars where temperature condition is like that of a nuclear furnace, these lighter elements fuse together and give rise to heavier elements like carbon (C), oxygen (O), nitrogen (N). The later elements are essential requirement for formation of various life forms as can be seen on Earth. The Universe does not waste anything. Take the case of a star. When a star dies it scatters most of its masses and elements into space, leading to formation of an entity, known as nebula. A nebula can be the assemblage of stardust i.e. gas and dust of a single dying star as well as subsequent colossal collection of them (Fig. 1). In course of time, again one or many stars are born from this stardust. In fact, nebulae are the most active star producing region within a galaxy.

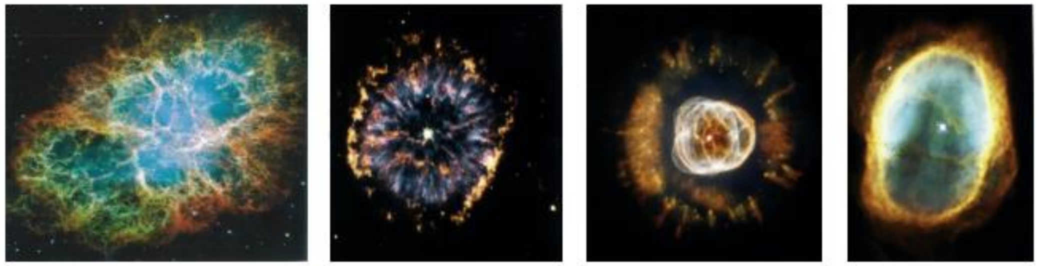


Figure 1 Different nebulae (from left to right: Crab, The Glowing Eye, The Eskimo and NGC 3132) in the Universe. A white dwarf star can be located at the centres of the last three nebulae (source: Bhowmik, 2016)

Our universe, as we observe today is continuously expanding, a fact which has been inferred from the Hubble space telescope data on colour spectra where most known galaxies are found to be red shifted (exception is like Andromeda galaxy which is blue shifted) i.e. galaxies are distancing themselves from each other. This also means that the intergalactic void spaces or the space inside the universe is also increasing.

How old and big is the Universe?

There is a quote by famous Astrophysicist Sir Arthur Eddington which states that "The Universe is not only stranger than we imagine, it is stranger than we can imagine". In the past decades nations of the world have launched some amazing instruments and satellites into our nearby space (we can call them "eyes in the skies"); these have helped unravelling a lot of mysteries about the universe, space and atmosphere. These are for example Hubble Space Telescope, ISS, WMAP (Wilkinson Microwave Anistropy Probe) and COBE (Cosmic Background Explorer) satellites. As per the present knowledge, the Universe could be as much as 13.7 billion yrs old. And how big is it? At least as big as the distance that light can travel in 13.7 billion yr.

The "BIG BANG" theory is the most accepted theory with regard to the origin of universe. According to the theory, universe started with a huge explosion and matter (dust and gases) filled the entire space. The temperature of the universe then, was about hundred billion degrees Celsius. Scientists believe that the big bang occurred about 15 to 20 billion years ago. The huge collection of dust and gases then began to spin. As it spun faster and faster, the centre became very hot. It became the Sun. From the edges of this ball of dust and gas, big blobs or chunks of dust broke off and formed eight ball shaped planets. This founded our solar system. The earth broke off about 4.5 billion years ago with an explosion. It was a burning hot white mass of gas and dust. Over a long period of time, dust and gas gradually condensed to form solid rock. Such condensation and shrinking made the earth heat up so much that the rock melted into a gluey liquid. After millions of years, the outer surface of the earth or the earth's crust cooled and formed hard rock again, just as melted chocolate or wax solidifies upon cooling. The interior of the earth is still very hot.

1.3 The solar family

As stated earlier, small or big, at whatever scale we look inside the Universe, there is an apparent similarity everywhere. The galaxies rotate around the universe; within galaxies, stars, many of which have families consisting of planets, moons and asteroids, orbit the galactic centre. It is quite evident that the scene inside any one galaxy or star system repeats itself in more or less the same manner in others. A complete discussion on one such system is provided here to understand the state of affairs of space and atmosphere across the universe.

We live inside the Milky Way, which is a spiral galaxy with a dazzling, massive bulge at the centre. It has atleast 200 billion stars (Sun is one of them) and houses more than 300 planetary systems. The end to end distance and thickness of Milky Way is about one lakh and one thousand light years (1 LY ~ 9.5 trillion Km), respectively. The Earth is located at a distance of about 26000 LY from the centre of Milky Way galaxy and at 93 million miles away from our controlling star i.e. the Sun. The Sun belongs to the big (nearly one million times bigger than Earth) bright class of stars in the Universe. There are eight principal planets (including Earth), several 'dwarf planets' and numerous small solar system bodies that rotate around the Sun in fixed orbits (Fig. 7). The four planets which are nearest to the sun, viz., Mercury, Venus, Earth and Mars are rocky planets i.e. they have solid surfaces; beyond that the planets are gas giants i.e. they have solid cores but do not have solid surfaces. In between the orbits of Mars and Jupiter there is belt of small solar system bodies made up of rocks. Baring Mercury and Venus, the six other planets have natural satellites (also called as moons) revolving around them. The Earth and most other planets of the solar family have gaseous envelopes that surround them, although the composition and features of these atmospheres vary.

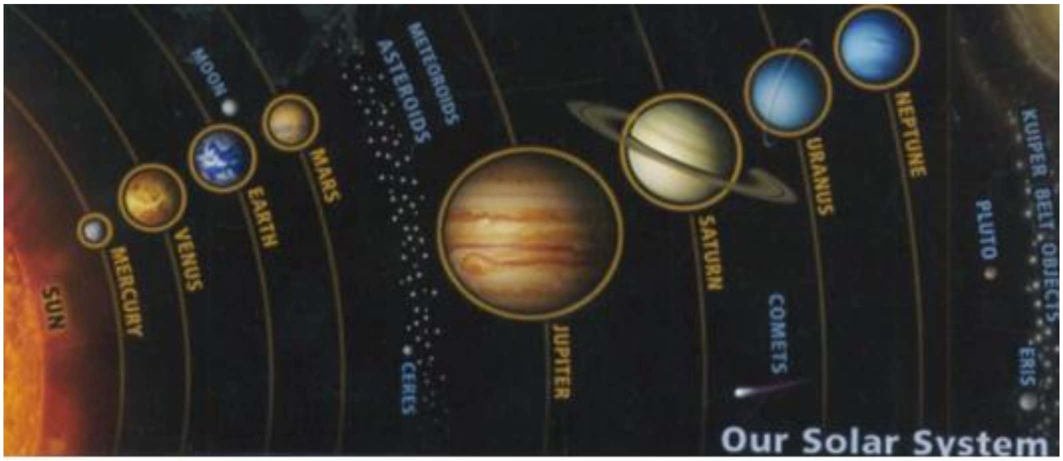


Fig. 7 :The Solar system (source: Bhowmik, 2016)

• **Sun:** The Sun's photosphere i.e. its surface is as hot as about 6000 oC (average) and guess the temperature at its core. The core is a nuclear furnace where continuous fusion reaction is taking place producing enormous energy and light, and temperature reaches there as much as 15 million oC. The sun burns about 600 million tons of H2 per second; although, it currently is as old as about 4.6 billion years, there is still enough stock to keep its fire going for 5 billion years more. Explosions of huge magnitude are always happening on the Sun's surface, throwing its fires thousands of kilometers into the sky which also falls back again onto its surface, a phenomena similar to the restive oceans.

• **Mercury:** It has a very feeble and highly variable atmosphere where pressure becomes as low as 10−14 bar. It contains hydrogen, helium, oxygen, sodium, calcium, potassium and water vapor. Because the planet is very near to the sun, radiation and wind coming from the Sun exert strong influences on it. Solar light pushes neutral atoms away from Mercury, creating a comet-like tail behind it whose main constituent is sodium. Daytime temperature here reaches 450 oC whereas at night it becomes as cool as minus 170 oC.

• **Venus:** The atmosphere in Venus is known to be the hottest (temperature reaches as high as 482 oC) among all planets of the solar family, although it is not the nearest from the Sun. The reason being, very high presence of CO2.The atmosphere there is a choking, smoggy mixture of CO2 and thick clouds suffused with deadly sulphuric acid (H2SO4). Hurricane velocity winds exceeding 300 km per hour, drives the acid cloud around the planet. The Venusian sky is filled with thunder and lightning almost all the time, although rains never happen. The atmospheric pressure on its surface is about ninety times greater than that on Earth.

• **Earth:** So far as we know, Earth is only entity in the solar system, that has been able to support life and its atmosphere has played a great role in the evolution of life and maintaining it till present. Various natural factors cause changes in the Earth atmosphere system and in past brought warm and cold phases in cycles. In recent times, due to increased anthropogenic interferences there is a build-up of greenhouse gases like CH4, CO2 and oxides of N2 in its atmosphere and this is threatening the very existence of life forms in our future Earth by way of global warming and climate change. The estimated temperature on Earth in its early days was even higher than that of Venus today. Due to volcanic activities, the gases that came out along with lava from its core produced the atmosphere. The primeval atmosphere on Earth comprised of N, CO2, CO and water vapour (H2O), some CH4and NH3. With the presence of water vapour, the hydrological cycle began i.e. cooling and condensing of water vapour as clouds at heights of the atmosphere followed by rain. As the process occurred repeatedly, the initial massive heat of Earth gradually went away and then formed the ocean and other water bodies. First life forms on Earth was conceived in these water bodies only. The present atmosphere of Earth is composed mainly of N2 and O2 (total about 99 %) and the rest are some inert gases, CO2 and highly variable content of water vapour. The atmosphere here shows distinct vertical temperature profile.

• **Mars:** The temperature on Mars does not exceed the freezing point even in summer, and the land remains permanently frozen the rest of the time. It has a thin atmosphere. Storms of red dust (mainly iron oxide) whipped up by strong Martian winds rage across its surface frequently. Evidences indicate a possibility of life forms in Mars. Frozen water can be seen in its poles, and also there are features on its now dry surface that appear to have been formed by once free-flowing water. Much of the water probably has now vaporized and escaped through its thin atmosphere.

• **Asteroids and Meteoroids:** Lakhs of chunk of rocks (sizes as variable as a dust particle to moon) spread over a vast swath can be found oribiting the Sun, staying between the interplanetary orbital space of Mars and Jupiter. This is known as asteroid belt. Nowadays asteroids are termed as small solar system bodies. During the formative stage of the solar.system, inner planets, viz., Mercury, Venus, Earth and Mars used to be frequently hit by asteroids and comets, the signs of which can still be seen on the surface of these planets. Small asteroids are often knocked out of their orbits and wind up on their trajectory towards Earth. Then these are termed as meteoroids. When these objects enter our atmosphere we call them as meteors. Most meteors are small enough to burn up due to the friction offered by the atmosphere, hence they never reach the surface of the planet. We generally know them as the shooting stars of night sky. If any such falling object actually hits the surface of the Earth then we term them as meteorites. Occasionally, a large asteroid travels quite close to Earth, however, the possibility of actually hitting the Earth is quite low such as once in every 65-100 million yrs. Most recently (in the year 2006), one asteroid (about the size of one kilometre in diameter) came close to the Earth (about the distance between Earth and moon). Had it collided with the Earth, the impact would have been equivalent to the simultaneous explosion of twenty thousands 1 megaton size hydrogen bombs!

- Jupiter: The atmosphere in Jupiter is quite stormy. Galileo spacecraft measured wind speeds of 530 km h-1 and gusts as high as 1600 km h-1on it. There is a distinctly identifiable storm zone on Jupiter, known as Great Red Spot which is a persistent turbulence system about 8km high and width wise three times that of Earth. Thunderclaps and jagged bolts of lightning shake and sear Jupiter's atmosphere. Unlike in Earth, the violent storms of Jupiter are possibly driven by its internal heat which is supported by the fact that this planet radiates more energy than it receives from the sun. Jupiter is surrounded by atleast three rings that formed when dust from its nearest moons was tossed up into space.

- Saturn: Saturn is bit less turbulent than Jupiter, but from time to time it experiences great storms which form the coloured bands in its atmosphere. Billions of ice particles mixed with rocks and silicates (sizes varying between small sand grain to as big as one meter in diameter) encircle and orbit the planet and appear as some prominent rings of varying width.
- **Uranus:** It is gas giant with a rocky core. The fastest wind speeds on Uranus is as high as 700 kmh-1 . The atmosphere is rich in methane. Sunlight scattered from the clouds surrounding Uranus is reflected back through these methane layers, giving this planet its blue green appearance. The temperature at the top of Uranus's icy methane clouds is about minus 215 oC.

• **Neptune:** Its atmosphere is composed of H_2, He and CH_4.No place in the solar system is as stormy as Neptune; here storm speeds can be as high as nine times the speed of any on Earth. The planet appears aqua blue.

• **Pluto:** As per the new definition of planets, now Pluto is designated as a dwarf planet and it could be one of the many such in solar family. Because of its distance from Sun only very little sunlight reaches Pluto. Indirect evidences suggest that Pluto has an atmosphere and that the planet may be like a frozen snowball of gas and dust.

• **Earth's Moon:** Atoms and molecules of some gases are present surrounding the lunar surface, but in very very small quantity. In fact, the density of the atmosphere at the Moon's surface is comparable to that at the outermost fringes of Earth's atmosphere, where the International Space Station orbits. For practical purposes, such an ambience can be equated with vacuum. Due to such small mass of gas (total weight may be lower than even 10 metric tonnes), the pressure in the "lunar atmosphere" is only around 3×10^{-15} atm and it also varies throughout the day. Because of the absence of a real atmosphere, moon cannot absorb appreciable quantities of radiation and does not appear layered or self-circulating. Due to low gravity condition, gases are lost to space at a high rate and it requires constant replenishment. Presence of gases like argon, helium, oxygen, methane, nitrogen, carbon monoxide and carbon dioxide has been detected in Moon's atmosphere. Two more gases, viz., sodium and potassium are also found on moon that is unusual in the atmospheres of Earth, Mars or Venus.

• **Titan:** This is a moon of Saturn. As per the Voyager 2 spacecraft data its atmosphere consists of N_2, Ar, CH_4 and other gases; this is similar to what our Earth had 4 billion yrs ago. Hence, Titan is of special interest to us to get clue of the primordial Earth. Titan is more similar to Earth than any other members of solar family. Its atmosphere is as thick as that of Earth, although the gravitational attraction is only 14 % of that on Earth i.e. on can fly like a bird with the help of some wings, on Titan.

• **Triton:** It is one of the moon of Neptune; So far it is known as being the coldest place in the solar system with temperature at minus 235 ^oC.

• **Kuiper Belt:** It is situated at the outermost coast of the solar system, over a billion kilometer beyond the orbit of our last planet. Kuiper Belt Objects (KBOs) are the leftovers from the creation of our solar system. These are like dirty snowballs-clumps of packed ice and rocks of various sizes, some of them nearly as big as a thousand kilometres across fly in this belt or to say, orbit the Sun. Kuiper belt is known as one of the two places in the solar system from which comets begin their journey. Whenever, any of the giant snowballs in this belt is nudged out of orbit due to the force of gravity, it heads straight for the sun and become known as a comet. Any such comets may one day wander within Earth's view. As the above snowball like KBO object moves towards the sun, its ice is vaporized and forms the long tail of a comet. The comets which usually make orbit in 200 yrs or less time originate in the Kuiper belt.

- **Oort cloud:** Well beyond the Kuiper belt, at the very edges of the solar system (about 7 trillion Km from Sun) lie another dark region known as Oort cloud. This is like Kuiper belt, however, the objects there have much longer trajectories i.e. orbit the Sun in thousands and thousands of years. This region gives rise to so-called long period comets.

1.4 Earth's Crust and Its Internal Structure

1.4.1 The Earth's Crust

The earth's crust is the outermost and the thinnest layer with an average depth of 5km below oceans and 40km below the continents. Its depth reaches about 70 km below the mountains. Apart from a very thin sedimentary layer on the continental crust and adjoining ocean floors, it is primarily composed of igneous and metamorphic rocks. Its lower limit is very clearly marked as both P and S earthquake waves increases due to abrupt change in density. At the lower limit of the crust, the velocity of P waves is 7 km/second which increases to 8 km/second immediately entering the mantle lying below. The same thing is happening with S waves which is 3.7 km/second in the crust but it increases to 4.5 km/second after its boundary. The density of the crust at the surface is2.7 g/cm3 and at the bottom limit, it is 2.9 g/cm3. The demarcating limit is known as Mohorovicic or Moho discontinuity from where mantle starts.

1.4.2 The Mantle

Just after the upper layer, the density of the mantle at the boundary increases to 3.0 g/cm3 from where the velocity of both P and S waves increase very significantly. As mentioned in the above paragraph, the increase in velocity of seismic waves is due to increased density existing there. It extends from the base of the crust to about 2900 km below the surface. It occupies over 80% of the earth's volume and 65% of the total mass. Mantle is composed of ultramafic rocks. It is igneous in nature and very rich in minerals. It is composed of magnesium and iron with very low silica content. The chemical composition of mantle is almost similar throughout. But there is change in temperature and pressure inside. With increasing depth, the physical properties changes and, therefore, the behavior of the rocks also changes accordingly. Roughly upto a depth of 100 to 250 km from the surface, rocks are firm, solid and rigid. Below this depth, the state of the matter is partially molten and plastic in behavior. This plastic and semi-solid belt extends about a depth of 700 km.

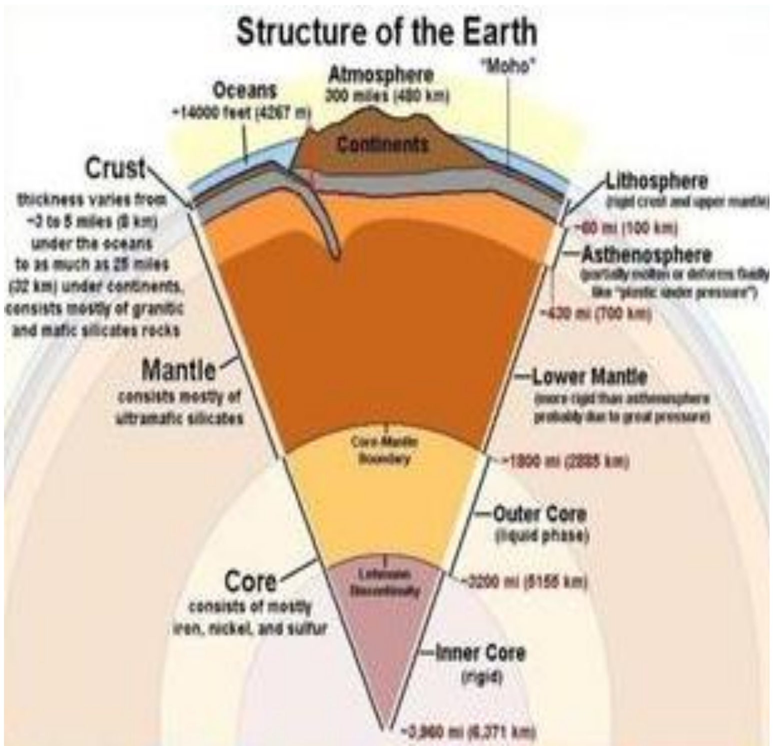


Figure: Earth's Internal Structure

Source: https://ase.tufts.edu/cosmos/print_images.asp

Lithosphere: It is a top upper solid and rigid layer of the earth. Its depths varies from 100 km to 250 km below which the matter is in semi-solid state. Therefore, lithosphere consists both upper solid part of mantle and entire crust. Complete solid upper part of the earth is divided into several plates of which the surface is made up of, including both continental and oceanic.

Asthenosphere: The term asthenosphere is derived from the Greek word 'asthenos' meaning 'weak'. Therefore, the literal meaning is to denote the layer which is weak in terms of fluidity. Geologists believe that the asthenosphere is semi-solid. It is composed of silicates both iron and magnesium. The overall consistency is just like hot tar, the material used to make blacktop road. Its depth is from 100 km to 700 km. Both waves, P and S, slow down while propagating through this layer. This clearly suggests that this layer is not fully melted, as S waves is not stopped but passes with slower velocity. Both asthenosphere as well as the solid upper portion of the mantle together are known as upper mantle.

Lower Mantle: The concentric layer from a depth of 700 km to about 2900 km is solid. In this zone, the velocity of both waves, P and S, increases abruptly until it reaches a depth of 2900 km. beyond this depth, the velocity of P waves decreases very drastically from 13.7 km/second to 8.4 km/second and S waves disappears completely. It clearly suggests that at this depth, the stat of matter is liquid or molten form as S waves is not entering. This distinct characteristics is defined by a boundary between two dissimilar sections of the earth. It is known as Gutenberg discontinuity. It is referred as core-mantle boundary (CMB).

The Core: It is the innermost layer of the earth starting from the Gutenberg discontinuity to the center of the earth. It is completely spherical in shape. It has a volume of only 17% of the earth but it contains 34% of the mass. It is because of the very high density of the material existing there. The density of the core at the Gutenberg discontinuity is 5.5 g/cm3 whereas the density of the core near the boundary is about 10 g/cm3. The core is made up of iron and nickel. Both of them have lower melting temperature than the material lying above. As mentioned in the above paragraphs, the disappearance of S waves and abrupt reduction in the P wave's propagation leads to conclude that the material is in liquid state. The liquid state of matter is recorded till a depth of 5150 km. After this depth, it is in solid state. Here, the velocity of P waves increases. It is solid because the pressure is excessive and the melting temperature is increased but the temperature needed to melt is lower than the required at that pressure (Fig). Therefore, upper liquid part is known as the outer core and inner solid is the inner core.

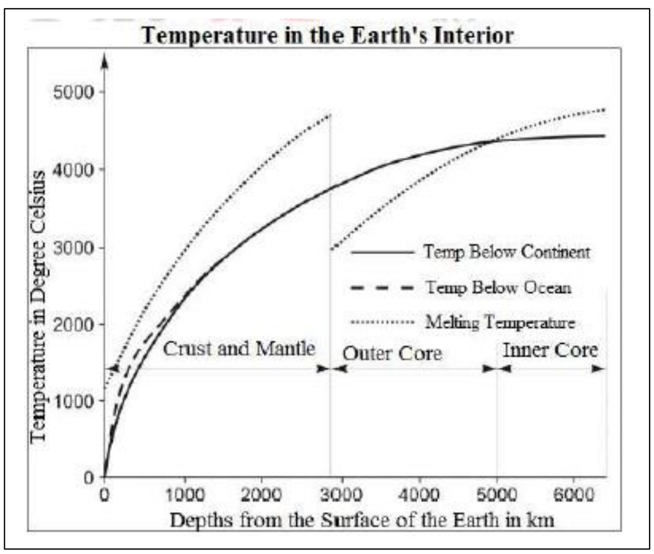
1.4.3 Chemical Composition of the Earth

There are three major and almost concentric layers in the earth. These are explained by Swess and they are SIAL, SIMA and NIFE.

SIAL: It is the topmost layer of the earth found just below the sedimentary thin cover of the crust. Silicon (Si) and Aluminum (Al) are two very important elements found in abundance in this layer. They are named as SIAL. The average density of this layer is 2.75 to 2.90 g/cm3 and its average depth is 40 km. It is very thin below oceanic water (5 to 10 km) but below the mountains, it is very thick (upto 70 km). The main rock in this zone is granite.

SIMA: It is the second layer after SIAL from the surface towards the interior. It is named after Silicon (SI) and Magnesium (MA) as both of these elements are very much abundant in this layer. It is a very thick layer which goes almost upto a depth of 2900 km. It starts from a depth of 70 km below continents while below the oceans, it is found at 5 to 10 km depth. Its average density varies from 2.90 g/cm3 to 4.75 g/cm3. The main rocks in this layer are silicates of magnesium and iron. This layer is largely composed of basalt.

NIFE: It is the innermost layer of the earth. This layer is made up of Nickle (NI) and Ferrous (FE) and so it is named as NIFE. It is just below the SIMA from a depth of 2900 km to the earth's centreencircling from all directions. Nickle and Ferrous are found here. They are very heavy and denser elements. Therefore, this layer have higher density. Its density is about 11 to 12 g/cm3. It is believed that the existence of nickel and iron in the NIFE is the main cause for earth's magnetic properties.



The upper thin layer of the earth is accessible to the humankind and can be studied to know every details directly. The interior of the earth is thousands of km deep and directly inaccessible. Therefore, direct method of study is impossible. Based on the principles of the science and their derivations, interior is studied indirectly. In a very conclusive manner it can briefly be stated that the temperature, pressure and density are increasing with increasing depths. The nature of the materials is changing. The surface is made up of such materials which are lesser in density. The minerals constituting the surface rocks are different than that of the interior. Based on the chemical constitution, interior is classified into three SIAL, SIMA and NIFE. Seismic waves are the only source to reveal the interior. Depending upon the propagation of P and S waves in the interior, three very distinct layers crust, mantle and core are identified with distinct separating boundaries.

1.5 Geological History of Earth: Geological Time Scale

Life on the earth did not come into being with its birth. The earth has a long history and has seen many changes on her surface through different periods. The earth cooled from its gaseous state into liquid one and transformed into solid layer on further cooling. For an instance, there was a great ocean in place of the Himalayas only 150 million years back. With one cellular organism, life began which belonged to both animal and vegetation kingdom. Later on, the animals and vegetation both evolved into more complex life-forms. The animals evolved into fish, reptiles, mammals and finally into human beings. The great age of the earth were based on the rate of sedimentation, age of fossils, and the rate of cooling of the earth, salinity of the oceans and the tidal force of the moon. As far as, the age of the Earth is concerned, there is a lot of difference of opinion among the scientists. On the basis of current methods of radio-metric dating, most of the modern scientists agree that the life of the Earth may range from 3 to 5 billion years.

James Hutton believed in the principle of uniformitarianism and he knew that the earth was very old but they had no method of knowing its exact age. Several methods were devised by others which were in use till about the beginning of the 20th century. Lord Kelvin (in 1897), a renowned physicist, had assumption that the earth was originally molten and cooled to its present condition, put the earth's age at not more than 100 million years, and perhaps much less.

Rutherford, (in 1904) for the first time took the help of radioactive substances in determining the age of the earth. For calculating the ages of rocks and minerals, the discovery of radio-activity provided a reliable means; contain radioactive isotopes (elements). This method is called radiometric dating. Till about 40 years ago the age of the earth calculated on this basis was placed at about 3,000 million years. In recent years, it has been possible to make more accurate calculations due to more precise scientific knowledge.The relative percentage of lead isotopes in ancient rocks and meteorites has also been taken into account and the age of the earth is now placed at around 4,600 million years. Chances of error in this calculation are very small;therefore this age is now widely accepted.

1.5.1 Geological History of the Earth

Though life on earth has existed only for a small fraction of her history, fossils, which are remains of extinct animals, indicate a good deal. It is possible to estimate the depth of the sea on the basis of fossils of certain marine animals like corals, where particular sediment was precipitated. Furthermore fossils provided indications of past environments. Radiometric dating has made possible the specific or absolute dating of rock units that represent various events in the earth's distant past. When a complete sequence of rocks representing the entire period is not available and there are breaks in the rock record, then it is known unconformities.

The principal divisions of geological time are called eras. Three eras are recognized- the Plaeozoic (ancient life), the Mesozoic (middle life) and the Cenozoic (recent life). Each of these eras is subdivided into smaller time units known as periods.

The Palaeozoic has seven periods, Mesozoic and Cenozoic has three andtwo periods respectively. Each period is characterized by its profound changes in life forms. These twelve periods is further sub-divided into epochs and epoch into ages. It will be observed that the Palaeozoic era begins some 600 million years ago. The enormously long period of more than 4 billion years prior to the Pre-cambrian with no further subdivision, as our knowledge about those early times is very limited. This is so, because prior to the Cambrian, very simple life forms such as algae, bacteria, fungi, sponges and worms have not left adequate fossil record.On the basis of the above discussion a standard geological timescale has been prepared which is accepted throughout the world and with reference to which the geological history of the earth can be studied.

Era	Period	Epoch	Million Years Age	Distinctive Life	Major Structural Episodes
Cenozoic	Quaternary	Recent/ Holocene	0.01	Ice age ends Humans are dominant	
		Pleistocene/ more recent	2.5	Age of Man	Main Alpine Episode
	Tertiary	Pliocene	12	Age of mammals-(flowering plants and broad leaved trees)	
		Miocene	25		
		Oligocene	35-40		Laramide Phase
		Eocene	60		
		Paleocene	70		
Mesozoic	Cretaceous (Creta=chalk)		135	Age of reptiles (Dinosaurs) and birds	
	Jurassic(after Jura mountain)		180		
	Triassic (three fold division in Germany)		225		
Palaeozoic	Permian		270	Age of Amphibians	
	Carboniferous		350	Widespread forests	
	Devonian		440+101	Age of fishes	
	Silurian		440+10	Age of marine	
	Ordovician		500	Invertebrates	
	Cambrian		600	Abundant fossils first appear	Main Caledonian Episode
Azoic or Precambrian			Oldest rocks 3787+85 Several Mountain Building Episodes		Several Mountain Building Episodes

Source: Dayal, P. "A Textbook of Geomorphology", Shukla book depot, Patna, 1994 &
https://andyckh.deviantart.com/art/Geological-Timeline-Chart-283922560

It is clear from the above table that man is comparatively a new comer on the Earth. Even this history of the earth constitutes not more than one sixth of the life of the earth, nothing is known about 5/6th of the Earth's history.

1.5.2 Division of Geological Time into Eras

We have noticed above that geological time has been divided into four major divisions called Eras - Precambrian, Palaeozoic, Mesozoic and Cainozoic or Cenozoic. The oldest and by far the longest is Pre-Cambrian which covers 90 per cent of geological time but our knowledge about this era is too little.

1.5.2.1 Precambrian Era (Eozoic)

This is the oldest era of geological history. The duration of this era is from the beginning of the earth nearly 4.6 billion years or more till about 0.6 billion years ago. In other words Pre-Cambrian alone compasses 90 per cent of all geological time.

Pre-Cambrian rocks are,which are said to be the oldest one,belong to the Archaean period. Most part ofthe Peninsular plateau of India is composed of Archaean rocks which include the rocks of the Dharwar system which were originally sedimentaries. Just above the Archaean system are the Late Pre-Cambrian or Proterozoic rocks, the rocks of the Vindhyansystem and theCuddapah system in India belong to this period.The rocks of the Pre-Cambrian era cover extensive areas in all the continents and usually form areas of low or moderate relief on account of the denudation of ages: These are called continental shields. In this era, Pangaea continent was born and at the end of the period the four shields had come into existence- i.e. Laurentian shield; Siberian shield; Gondwana shield; Baltic shield.

The Pre-Cambrian rocks are extremely rich in metallic minerals, and almost all the important occurrences of iron ore, gold, copper, manganese, uranium, chromium, lead, zinc and mica in the world are found in the rock of this era.

1.5.2.2 Paleozoic Era

The Palaezoic started 600 million years ago and continued till about 225million years. Its time range is about 30 million years. The animals in the seas and oceans were invertebrate. Non-floral vegetation came into existence. The chief rocks of this period are shale, slate, hard sandstone, hard limestone, and rocks of this period are found large deposit of valuable minerals. The rocks of this period in North America abound in gold, oil, coal and iron ore while in Europe tin, copper and iron are found in the rocks of this period. This era further sub-divided into six periods of which the oldest one is the Cambrian followed by the Ordovician, Silurian, Devonian, Carboniferous and the Permian.

During this era, the South Pole was possibly somewhere in the South Atlantic Ocean and the North Pole in the North Pacific Ocean and the equator passed through South Australia, Arabian Peninsula, Middle Europe and eastern North America.In the Devonian periodpresence of coral limestones in North America, Europe and South-east Asia and

Australia indicates a hot climate. On the other hand, in the Devonian and Permian periods there are evidences of relatively cold climates in South America, South Africa and India.

(i) Cambrian Period- This period was about 90 million year long (from 600 to 500 million years). CambrianPeriod saw the transgression of sea over the land surface. Land submerged under water due to earth movement that gave rise to sedimentary rocks. It is why the rocks of this period are quite extensive. The rocks of this time have light limestone at the bottom over which are laid the layers of sandstone, shale and at the top is a thin layer of limestone again. These rocks not only contain the fossils of the oldest life but also hold the first evidence of life.

(ii) Ordovician Period- The period witnessed a large portion of the land surface being submerged under water and half of North America was under water. There was an expansion of oceans in this period.Several volcanic eruptions took place in this period and the eastern portion of the U.S.A. was overlaid with the volcanic ash and dust. Among the animals the greatest evolution of Trilobites took place. The sea-grass was the main vegetation with characteristic of the birth of molluscus in this period. Slates, limestones and volcanic rocks spread over a large area.

(iii) Silurian Period- It was the third period and followed the Ordovician Period and preceded the Devonian Period. This period was important for the birth of fish and land vegetation. The Caledonian earth movement affected all the continents. For the first time, the animals which could breathe came into existence that means animals with lungs developed. Fish came into existence. The red sandstone also came to be formed in this very period.

(iv) Devonian Period- It was abouta million year long period. It began 440 million years ago and ended 350 million years ago.Devonian Periodsaw at its beginning the well-known mountain building movement i.e.Caledonian movement.The mountains of Scandinavia, North England, Scotland and Spitbergen were formed in this period. It is called the age of fishes because the seas were full of them. In the late Devonian, the first amphibians and vertebrate colonisation ofthe dryland had begun. All the rocks of this system hold the fossils of fish. The chief creatures of this period were predominantly aquatic.

(v) Carboniferous Period- It was 80 million year long. It began 350 million years ago and ended in 270 million years ago.The importance of this period is that the coal beds of the earth came to be formed, hence it is also known as the Coal Age. Thus in course of time due to intense heat and pressure, the successive layers of decaying vegetation, entrapped in the sediment layers, were transformed into coal beds. This period also saw the beginning of such animal life which could live both on land and water.

(vi) Permian Period- This period is 45 million years long. It began 270 million years ago and ended 225 million years ago.Permian Periodwas the time when the Hercynianmountain building movement occurred. This movement left its mark in central Europe, North America and several other places. There was a heavy deposition of red rocks and limestones in South-West U.SA.The animals which could live both on land and sea came to evolve all the more and reptiles saw the light of day. The temperature began to rise and the climate started getting dry in this period.

1.5.2.3 Mesozoic era

Mesozoic or secondaryErais formed of two words-mesoi.e. middle and zoici.e. life. In other words, it is the meeting time between the old and the new Eras. The Mesozoic era is of a much shorter duration than the Palaeozoic. The climate started getting warm and dry. The snow cover of Antarctica began to melt. This era is best known as the age of dinosaurs and reptiles.In this era, birds make their appearance in Jurassic and the small mammals begin to appear in the Triassic. The Tethys Sea was divided into two parts. This era consists of the following three periods:

a) Triassic Period
b) Jurassic Period
c) Cretaceous Period

a) Triassic Period: It started 225 million years ago and ended 180 million years ago.It was about 40 million year long. During this period,one compact landmass known as Gondwanaland; South and Central Africa, Madagascar, South India and Australia were part of it. During this period, while the northern hemisphere was having dry climate, the southern hemisphere was underlaid with an ice sheet. The Tethys Sea which had come into existence by the end of the Palaeozoic era, continued to exit till the Cretaceous without any significant deformation. The places in Europe where we now find the Mediterranean Sea and the Alps mountains, there used to flow the Tethys Sea.

The shales and sandstones of the Panchet series of the Gondwana system belong to the Triassic and the sandstones and shales of the Jabalpur series belong to the Jurassic. In this period; shale, limestone, sandstone, etc. were formed.The first dinosaur was born;mammals also came into existence in the elementary form.

b) Jurassic Period: It is considered to be 45 million year long. It started 180 million years ago and ended 135 million years ago.Reptiles reach their greatest proportions in this period. They dominated the land, sea and air.The fossils of the first bird also belong to this period. A lot of deposition took place in the seas of western USA. Nevoda and Laramide movements also took place in Jurassicperiod. Formation of Sierra Nevada Mountains was the result of these movements.

c) Cretaceous Period: It began 135 million years ago and ended 70 million years ago.It was about 60 million year long. It is well-known for its widespread deposits of chalk. The other major rocks of this period are soft sandstone, clay and limestone. Due to Laramidemovement, the American Cordilleras were formed. It was during this period that deciduous trees appeared. Undoubtedly, the most dominating among the animals were the reptiles. The first birds and mammals were also appeared in this period. Huge animals(Dinosaurs) began to decay and were almost extinct by the end of the period.

1.5.2.3 Cenozoic Era

This latest era in the earth's geological history has began about 65 million years ago. Cenozoic is made oftwo words-ceno, i.e.new and zoic, i.e.life. It is an era of new lifewhich normally divided into two periods-Tertiary and Quaternary. But there are some people who are in favour to regard the **Tertiary** and **Quaternary** as two separate eras. Tertiary period ended about one million years ago. At present we are living in the Quaternary period.

The **Tertiary period** is sub-divided into five epochs. These are, beginning from the oldest, - Paleocene, Eocene, Oligocene, Miocene and Pliocene. It was during this era that the vegetation increased and the ape-man appeared.

(i) Paleocene Epoch: This epoch began 70 million years ago and ended 60 million years ago. It is considered to be about 10 million years long.The Rocky Mountains were formed under Laramide movement. Grass land area also increased in this epoch.

(ii) Eocene Epoch: It is considered to be 20 million years long. It started 60 million years ago and ended 40 million years ago. The land area developed many fissures which belched out lava over a big area. Mammals evolved into many branches. During this epoch plants bearing fruits and grains developed on a large scale.

(iii) Oligocene Epoch: It began 40 million years ago and ended 25 million years ago.It was about 15 million years long. It was the epoch of Alpine Orogeny. Sediment started depositing in the seas of Pacific coast. The forefather of man, Anthropoid, was born in this epoch.

(iv) Miocene Epoch: It was almost 13 million years long. It began 25 million years ago and ended 12 million years ago. The rivers continued to deposit sediments in the Great-Plains of U.SA. During this epoch the Alpine folds developed in Eurasia and trended in the east-west direction. Sediment was also deposited at large scale in the Atlantic ocean and Gulf coast. The whale and monkey came into existence.

(v) Pliocene Epoch: This epoch was about 10 million years long. It started 12 million years ago and ended 2.5 million years ago. Due to orogenetic movement, the sediment deposited in the shallow seas rose in the form of plains. During this epoch large plains developed, the important ones are the Northern Plains, plains of Europe, the Po basin of Italy, the Mesopotamian plain, Ganga and Sindh plains. Horses, elephants and huge carnivorous animals evolved. This epoch is also considered to be the evolution of man.

The Quaternary period started about two and a half million years ago. It is further subdivided into two epochs- Pleistocene and the Recent (or Holocene). This is the most recent of the periods of geological history. The alluvial deposits of the world were also laid in this period. The rocks of this period contain the fossils of horses, elephants, camels and several other oceanic mammals. This period saw the evolution of man and the growth of his intellect.

(i) Pleistocene Epoch: The Pleistocene Epoch is typically defined as the time period that began about one million years ago and lasted until about 10,000 years ago. Man appeared on this planet only towards the beginning of Pleistocene but the modern man developed in the Holocene epoch. At the beginning of this epoch, the temperature of the atmosphere became so low that the surface of the earth came under a vast ice sheet. Besides these, the Himalayas and the Alps were having small patches of ice-caps. On account of these, this era is also known as the Great Ice Age. The land masses of the Southern Hemisphere, however, remained free from ice. North Africa, North America (Canada and northern U.SA.), Arctic and Antarctica were all covered with a thick layer of snow. The snow caps Of high Mountains expanded. The snow cover of North America has disappeared hardly 10,000 years ago.The snow cover had a prevalent effect upon human life. Large and violent animals were killed. Mammals had evolved very fast. Monkeys, chimpanzees and human beings increased in number at large. Man's fossils are found in rocks about one hundred thousand years old. It is, therefore, estimated that man is only one hundred thousand years old.

The snow cover was not static in this age. From a study, snow cover advanced and retreated four times. Hence this period is called ice age and divided into four ice-ages (a) Gunz (b) Mindel (c) Riss and (d) Wurm. There is no unanimity among the scientist regarding causes of ice-ages. Some of the causes have been attributed to the birth of mountains, the eruption of volcanoes, the interruptions in the receipt of solar energy, etc. The five Great Lakes of North America were formed by the retreat of the snow cover. The mountain stops of Europe and America were rounded and the river valleys developed U-shape. The landscapes features of Sweden, Finland and Russia are a testimony to the work of snow cover.

(ii) Holocene Epoch: This epoch started 10,000 years ago. 'Man' is the most important feature of the Holocene epoch that is why Holocene can be called the age of human-evolution. However, the theory of human evolution is still in question. Man, by the development of his intellect has established his control over the flora (plants) and fauna (animals) of the world. He has accelerated some changes in the landforms and has converted the Earth into a place for his existence. Though no large scale changes have been effected by rivers, sea waves, winds, etc., in the landforms during the Holocene, yet man has made tremendous progress in human civilization.

During his relatively short period man by his intelligence, mental ability and power of organization has greatly speeded up the pace of development. Therefore the climatic conditions in the past have played an important role in the way of human life. The effects on the life of man are visible on the type of environment creating for his comfort. Man has also been able to move out of the pull of the Earth and visited the Moon and constant efforts may make human landing on Mars.

References

Adapted from E PG Pathshala, Geography, Geomorphology, Module 13 - Constitution of the Earth’s Interior and Geography, Module 3 - Geological Time Scale.

Unit 2: Development and Evolution of Earth's Atmosphere

Unit Structure

2.0 Learning Objectives

After completion of this unit you will be able to understand:

- The basics of atmospheric stratification into different layers and significance of the roles played by these layers.
- The dynamics (physical & chemical) of the atmospheric layers and importance of atmospheric layers for survival of life.

2.1 Introduction

Atmosphere refers to a thin layer of gases, surrounding earth , held in place by gravity of the earth. This gaseous envelope is the source of oxygen which sustains organisms and carbon dioxide, used by plants, algae and cyanobacteria. It also protects living organisms by preventing the entry of ultraviolet radiations from sun.

2.2 History and trend of research on atmospheric structure

In recent years, with global discussions about air pollution, ozone formation and climate change and developments in technologies such as measuring instruments, airplanes, satellites and computer programs, there has been extensive research on atmospheric dynamics, characterization of spatiotemporal stratification and their sustainability and so forth.

2.2.1 Exploring the Atmosphere

The fundamental exploration of the nature of atmosphere is contemporary to origin of human civilization itself. But a detailed recording of environmental parameters started in the line of present research since 16th to 18th century with inventions of basic equipments (thermometer and barometer by Galileo on 1593 and by Evangelista Torricelli on 1643, respectively), the theories and principles (decrease of pressure with altitude by Florin Périer in 1648; Gabriel Fahrenheit‟s introduction of temperature scale on 1714, James Espy‟s empirical estimation and William Thomson‟s derivation of dry and saturated lapse rate in 1850‟s & 1862, respectively, development of laws of thermodynamics in 1940‟s and kinetic theories of gases by James Maxwell in 1866). Based on these bases, the exploratory study of atmospheric layers began with Alexander Wilson‟s use of a thermometer on a kite on

1749, followed by manned balloon exploration by Joseph Louis GayLussac on 1804 and subsequent use of instrumented balloons by Léon-Philippe Teisserence de Bort

on 1898. This exploratory spree manifested in terms of better understanding of atmospheric structure, especially with G. J. Storey‟s proposition of exosphere on 1868, Balfour Stewart‟s study on existence of electrical currents in upper atmosphere 1882, Teisserence de Bort‟s discovery isothermal layer about 12 km upwards in 1901 (and nomenclature of the words "troposphere" & "stratosphere" on 1908) as well as D Guglielmo Marconi‟s reception of trans-Atlantic radio signal reflected back from upper atmosphere in 1901 and prediction of existence of ionosphere by Oliver Heaviside and Arthur Kennelly independently in 1902.

2.2.2 Zone of Silence

Discovery of „zone of silence‟ to imply temperature inversion existing above troposphere during 1915 is probably first well documented experimental studies on atmospheric stratification. The railway gun (capable of firing a 106-kilogram shell to a range of 130 kilometers and a maximum altitude of 42.3 km) used during World War – I to shell Paris 120 km away created a very loud noise. A noise gets fainter as listeners are farther away, but with very loud noises it was sometimes noted that there was a "zone of silence" where no noise could be heard but surprisingly the sound became audible again further away. Several explanations were offered to explain this apparent anomalous sound. After World War – I, scientists used loud guns to study the effect and from the results were able to show that the atmospheric temperature in the stratosphere increases up to an altitude of about 50 km.

2.2.3 Thermal Stratification

By 1920, the thermal stratification of lower atmospheric layers were fairly well understood, with additional inference from observed altitude of meteors by Gordon Dobson during 1920. In 1924, Edward Appleton developed ionosonde to explore upper atmosphere, using which he confirmed existence of ionosphere (nomenclature by Robert Watson-Watt in 1925). The era of usage of rockets and satellites in atmospheric investigations started Robert Godddard‟s first rocket probe of atmosphere in 1929, continued with regard to upper atmosphere during 1948, and subsequent launching of Sputnik I (1957) to study general stratification, Explorer I (1958) to discover Van Allen radiation belt and Explorer 12 (1963) to detect magnetopause. During this period there was better understanding of magnetosphere, which was proposed by Sydney Chapman and Vincent Ferraro in 1930 (the name coined by Thomas Gold in 1959). The discovery of the mesopause and plasmapause were carried out by W. G. Stroud‟s team (1959) and Donald Carpenter (1963), respectively. Since then, the studies have been more directed towards routine investigation and monitoring, as well as computational modeling and simulation of the atmospheric layers. The political, economic and social changes that came after World War II have also had an impact on the atmospheric sciences and how they are carried out. During the Cold War, important innovations like "Lidar" (Light Detection and Ranging) and new satellite technologies emerged and global models and computer simulations were applied. In addition, the atmospheric sciences have become politically relevant in the domains of air transport, air pollution and climate change.

2.3 Evolution of Atmosphere

Stage-1

Earliest atmosphere is expected to have consisted of gases in the solar nebula, primarily hydrogen and possibly simple hydrides (as observed in gas giants like Jupiter and Saturn), water vapour, methane and ammonia. With dissipation of solar nebula, these gases would have escaped, partly driven off by the solar wind.

Stage-2

Second atmosphere is likely to be consisting largely of nitrogen plus carbon dioxide and inert gases, which was produced by out gassing from volcanism, supplemented by gases produced during the late heavy bombardment of Earth by huge asteroids. A major part of carbon dioxide emissions would have dissolved in water and built up carbonate sediments. An influence of life (which would have originated as early as 3.5 billion years) has to be taken into account in evolution of the atmosphere, because hints of early life forms are to be found. In fact, in the late Archaean eon an oxygen-containing atmosphere began to develop, apparently from photosynthesizing cyanobacteria which have been found as stromatolite fossils from 2.7 billion years ago.

Stage-3

Third atmosphere is the atmosphere we experience now, with increasing oxygen content. In fact, the constant re-arrangement of continents by plate tectonics would have influenced the second atmosphere through the long-term evolution of the atmosphere by transferring carbon dioxide to and from large continental carbonate stores. As per available existence, the free oxygen did not exist in the atmosphere until about 2.4 billion years ago during the Great Oxygenation Event (its appearance is indicated by the end of the banded iron formations). Before this event, any oxygen produced by photosynthesis was consumed by oxidation of reduced materials, notably iron. Molecules of free oxygen did not start to accumulate in the atmosphere until the rate of production of oxygen began to exceed the availability of reducing materials. This point signifies a shift from a reducing atmosphere to an oxidizing atmosphere. O2 showed major variations until reaching a steady state of more than 15% by the end of the Precambrian.

Composition of the Atmosphere:

About 75% of the total gas and 99% of the total water vapour of the entire atmosphere constitutes he troposphere, thus representing the 80% of total mass of the atmosphere. Following Table lists the composition of constituents of atmosphere and their volume percentage of permanent and variable gases. Nitrogen, oxygen and argon account for more than 99.96% of the atmosphere by volume. The permanent gases have virtually constant volume ratios up to an altitude of about 60 km. Although the amounts of the variable gases are small, they are extremely important in determining the atmospheric temperature.

2.4 Thermal Structure of Atmosphere

Based on the change composition with height, the atmosphere can be divided into two layers-the lower layer is called the homosphere because of homogeneity in composition, especially, the tropospheric gases, which ranges from troposphere to mesopause (discussed in details below), overlain by the heterosphere (mostly, thermosphere), in which the gases are stratified into four shells- the lowermost shell is dominated by molecular nitrogen (N2); next, a layer of atomic oxygen (O) is encountered, followed by a layer dominated by helium atoms (He), and finally, the topmost layer consisting of hydrogen atoms (H). However, the most exhaustive and characteristic stratification of atmosphere, has been based on the vertical thermal profile of the layers. The temperature variation in these layers may be accounted to the absorption of solar radiation; (visible light at the surface, near ultraviolet radiation in the middle atmosphere, and far ultraviolet radiation in the upper atmosphere).The characteristics of various layers of atmosphere and their characteristics are presented below:

2.4.1 Troposphere

Troposphere means "region of mixing" and is so named because of vigorous convective air currents within the layer. It is closest to earth, situated between 0 to 12 km , this layer contains 75% of the gases and the largest percentage (around 80%) of the mass of the total atmosphere and is where all weather phenomena occurs, although turbulence may sometimes extend into the lower portion of the stratosphere. Here, with altitude, the temperature and water vapour content decreases. The troposphere contains 99 % of the water vapour in the atmosphere and this water vapour (highest at tropics and lowest at polar regions) plays a major role in regulating air temperature because it absorbs solar energy and thermal radiation from the planet's surface. Tropopause, where temperature remains fairly constant (-600C) with altitude and is located at the upper boundary of this layer (separating the troposphere from the stratosphere), whose height varies spatially (from height of 8 km near the poles up to 18 km above the equator) and temporally (highest in the summer and lowest in the winter). In tropopause, we find the jet stream, which are very strong winds that blow eastward and affect planetary circulation pattern.

2.4.2 Stratosphere

Stratosphere (or stratified sphere) is the layer just above tropopause, situated between about 25 to 50 km, where temperature increases gradually to up to the stratopause. In this layer, unlike troposphere, there is no convection and it is fairly stable. In stratosphere, there is the ozone layer, centered at an altitude between 15-25 km, consisting of 90 % of the ozone of the entire atmosphere, with concentration of about 10 parts per million by volume (ppmv) as compared to approximately 0.04 parts per million by volume (ppmv) in the troposphere. Ozone acts as a shield for in the earth's surface in absorbing the bulk of solar ultraviolet radiation in wavelengths from 290 nm - 320 nm (UV-B radiation), which are harmful to life because they can be absorbed by the nucleic acid in cells leading to increase in cancers in animals and damage in plant cells. Ozone is responsible in regulating the thermal regime of the stratosphere, converting solar energy to kinetic energy, this causes a temperature increase in the upper part of the layer (because, temperature increases with ozone concentration). Stratopause, the transitional zone of maximum temperature, between the stratosphere and the mesosphere, is located within 50-55km above ground level.

2.4.3 Mesosphere

Mesosphere (or middle sphere) is characterized by the portion of the atmosphere, from about 50 to 80 kilometers above the earth's surface, characterized by temperatures that decrease from 10°C to -90°C with increasing altitude, extending from stratopause to mesopause. The coldest temperatures in Earth's atmosphere occur at the top of this layer, especially in the summer near the pole. This layer protects the earth from meteoroids, which gets burnt up in this region. The mesosphere has sometimes jocularly been referred to as the "ignorosphere" because it had been probably the least studied of the atmospheric layers. The stratosphere and mesosphere together are sometimes referred to as the middle atmosphere. The mesopause is the temperature minimum (the coldest place on Earth with temperatures as low as -100°C) at the boundary between the mesosphere and the thermosphere due to the lack of solar heating and very strong radiative cooling from carbon dioxide. The mesopause is the temperature minimum zone (at the boundary between the mesosphere and the thermosphere atmospheric regions at 80 - 85 km), due to the lack of solar heating and very strong radiative cooling from carbon dioxide.

2.4.4 Thermosphere

Thermosphere (or heat sphere) is the layer of the earth's atmosphere extending from the top of the mesopause (80 km - 90 km above the surface) to thermopause (about 500 km) and is characterized by a rapid increase in temperature (due to the absorption of intense solar radiation by the limited amount of remaining molecular oxygen) with increasing altitude up to about 200 km, followed by a leveling off in the 300 km - 500 km region (reaching upto 1700 0C to even more than 20000C). At this extreme altitude gas molecules are widely separated and above an altitude of 100 km, the chemical composition of air becomes strongly dependent on altitude and the atmosphere becomes enriched with lighter gases (atomic oxygen, helium and hydrogen). Above about 160 km altitude the major atmospheric component becomes atomic oxygen. At very high altitudes, the residual gases begin to stratify according to molecular mass, because of gravitational separation. The thermopause is the atmospheric boundary located at the top of the thermosphere.

Karman Line

In fact, the low gravitational attraction in this zone is unable to support aircraft and, therefore, vehicles need to travel at orbital velocities to stay aloft. This demarcation between aeronautics and astronautics is known as the Karman Line.

This line is named after Theodore von Kármán (1881–1963) a Hungarian-American engineer and physicist, who was the first to calculate that around this altitude and commonly represents the boundary between the Earth's atmosphere and outer space (standardized by the Fédération Aéronautique Internationale (FAI), which is an international standard setting and record-keeping body for aeronautics (the science or art involved with the study, design, and manufacturing of air flight-capable machines, and the techniques of operating aircraft and rocketry within the atmosphere) and astronautics(or “science and technology of spaceflight” is the theory and practice of navigation beyond the Earth's atmosphere).The electromagnetic characterization of thermosphere constitute three overlapping layers, viz. ionosphere, magnetosphere and plasmasphere, whichwe shell now discussed.

2.4.5 Ionosphere

Ionosphere is the zone extending from stratosphere to the lower part of the thermosphere, where gas particles absorb ultraviolet and X-ray radiation from the sun, and become electrically charged (ions). Radio waves are bounced off the ions and reflect waves back to earth. This generally helps radio communication. However, solar flares can increase the number of ions and can interfere with the transmission of some radio waves. The transitional zone in the atmosphere between the ionosphere and the exosphere, about 644 km from the earth's surface, is known to be ionopause.

2.4.6 Magnetosphere

The outer layer of ionosphere (some sources consider them to be separate), where the earth's magnetic field operates is called Magnetosphere. It begins at about 1000 km. It is made up of positively charged protons and negatively charged electrons, which traps the particles that are given off by the sun and are concentrated into belts of deadly radiation, called the Van Allen radiation belts. When large amounts of such particles are given off during a solar flare, the collision of these particles among one another, causes the aurora borealis or the northern lights (a natural light display in the sky particularly in the high latitude regions). In this layer, the magnetic field lines are unable to co-rotate because they are influenced strongly by electric fields of solar wind origin. Thus, the magnetosphere is a cavity (also not spherical) in which the Earth's magnetic field is constrained by the solar wind and interplanetary magnetic field (IMF). This gives rise to an elongated teardrop shape with the tail pointing away from the Sun. The outer boundary of the magnetosphere is called the magnetopause, which is typically located at some 56,000 km (about 10 Earth radii) above the Earth's surface on the day side and stretches into a long tail, the magnetotail, a few million kilometers long (about 1000 Earth radii), well past the orbit of the Moon (at around 60 Earth radii), on the night side of the Earth.

2.4.7 Plasmasphere

Plasmasphere (also considered as inner magnetosphere) is essentially an extension of the ionosphere. It is a region of the Earth's magnetosphere consisting of low energy (cool) plasma (composed mostly of hydrogen ions (protons) and electrons) and is located above the ionosphere. This is not really spherical but a doughnut-shaped region (a torus) with the hole aligned with Earth's magnetic axis. [In this case the use of the suffix -sphere is more in the figurative sense of a "sphere of influence".] The outer edge of this doughnut over the equator is usually 19,000-32,000 km above the surface (some 4 to 6 times Earth radii). The plasmasphere has a very sharp edge, known as the plasmapause, inside which the geomagnetic field lines rotate with the Earth. The inner edge of the plasmasphere is taken as the altitude at which protons replace oxygen as the dominant species in the ionospheric plasma which usually occurs at about 1000 km altitude.

2.5 Exosphere

The uppermost part of the thermosphere, that extends from about 550 km to thousands of kilometres, is known to be exosphere. Air is very thin here unable to retain upward travelling molecules‟ attempts to escape to space (especially, if they are moving fast enough) or be pulled back to Earth by gravity (if is slow) with little probability of colliding with another molecule. This is the area where satellites orbit the earth and the altitude of its lower boundary, known as the thermopause or exobase, ranging from about 250-500 km depending on solar activity. The upper boundary can be defined theoretically by the altitude (about 2,00,000 km, half the distance to the Moon, i.e., 3,84,403 km) at which the influence of solar radiation pressure on atomic hydrogen velocities exceeds that of the Earth's gravitational pull. The exosphere is observable from space as the geocorona (where the solar far-ultraviolet light that is reflected off the cloud of neutral hydrogen atoms that surrounds the Earth) and is seen to extend to at least 96000 km from the surface of the Earth. The exosphere is a transitional zone between Earth's atmosphere and interplanetary space.

2.6 Factors Affecting Atmospheric Temperature at Troposphere

As mentioned before, the troposphere is characterized by a decrease in temperature with respect to height (from a mean surface temperature of about 150C to a temperature of about -530C). The temperature structure of this layer is a consequence of radiative balance and the convective transport of energy from the surface to the atmosphere. Virtually all water vapour, clouds and precipitation are confined in this layer. Since this is the most studied component of atmosphere, because of its direct relationship with most of the weather phenomena. Atmospheric temperature is governed by many factors. We will now look into their explanations.

2.6.1 Insolation

Insolation (short for incident or incoming solar radiation) is a measure of solar radiation energy received on a given surface area and recorded during a given time. It is also called solar irradiation and expressed as "hourly irradiation" if recorded during an hour or "daily irradiation" if recorded during a day. Increased insolation directly increases temperature.

2.6.2 Humidity

It is the amount of water vapor in the air, measured by mass of water vapour per unit volume of total air and water vapour (called absolute humidity) or as ratio partial pressure of water vapour in air water mixture to saturated water vapour of water (called relative humidity). More than 50% of water vapour is concentrated below about 850 mb (millibar), while more than 90% is confined to the layer below about 500mb. The variability of the H_2O concentration shows bimodal distribution with a maximum in the subtropics of both hemisphere below about 700 mb. The variability is very small in the equatorial region and poleward of about 600. The stratospheric H_2O concentration is relatively small, with a value of about 3-4 ppmv (parts per million by volume) in the lower stratosphere. It has been suggested that H_2O in the lower stratosphere is controlled by the temperature of the tropical tropopause, and by the formation and dissipation of cirrus anvils due to outflow from cumulonimbus clouds.

2.6.3 Altitude

This is the distance measurement, usually in the vertical or "up" direction, between a reference datum and a point or object. In troposphere, temperature decreases with altitude (as discussed before) and the rate of decrease is called lapse rate. Although the actual atmospheric lapse rate varies, under normal atmospheric conditions the average atmospheric lapse rate results in a temperature decrease of 6.5°C/ km of altitude. The measurable lapse rate is affected by humidity. A dry lapse rate of 10°C/ km is often used to calculate temperature changes in air not at 100% relative humidity. This is called dry adiabatic lapse rate (DALR). A wet lapse rate of 5.5°C/ km is used to calculate the temperature changes in air that is saturated. This is called saturated lapse rate (SLR). However, in a particular region, sometimes the temperature can increase with height in the lower troposphere, based on the atmospheric condition. When this happens, it is called an "inversion". However, if the temperature remains the same with height, it is called "isothermal". Thus, the actual lapse rate at any region (called environmental lapse rate) varies with location, time of day, weather conditions, season, etc.

2.6.4 Type of Biome

Also known as ecosystem, this refers to contiguous areas with similar climatic conditions on the Earth, such as communities of plants, animals, and soil organisms. Depending on the biome, there is variation of transpiration and gaseous exchange, which can affect the temperature, mostly at surface level. The height of troposphere varies spatio-temporally too. It is more like 8 km over the polar regions in winter (cold air tends to settle downward) and 18 km over the equatorial regions, due to greater convection there (heating caused by the direct rays of the sun).In the mid-latitudes, it's lower in winter and higher in summer, for the same sorts of reasons.

2.7 Instruments in Study of Atmospheric Layers

The standard equipments used globally in study of atmospheric layer characteristics on regular basis is a weather or sounding system, which is a balloon (specifically a type of high altitude balloon) which carries instruments aloft to send back information on atmospheric pressure, temperature, humidity and wind speed by means of a small, expendable measuring device called a radiosonde. To obtain wind data, they can be tracked by radar, radio direction finding, or navigation systems (such as the satellite-based Global Positioning System, GPS). Balloons meant to stay at a constant altitude for long periods of time are known as transosondes.

2.7.1 Weather Balloons

The balloon itself produces the lift, and is usually made of a highly flexible latex material, though Chloroprene may also be used. The unit that performs the actual measurements and radio transmissions hangs at the lower end of the string, and is called a Specialized radiosondes are used for measuring particular parameters, such as determining the ozone concentration. The balloon is usually filled with hydrogen due to lower cost, though helium can also be used. The ascent rate can be controlled by the amount of gas with which the balloon is filled. Weather balloons may reach altitudes of 40 km or more, limited by diminishing pressures causing the balloon to expand to such a degree (typically by a 100:1 factor) that it disintegrates. In this instance the instrument package is usually lost. Above that altitude sounding rockets are used, and for even higher altitudes satellites are used.

2.7.2 Global Distributions of Weather balloons

Major manufacturers of balloons are Zhuzhou Research & Design Institute, Chemchina Rubber Corp (Brand: Hwoyee)[China], Totex and Cosmoprene of Japan and Pawan Rubber Products (Pawan Exports, Brand: PAWAN) of India. Weather balloons are launched around the world for observations used to diagnose current conditions as well as by human forecasters and computer models for weather forecasting. About 800 locations around the globe do routine releases, twice daily, usually at 0000 UTC and 1200 UTC. Some facilities will also do occasional supplementary "special" releases when meteorologists determine there is a need for additional data between the 12 hour routine launches in which time much can change in the atmosphere. Military and civilian government meteorological agencies such as the National Weather Service in the US typically launch balloons, and by international agreements almost all the data are shared with all nations. Specialized uses also exist, such as for aviation interests, pollution monitoring, photography or videography and research.

2.7.3 Use of Optical Beams

Cloud height and visibility are two other important parameters which are required for meteorological measurements, especially in tropospheric and lower stratospheric studies. Both use optical beams of various types - often Lidars. For example, ceilometers determine the base of the cloud height by sending up pulses of light towards the cloud. Upon encountering the cloud, the light pulses are (partially) reflected to the ground, where they are detected. The time delay between transmission and reception of the light pulses is used to determine the base height of the clouds. Visibility instruments usually measure the reduction of intensity of narrow light beams as they traverse across a designated region.

2.7.4 Sky cameras

In relation to clouds, it is also not uncommon to record the percentage of cloud cover, and often allsky cameras are used to do this. A simple all-sky camera can be made by photographing the image seen in a highly polished metal sphere with a radius of typically 15-30 cm.. After those early flights, and especially in the 1960's and 1970's, scientists started developing their own rockets for middle atmosphere research. These rockets were smaller than the V2's, but were especially designed for scientific payloads. These rockets carry a variety of different payloads, and the compositions of the payloads vary from rocket to rocket, depending on the planned experiments. Examples include pressure sensors, density sensors, mass spectrometers, dust detectors (for detecting meteoric dust), ion gauges, Langmuir probes, electron density gauges, and many others. Winds and dynamical motions form a key subject for investigation at these high altitudes.

2.7.5 Use of Rockets

The winds are very large and highly variable, especially at heights of 80 to 100 km. One early method for measurement of upper level winds was to release a trail of luminescent gas behind the rocket as it flies upward. These particular measurements are best made at sunset or sunrise. The trail is blown around by the wind, and also develops a "puffy" appearance due to local turbulence. By taking photographs of these trails from the ground using high resolution cameras, and using multiple cameras so that triangulation can be used, it is possible to determine both the upper level winds (from the trail drifts), and the strengths of turbulence (from the rate of expansion of the puffy trail). Many other rocket experiments are carried out, but there is currently no real regular worldwide program of middle atmosphere rocket measurements like the radiosonde program. Much of the information about the long term variability of middle atmosphere winds is determined by radars and satellites.

2.7.6 Use of Satellites

As rockets became more powerful, it was eventually possible to use them to place satellites in orbit. The first successful satellite was lifted to orbit by Russian scientists and engineers on 4th October 1957, and was called Sputnik. Since then, many other satellites have been placed in orbit.

2.8 Human and Natural Influences on the Structure of Atmosphere

The composition of the atmosphere plays an important role in the thermal structure, especially at troposphere. When we look at the typical composition of atmosphere as shown in the earlier Table, although carbon dioxide is listed as a permanent constituent, its concentration has been increasing by about 0.4% per year as a result of combustion of fossil fuels, absorption and release by the oceans, and photosynthesis. In addition, a number of measurement series indicate that the atmospheric methane concentration, with a present value of about 1.7 parts per million by volume (ppmv), has increased by 1-2% per year and that it may have been increasing for a long period of time. The most likely cause of the increase in the CH4 concentration is the greater biogenic emissions associated with rising human population. Rice paddies seem to be another prime source of CH4. (Methane) There is no direct evidence of an increase in carbon monoxide concentration. However, deforestation, biomass burning, and modification of CH_4 (Methane) sources could lead to changes in the atmospheric CO (Carbon monoxide)concentration. There is also some evidences of an increase in nitrous oxide. A possible global increase of about 0.2% per year in N_2O (Nitrous oxide) has been suggested. This increase is attributed to the combustion of fossil fuels, biomass and, in part, to fertilizer denitrification.

2.8.1 Ozone Concentration

Ozone concentration also varies significantly with space (latitude) and time (season), maximum occuring during polar night. Although it occurs principally at the ozone layer (15-30 km), where it is continually created and destroyed by photochemical processes associated with solar UV-radiation (and thus protects the life on earth by absorbing these deadly solar radiations), it is also formed in troposphere by anthropogenic activities, in which case ozone is toxic to all living beings. In fact, many photochemical reactions associated with ozone involve water vapour, methane and carbon monoxide, which are directly related to various anthropogenic activities, affecting ozone balance of the lower atmosphere.

2.8.2 Change in Temperature regime of atmosphere

Since the late 1970s, satellite-based instruments have monitored global changes in atmospheric temperature. These measurements reveal multidecadal tropospheric warming and stratospheric cooling, punctuated by short-term volcanic signals of reverse sign. Similar long- and short-term temperature signals occur in model simulations driven by human-caused changes in atmospheric composition and natural variations in volcanic aerosols. Most of the studies involve two primary approach : (1) comparison of modeled and observed atmospheric temperature changes, using results from individual models and individual observational records, or (2) use of large multimodel archive and multiple observational datasets to identify (with high statistical confidence in satellite data) the human-caused latitude/altitude pattern of atmospheric temperature change.

2.9 Structures of Atmosphere in other Planets

All planets of the Solar System's planets have atmospheres. This is because their gravity is strong enough to keep gaseous particles close to the surface. Larger gas giants are massive enough to keep large amounts of the light gases hydrogen and helium close by, while the smaller planets lose these gases into space. The composition of the Earth's atmosphere is different from the other planets because the various life processes that have transpired on the planet have introduced free molecular oxygen. Much of Mercury's atmosphere has been blasted away by the solar wind. The only moon that has retained a dense atmosphere is Titan. There is a thin atmosphere on Triton, and a trace of an atmosphere on the Moon.

2.9.1 Dynamic Weather Systems in the Planets

Planetary atmospheres are affected by the varying degrees of energy received from either the Sun or their interiors, leading to the formation of dynamic weather systems such as hurricanes, (on Earth), planet-wide dust storms (on Mars), an Earth-sized anticyclone on Jupiter (called the Great Red Spot), and holes in the atmosphere (on Neptune).At least one extrasolar planet, HD 189733 b, has been claimed to possess such a weather system, similar to the Great Red Spot but twice as large.

2.9.2 Terrestrial Planets

Both Mars and Venus have tropospheres of greater extent than the Earth, though for different reasons. The atmosphere of Mars is much thinner than Earth's and there is less compression because of the weaker gravity of the Mars. Although Venus has weaker gravity than Earth, it has over ninety times the amount of atmosphere because of a runaway greenhouse effect that occurred at least hundreds of millions of years ago. That will be described further later but it does provide a warning to us that drastic global climate change is possible. Because their tropospheres extend over a greater distance than the Earth's troposphere, the clouds of Mars' and Venus' clouds are found at higher altitudes. Mars and Venus also possess thermospheres. What is missing is the temperature bump of a stratosphere (and mesophere) because they do not have an ozone layer to absorb the ultraviolet light. (Planet atmosphere models courtesy of Jere Justus at the Marshall Space Flight Center, NASA.)

2.9.3 Jovian Planets

The jovian planets (i.e., the planets that are essentially big balls of gas, each surrounded by many moons and rings, such as. Jupiter, Saturn, Uranus and Neptune), in contrast to terrestrial planets, are all slightly oblong and rotate much faster than any of the terrestrial worlds. Gravity by itself would make a planet spherical, but their rapid rotation flattens out their spherical shapes by flinging material near the equator outward. Observations of clouds at different latitudes suggest that the jovian planets rotate at different speeds near their equators than near their poles.

The atmospheres of Jupiter and Saturn are made almost entirely of hydrogen and helium, although there is some evidence they contain hydrogen compounds. Uranus and Neptune are made primarily of hydrogen compounds, with smaller traces of hydrogen, helium, metal and rock. The most common hydrogen compounds are methane (CH_4), ammonia (NH_3), and water (H_2O). The farther away a planet is from the Sun, the cooler its atmosphere will be. This means that the same gases will condense to form clouds at different altitudes on different planets because the condensation of a gas requires a specific amount of pressure and temperature. Ammonia, ammonium hydrosulfide and water make up the 3 cloud layers of Jupiter and Saturn. Refer to Fig 1.5 to see these gases condense at lower altitudes in Saturn's atmosphere than they do in Jupiter's atmosphere.

Conclusions

Atmosphere con be divided into five primary layers- troposphere, stratosphere, mesosphere, thermosphere and exosphere, based on the thermal characteristics with altitude, which is affected by the varying composition, and reception of types of solar radiation. Each layer is responsible for maintenance of life of the planet. In fact, although most of the planets do have atmosphere, yet with one or more lacking layers, rendering them unsuitable for sustenance for life. The progress of science has been directed towards better understanding of the characteristics and significance of these layers for utilizing them for development of space and communication technologies as well as trying to control the anthropogenic activities so as not to disturb the natural stratification of the planet.

Summary

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have atmosphere, yet with one or more lacking layers, rendering them unsuitable for sustenance for life. The progress of science has been directed towards better understanding of the characteristics and significance of these layers for utilizing them for development of space and communication technologies as well as trying to control the anthropogenic activities so as not to disturb the natural stratification of the planet

References

Adapted from E-PG Pathshal, Earth Science, Meteorology & Climatology, Module title Thermal Structure of Atmosphere.

Unit 3: The Atmosphere: Origin, Composition and Structure

Unit Structure

3.0 Learning Objectives

After studying this unit, you will be able to:

- discuss atmospheric properties
- define structure and composition of atmosphere,
- enlist various gases and components of atmosphere,
- enumerate different layers of atmosphere,

- understand the significance of various gases of atmosphere,
- explain various layer of the atmosphere and
- explain the importance of atmosphere as a living planet

3.1 Introduction

The atmosphere of the earth is a vast expanse of gases enveloping our entire earth. Within this envelope, we are surviving and all our activities are confined. It is made up of several gases, water vapour and minute particles suspended in the gaseous substance of air. The atmosphere extends several hundred km above the earth surface. It is not uniform at every height we climb above, but it has drastic changes with height. The atmosphere is composed of several layers. At the transition zones of the layers, the change is very sharp but within a layer, the changes are slow. In this module, we will discuss about the composition and structure of the atmosphere. Apart from these, our concern will also be there to through light on its importance and utility of the atmosphere for us as well as for the entire living organisms.

3.2 Atmospheric Properties

The basic properties of the atmosphere include temperature, density, pressure, and humidity.

3.2.1 Temperature

Temperature is the measure of thermal or internal energy of the molecules within an object or gas. We can measure temperature of an object using either direct contact or remote sensing. Temperature of air is closely related to other atmospheric properties, such as pressure, volume and density.

In the atmosphere, temperature is related to volume, pressure, and density. Temperature is inversely related to density but directly related to pressure and volume. This means, for example, when temperature increases, density decreases, and volume and pressure of the gas also increase. So, air that is warm and dry will tend to rise when surrounded by cooler air because warm air is less dense than the cooler air around it.

Temperature controls planting dates and the growth of plants as well as insect pests and crop diseases. As an integral part of weather, temperature also determines the type of precipitation (rain/snow/sleet) that might occur if you are in a location that is experiencing near freezing conditions.

Temperature is a measure of how much internal energy an object or gas has. For example, a gas with fast-moving molecules feels "hot" because when that gas touches something that is cooler, some of the energy of the hot gas is transferred to the cooler object and the cooler object responds by warming up. If there are two objects with different temperatures, energy always flows from the warmer object to the colder object. Atmosphere is a mixture of gases and follows the principle of fluid (liquids and gases) dynamics.

Heat energy transfer is the cause of temperature change and like any other fluid system, in atmosphere also the main mode of energy transfer is a process called convection. It works because in a fluid, "chunks" of matter (or parcels) can move up or down with respect to the rest of the fluid as they are being heated or cooled, respectively. The processes of convection are, however, governed by the laws of thermodynamics. Understanding these laws helps us quantify these processes, make predictions on the formation of clouds and fog, and explain how the vertical profile of temperature in the atmosphere is determined.

3.2.1.1 Thermodynamic properties of dry air - adiabatic temperature change

The equation of state - ideal gas law If air contains no water it is called dry air. The state of a parcel of dry air is described by three properties: temperature (T, expressed in °K, where 273°K = 0°C), pressure (p, force per unit area, expressed in Newtons m^{-2}) and density (ρ, the mass of a unit volume, in Kg m^{-3}). In a gas these properties are related by a relatively simple physical law called the ideal gas law (ideal because it is not exact, albeit quite accurate for most applications in meteorology). This law states that:

$$p = \rho R\, T$$

R is a coefficient, called the gas constant. It does not depend on either p, ρ, or T. The gas constant depends only on the composition of gases that make up the air (every gas has its own gas constant). Since this composition (for dry air) is roughly constant throughout most of the atmosphere R of air is constant and equal to 287 Joules kg^{-1} $°K^{-1}$).

To understand the equation of state, it is assumed that we have a fixed mass of air enclosed in a container with rigid walls (hence with fixed volume). If we warmed the container, say by putting it over a flame, the temperature of the air (i.e. kinetic energy of the air molecules) will rise and the pressure (i.e., the force exerted by these molecules on the container walls) will increase. The density of the air will not change since we are not increasing the amount of gas in the container nor the volume of the container. The ideal gas equation states that the increase in pressure is directly proportional to the increase in temperature. Now if we replace the rigid wall of the container with flexible ones, that are allowed to stretch freely if the pressure inside rises above that on the outside. In that case, when we raise the temperature, the pressure inside will remain constant (and equal to the outside pressure), but the container's volume will increase. This means that the density will decrease (because the mass inside does not change). The ideal gas law states that the density decrease will be inversely proportional to the increase in temperature.

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3.2.1.2 The first law of thermodynamics and adiabatic expansion

Let us remove the flame that heated our flexible walled container, and put it in a chamber where the pressure can be controlled from the outside, lowered or raised at will. What will happen to the density of our air parcel when we lower the pressure surrounding our container? What will happen to its temperature?

Here too the pressure on both sides of the flexible container walls will equalize - as the outside pressure drops, the container will expand and the pressure inside will drop by the same amount. The density of the air parcel in the container will decrease as well, in agreement with the ideal gas law. But what the ideal gas law cannot tell us is what will happen to the temperature. To find that out we need to consider the first law of thermodynamics - a physical law that extends the principle of conservation of energy to include the concepts of heat and work.

In thermodynamics the simplest form of energy conservation is the balance between internal energy (the kinetic energy of the body's internal molecular motion - directly proportional to its temperature), and the amount of heat added to the body minus the work done by the body on its surroundings.

As our air parcel expands in response to the lowering of the outside pressure, the force of its internal pressure is moving the walls of the container outwards. When a force is moving an object over a given distance it does work. Thus the expanding air parcel does work on its surroundings. This work must come at the expense of internal energy (remember, heat is neither added nor taken away from the parcel in this experiment). Thus the molecular motion within the parcel will slow down, and the parcel's temperature will drop.

The expanding parcel will experience not only lowering of its pressure and density, but also of its temperature. All three state variables: pressure, density, and temperature will remain in balance as described by the ideal gas law. The process described above is called adiabatic expansion, implying the change in parcel density without the exchange of heat with its surroundings, and its consequential cooling. The opposite will occur when the parcel is compressed. Adiabatic compression leads to warming.

Using the equation of state, the first law of thermodynamics, and the hydrostatic equation we can find that the rate of adiabatic temperature change in an ascending air parcel (also termed the adiabatic lapse rate and denoted Γd) is constant:

$$\Gamma_d = -\Delta T / \Delta Z = 9.8\ ^{\circ}C\ km^{-1}$$

Note that Γd is defined as the negative of the actual temperature change, so that Γd is the amount of cooling that the rising parcel experiences. Sinking air will warm at the same rate as it is being compressed by the increasing pressure.

3.3.2 Density

Density measures the 'heaviness' of an object or how closely 'packed' the substance is. Density is related to both the type of material that an object is made of and how closely packed the material is.

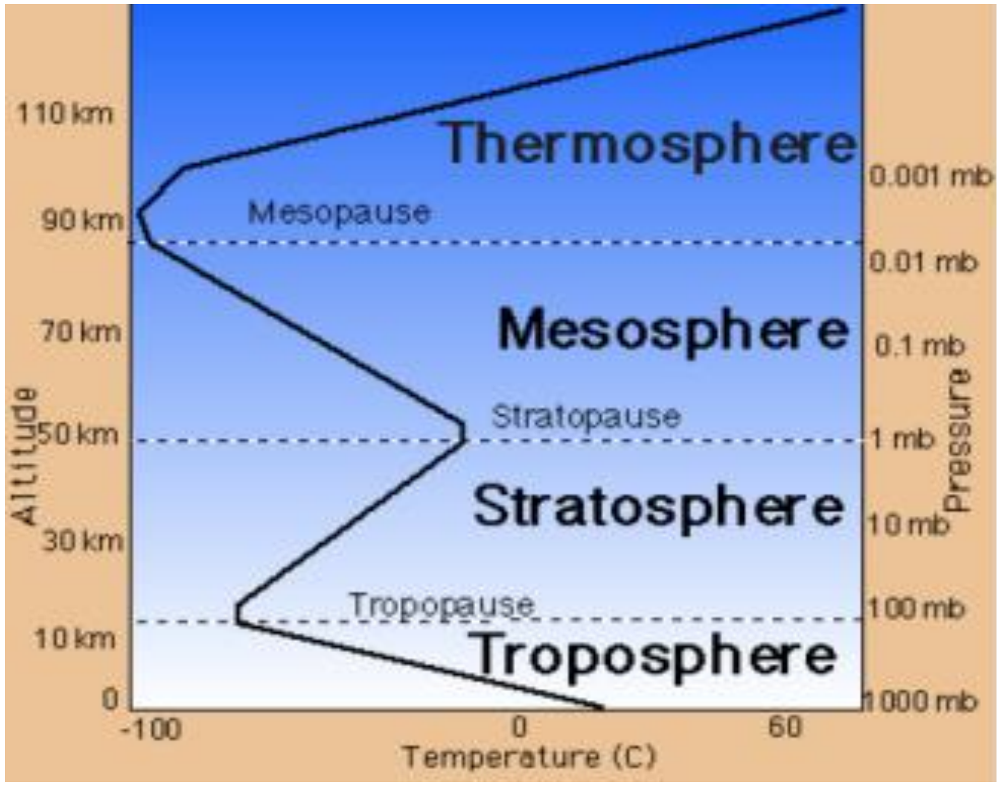

Fig. 1: This shows that the vertical variation of the Earth's temperature is not quite so simple to describe. There are regions where the temperature increases with height, and regions where the temperature decreases with height

(Source: http://teachertech.rice.edu/ Participants/louviere/struct.html)

The technical definition of density is mass per unit volume. Generally, density describes how tightly packed something is. An object with a lot of material in a small space is denser than an object that has lots of air space included. In the atmosphere, gas that is less dense has a lower concentration of molecules per volume than a denser gas and will tend to rise compared to the air around it.

Why do I care? When planting crops or plants, soil density is very important. If the soil is packed too tightly, the plant or crop won't be able to absorb any water or nutrients from the soil and will not be able to grow properly. Density in the atmosphere is also important in the formation of clouds and precipitation.

Warm air is less dense than cooler air. Air density varies with the relative humidity (amount of water vapor molecules in the air) along with temperature. Water vapor molecules (H2O in the gaseous phase) are composed of Hydrogen (H) and Oxygen (O) molecules. Hydrogen has a molecular weight of 1.01 g/mol. Dry air is composed mostly of Nitrogen (N) molecules since Earth's atmosphere is 78% Nitrogen and 21% Oxygen. Nitrogen has a molecular weight of 14.0 g/mol. In the atmosphere, the density of air particles decreases with height, with more gas particles remaining near the surface of Earth. When only taking into account humidity, dry air is denser than moist air because of molecular weights of the gases.

A hot air balloon is a good example of how people work with density. Hot air balloons use the properties of density in order to float. In the base of the hot air balloon, there is a torch that heats up the air inside of the balloon. When the air inside the balloon becomes warmer than the surrounding air, the balloon will begin to float. The person controlling the hot air balloon can add more heat to the balloon to reach the desired height. The air inside the balloon needs to cool in order for the balloon to land. The density of dry air can be calculated using the ideal gas law, expressed as a function of temperature and pressure:

$$\rho = p/R_{specific}T$$

where, ρ = air density (kg m-3) p = absolute pressure (Pa) T = absolute temperature (K) Rspecific = specific gas constant for dry air (J kg-1 K -1)

The specific gas constant for dry air is 287.058 J kg-1 K -1 in SI units.

This quantity may vary slightly depending on the molecular composition of air at a particular location. Therefore:

- At International Union of Pure and Applied Chemistry (IUPAC) standard temperature and pressure i.e. 0 °C and 100 kPa, respectively, dry air has a density of 1.2754 kg m-3 .
- At 20 °C and 101.325 kPa, dry air has a density of 1.2041 kg m-3
- At 70 °F and 14.696 psi, dry air has a density of 0.074887 lb ft-3

3.3.3 Pressure

Pressure is the force exerted over a given area or object, either because of gravity pulling on it or other motion the object has. Molecules in the air produce pressure through both their weight and movement, and this pressure is connected to other properties of the atmosphere.

Pressure is force exerted over a given area. In the atmosphere, the molecules in the air apply pressure to everything on earth, including us. For instance, individual molecules in the air push against tiny areas on the top of our head. The force that air exerts is called air pressure. The more air molecules there are above you, the greater the force they exert, so the greater the pressure.

Pressure is important because it is related to volume, density, and temperature. In the atmosphere, warm surfaces can heat the air above them, causing the air to become less dense and to rise. This can eventually result in clouds and precipitation in the areas of rising motion, such as in the center of low pressure systems. High pressure in the atmosphere causes the air to compress and sink, leading to clear skies and calm conditions.

We all live near the bottom of an ocean of air. At sea level, the weight of the air overhead presses on us with a pressure of ~105 N m^{-2} =14.7 lbs in^{-2}. We are not aware of this great weight because the air presses on us from all sides, even from our insides (due to the air in our lungs).

At higher altitudes, there is less air and less weight overhead, and the pressure is less. Also, because air is readily compressible, the lower layers of air are compressed by the weight of the air above. Thus, the pressure and density of air decrease at higher altitudes. That's why a helium balloon rises: the pressure on the underside of the balloon is greater than the pressure on the top.

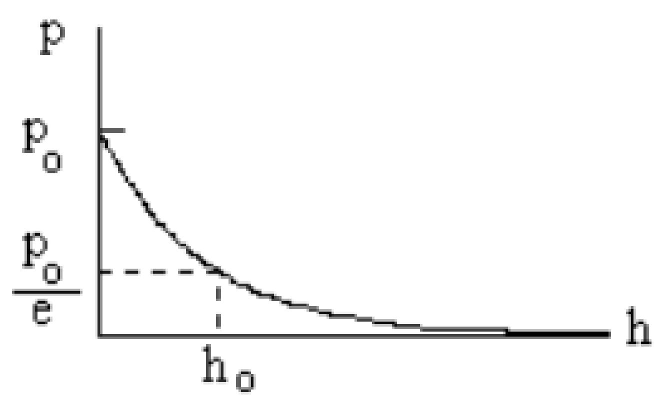

Figure 2. It shows how air pressure (in Y-axis) falls exponentially with increase in altitude (in X-axis). The mathematical form of this is given in equation 1 below. (Source:https://www.colorado.edu/physics/phys1140/phys1140_f98/Experiments/O2/O2.html)

Where, h is the height above a level where the pressure is po, m is the average mass of an air molecule, k is the Boltzmann constant (k =1.38×10-23J K-1) and T is the temperature in oK. Note that both mgh and kT have the units of energy, so the exponent is dimensionless. It is a remarkable characteristic of the exponential function that eqn. 1 is true regardless of where we set the zero of h, so long as the pressure at h = 0 is po. This equation (derived in the Appendix A) is not quite correct, because its derivation assumes that the atmosphere is isothermal when in fact, the temperature of the air varies considerably with altitude.

Eqn. 1 can be rewritten as

$$p = p_o e^{-\left(h/h_o\right)} \qquad (2)$$

Where, h0 = (kT/mg) is a characteristic height, called the scale height, of the atmosphere. The scale height is the height increase which reduces the air pressure by a factor of 1/e (= 1/2.718~0.368). If you started at sea level (p = 1 atm) and climbed a mountain with a height ho, the pressure at the peak would be (1 atm/e = 0.37 atm). At an altitude of $2h_o$, the pressure would be 1 atm / e^2 i.e. ~ 0.135 atm.

If the pressure change Δp can be measured over some small height change Δ h, then the scale height ho can be determined. (3)

$$\frac{\Delta p}{\Delta h} \cong \left.\frac{dp}{dh}\right|_{h=0} = p_o\left(-\frac{1}{h_o}\right)\left.e^{-h/h_o}\right|_{h=0} = -\frac{p_o}{h_o}, \quad \Rightarrow h_o = -p_o\frac{\Delta h}{\Delta p}$$

Change of pressure with temperature: According to the ideal gas law, if the volume V and number of molecules N are fixed, then the pressure p is proportional to the temperature T, and the fractional change in temperature is equal to the fractional change in pressure.

$$\frac{\Delta T}{T} = \frac{\Delta p}{p}, \quad \text{(T in Kelvin).} \qquad (4)$$

Appendix A

A layer of air has weight; it is held up because the pressure below is greater than the pressure above. Consider a layer of air of thickness Δ h, area A, and density ρ; its volume is A.Δ h and its weight is

$$w = mg = \rho \cdot A \cdot \Delta h \cdot g \qquad (A.1)$$

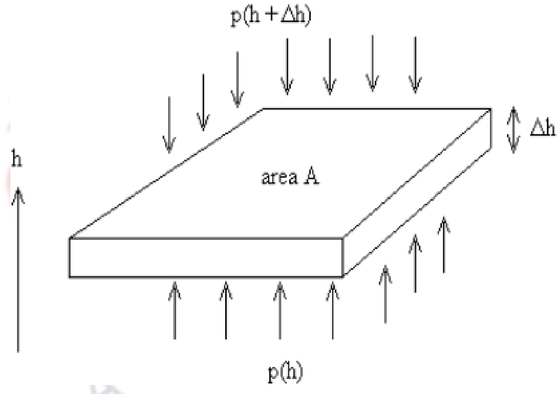

Fig. 3: This weight is supported by the net force on the layer due to both the pressure above and the pressure below (Source:https://www.colorado.edu/physics/phys1140/phys1140_f98/Experiments/O2/O2.html)

$$p(h)\cdot A - p(h+\Delta h)\cdot A = \rho\cdot A\cdot \Delta h\cdot g \qquad \text{(A.2)}$$

or

$$p(h+\Delta h) - p(h) = -\rho\cdot\Delta h\cdot g \Rightarrow \frac{dp}{dh} = -\rho g \qquad \text{(A.3)}$$

If the density is constant, we have

$$|\Delta p| = \rho g |\Delta h| \qquad \text{(A.4)}$$

Equation no. A.4 is the principle of operation of barometers. From this, one can show that the height of a column of mercury in a mercury barometer at STP (standard temperature and pressure) is 760 mm.

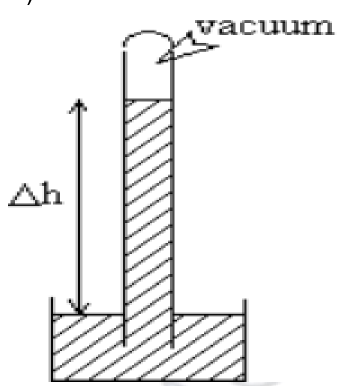

Fig. 4: It shows how the pressure due to the weight of a column of fluid (usually mercury) with density ρ and height Δh, is balanced by atmospheric pressure in a barometer

(Source:https://www.colorado.edu/physics/phys1140/phys1140_f98/Experime nts/O2/O2.html).

The density of air is not constant, however, it varies with pressure. From the ideal gas law,

$$p = \frac{N}{V}kT = \frac{Nm}{V}\frac{kT}{m} = \rho\frac{kT}{m} \quad \text{(A.5)}$$

Where, m is the average mass of an air molecule and ρ is the mass density of air. Hence,

$$\rho = \left(\frac{m}{kT}\right)p \quad \text{(A.6)}$$

Inserting the relation of equation A.6 into equation A.3 yields

$$\frac{dp}{dh} = -\left(\frac{mg}{kT}\right)p \quad \text{(A.7)}$$

The solution of this differential equation is

$$p = p_0 e^{-\left(\frac{mgh}{kT}\right)} \quad \text{(A.8)}$$

This equation is only approximately true because we have made two assumptions which are not strictly correct: air is an ideal gas and the atmosphere is isothermal.

Appendix B: Derivation of pressure change during an adiabatic volume change

The pressure change due to an adiabatic volume change depends on whether the gas in question is monatomic, like helium or neon, or diatomic, like the main components or air, oxygen and nitrogen. Assuming that the gas container is thermally isolated from the outside world, then no heat is exchanged during the volume change. However, the piston does work on the gas as the volume changes, so energy, in the form of work, is exchanged with the outside and the temperature of the gas varies.

We first derive the temperature change ΔT. We will need the First Law of Thermodynamics:

$$\underbrace{\Delta U}_{\text{energy added}} = \underbrace{-p\,\Delta V}_{\text{work done on the system}} + \underbrace{\Delta Q}_{\text{heat added}} \quad \text{(B.1)}$$

and an expression for the total internal energy of a gas of N atoms or molecules. For the case of a monoatomic ideal gas:

$$U = N \times \text{KE per atom} = \frac{3}{2}NkT \quad \text{(B.2)}$$

While for a diatomic gas,

$$U = N \times (KE + \text{rotational energy}) \text{ per molecule} = 3NkT \qquad (B.3)$$

Equations (B.2) and (B.3) can both be written as U = bNkT, where b is either 3/2 or 3. Assuming ΔQ = 0, (B.1), (B.2), and (B.3) yields

$$bNk\Delta T = -p\Delta V \quad \Rightarrow \quad \Delta T = -\frac{1}{b}\frac{p}{Nk}\Delta V = -\frac{1}{b}T\frac{\Delta V}{V} \qquad (B.4)$$

So, for an adiabatic change of volume, we have

$$\frac{\Delta T}{T} = -\frac{1}{b}\frac{\Delta V}{V} \qquad (B.5)$$

Now we can compute the pressure change. Starting from the ideal gas law, p = NkT/V, and differentiating, we have

$$\Delta p = \frac{Nk}{V}\Delta T - \frac{NkT}{V^2}\Delta V = \frac{p}{T}\Delta T - \frac{p}{V}\Delta V \qquad (B.6)$$

Substituting (B.5) into (B.6) gives

$$\Delta p = \frac{p}{T}\left(-\frac{1}{b}T\frac{\Delta V}{V}\right) - \frac{p}{V}\Delta V = -\left(1+\frac{1}{b}\right)p\frac{\Delta V}{V} = -\left(\frac{5}{3}\text{ or }\frac{4}{3}\right)p\frac{\Delta V}{V} \qquad (B.7)$$

The coefficient is 5/3 for a monatomic gas and 4/3 for a diatomic gas.

3.3.3 Humidity

Humidity is a measure of the amount of moisture in the air. It tells you how comfortable it is to be outside, and if there is enough moisture to create clouds and rain.

Humidity is a measure of the amount of moisture in the air. Moist air is air that contains water in vapor form. The moisture in the air is usually referred to as humidity. The average concentration of vapor in the atmosphere is 0.48%. Another way to appreciate the amount of water in the atmosphere is to note that if all of it was condensed and made to cover the Earth uniformly, it would make a layer of liquid 1 inch thick. Air can not carry unlimited amounts of water. Even in the most humid situations the concentration of vapor in the atmosphere can not exceed a few percent. The colder the air, the less amount of vapor it can hold.

The largest source of water in the climate system is the world ocean. Water evaporates from the ocean surface to mix in the air. Wet or forest covered land surfaces are secondary sources of atmospheric water. The highest concentrations of vapor are found near the surface in the tropics. The concentration drops quite rapidly with height, and half the way up the tropical troposphere it is a fraction of what it is near the surface. Vapor concentration also falls off rapidly as we move north or south of the tropical belt, and it is generally higher over the oceans than it is over land.

Measures of water vapor in the atmosphere

There are a few ways to measure the concentration of water vapor in the atmosphere.

i) **Vapor pressure (denoted e):** It is the partial pressure of water vapor molecules in the atmosphere. Partial pressure is a term in thermodynamics of gas mixtures (in our case - air). We can break down the air pressure into the pressure each of its individual gas constituents would exert, had all the others been removed. The pressure in an air parcel is the sum of the partial pressures of all the constituents. The smaller the concentration of a gas in the mixture, the lower its partial pressure.

   However, since molecules of different constituents have different mass, the partial pressure is not directly proportional to the molecular concentration.

   The concept of vapor pressure is important for understanding the processes of evaporation and saturation. If we hold a parcel of air still over flat water surface, water molecules will escape the surface and start mixing with the other gases in the air parcel. This is evaporation - it can happen even if the liquid is not at its boiling temperature. Evaporation can only go on until the maximum amount of water vapor that air can hold is reached. At this point, the pressure that the water molecules exert as they are trying to escape the liquid is equaled by the partial pressure of water in the air parcel, called the saturation vapor pressure. Saturation is a process of equilibrium where water molecules cross back and forth across the boundary between water and air, maintaining a fixed concentration in the air. The saturation vapor pressure is a function of temperature.

ii) **Relative humidity**: It is the ratio of actual vapor pressure to saturation vapor pressure (expressed as % if multiplied by 100). This is a common way to indicate air humidity.

Because perspiration plays a very important function in maintaining body temperature, relative humidity figures into consideration of the degree of comfort we have when following our daily activities.

iii) **Mixing ratio**: It is the mass of water vapor in grams per kilogram of air. This is the most common way to indicate air humidity in scientific applications. At the Earth's surface, mixing ratio varies from ~18 g kg-1 in the tropics to less than 2 g kg-1 near the poles.

iv) **Dew point temperature**: It is yet another way to express the vapor content of an air parcel. The dew point temperature gets its name from the process leading to the formation of dew. In the early morning hours before sunset, when the air is still, and the ground is cool (compared to its day time temperature) because it radiated its heat into the atmosphere and outer space, the air in immediate contact with it cools too by conduction. Since the air's ability to hold vapor decreases with decreasing temperature, any vapor in excess of the saturation value is rejected and condenses as droplets on the ground or its cover. Following this natural process we define the dew point as the temperature at which the vapor in a cooled parcel of air begins to condense. The dew point can be either lower than (if the air is not saturated) or equal to (if the air is saturated) the actual temperature. The bigger the difference between the actual air temperature and the dew point, the drier the air is.

3.4 Composition of Atmosphere

The literal meaning of composition is 'ingredients' or 'constituents' of something. In another words, it is a manner by which something is made up of. When we apply the same meaning with atmosphere, it signify the items or the elements with which our atmosphere is composed. Our atmosphere is composed of numerous gases and other substances, hence, it is a mechanical mixture of the gases, water vapour and dust particles. Let us discuss about the composition of atmosphere.

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it is a mechanical mixture of the gases, water vapour and dust particles. Let us discuss about the composition of atmosphere.

Groups	Gases	Volume % of dry air
Major Gases	Nitrogen	78.084
	Oxygen	20.9476
	Argon	0.934
	*CO2	0.04
Minor Gases (* are also variable gases)	*Methane	0.002
	Neon	0.001818
	Helium	0.000524
	Krypton	0.000114
	Hydrogen	0.00005
	Xenon	0.0000087
	*Ozone	0.00006
Variable Gasses (CO2, CH_4 and O_3 gases are also variable)	Water vapour	Variable amount
	Dust particles	Variable amount
	Aerosols	Variable amount

Table 1: Atmospheric Gases and their Proportions

3.4.1 Nitrogen

Nitrogen is the most abundant found in atmosphere constituting 78.084 percent to the total volume of dry gases (Table1). This is almost chemically inactive and have nothing to do with any sort of chemical actions in the atmosphere. It does not combine freely with other elements, hence, it is termed as neutral substance. This gas is found beyond a height of 100 km, but its concentration is below 50 km height from the sea level. This gas is significant for the growth and reproduction in plants and animals. Certain bacteria in the soil are capable of converting a very small amount of atmospheric nitrogen into nitrates and fix it to the soils and water bodies to be consumed by animals and plants. This process is called as Nitrogen fixation. The nitrogen fixed in the earth's surface is again converted and sent back to the atmosphere by bacterial action through a chemical reaction called denitrification.

3.4.2 Oxygen

It is the second largest gas of the atmosphere constituting 20.9476 percent of the total dry atmospheric gases (Table 1). It is very essential for the survival of many of the living organisms of this planet. It is chemically very active gas. It is combined with several other elements and forms varied compounds. Oxygen is vital for combustion of fuels. When anything burns, oxygen is consumed and helps in burning that substance. Though oxygen is found beyond 100 km but it is reasonably in good proportion within 16 km of height. With increasing height, the amount of oxygen decreases very rapidly. On mountain slope, the available oxygen for breath is very scanty and the mountaineers are supposed to carry oxygen for them.

3.4.3 Argon

In terms of percentage, argon is the third largest gas in the atmosphere constituting 0.934 percent of total dry atmosphere (Figure 1). It is an inert gas and chemically it is inactive. It is also found in the earth's crust and sea water. It is used in electric bulb and fluorescent lights.

3.4.4 Carbon dioxide

It is the fourth abundant gas of the atmosphere. It is densest gas and found in lower parts. It is found up to a height of about 30 km, it is concentrated in the lower strata. Its percentage is very low, i.e., 0.04 percent (Figure 1) but it is most vital for the growth of vegetative life of biosphere. It is transparent to the incoming solar radiation but does not allow to escape the same. And hence, it is called as greenhouse gas. It plays a very crucial role in increasing the global temperature. It is also known as variable gas as its amount is dependent upon the combustion, human activities and vegetative cover of the planet. The carbon dioxide is reaching to the atmosphere due to several human activities like energy utilization, transport, industry, agriculture, waste generation etc. (Figure 2). Apart from these human induced sources, some natural sources are like plant respiration and release to air from stored carbon in the rocks through natural process of

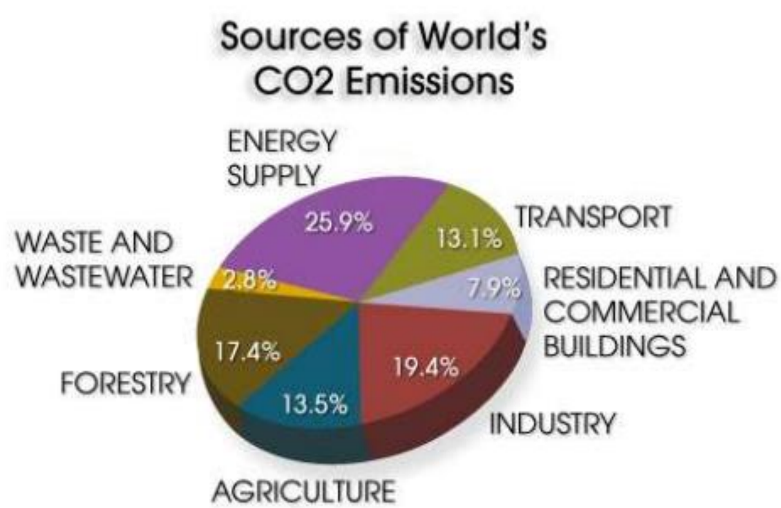


Figure 2: Different Sources of Carbon Dioxide;
Source: https://sites.duke.edu/tlge_sss29/files/2010/11/sourcesofCO2emissions.jpg

denudation. All these are leading to increase in the atmosphere. This gas is on rise with the

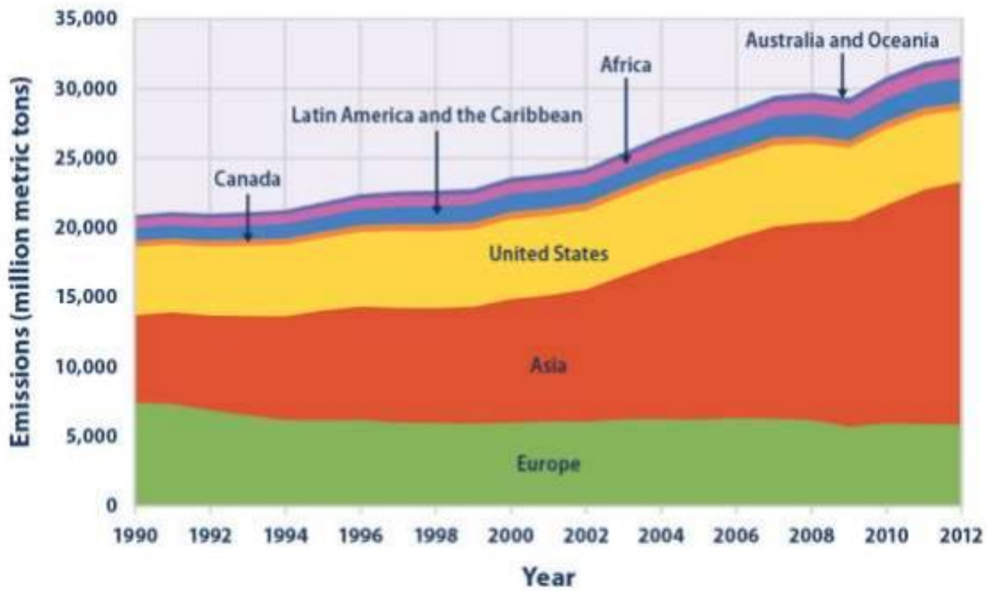


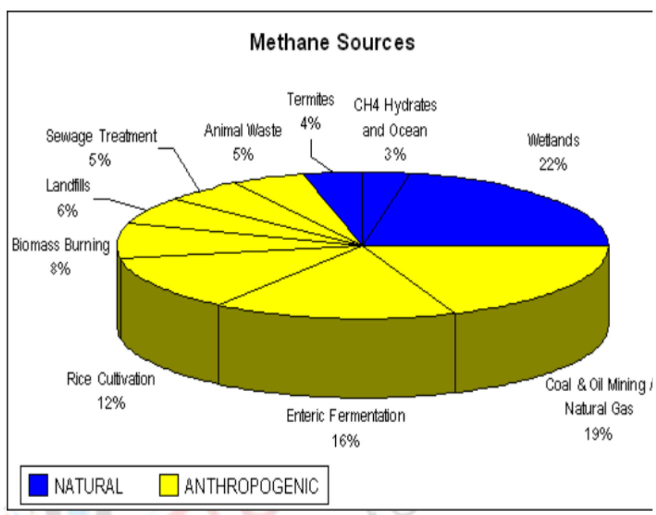
Figure 3: Global Carbon Dioxide Emission by Region: 1990-2012

Source: https://www.epa.gov/sites/production/files/styles/large/public/2016-07/global-ghg-emissions-figure3-2016.png

advancement in economic development of the society. Economically developed countries/ regions are generating big amount of carbon dioxide gases which may be seen from Figure 3.

3.4.5 Methane

Methane is the also a greenhouse gas which absorbs the radiation and cause more temperature of the air. Paddy cultivation also generates methane in the air. It is also produced 7 from the wetlands and waterlogged soils and released in the atmosphere. Fossil fuel is also a source to release of methane in the atmosphere.



Source: https://icp.giss.nasa.gov/education/methane/intro/methanesources.gif

Figure 4: Different Sources of Methane

Its amount in the atmosphere is variable. The numerous sources of methane can be seen from Figure 4.

3.4.6 Ozone

Ozone's concentration lays in a belt between the heights of 15 to 50 km of atmosphere. Instead of normal two atoms of oxygen, ozone has three atoms of oxygen formed together denoted by O3. It is formed when atmospheric oxygen molecules are broken by ultraviolet solar radiation. It may even be formed at the time of electrical discharge during thunderstorms. This gas is also termed as variable as its formation and disintegration is dependent upon numerous activities. Though ozone is very less in quantity (0.00006 percent), this thin layer is very significant for the survival of living world as it absorbs the dangerous ultraviolet rays and protects the earth. Neon, helium, krypton, hydrogen, xenon are other minor gases. Some gases are still extremely less in quantity, they are termed as trace gases. Important among them are ammonia, carbon monoxide, sulphur dioxide, nitrogen dioxide, nitrous oxide and sulphur hexafluoride etc.

3.4.7 Water Vapour

Water vapour is small in amount but it is one of the most important part of atmosphere with respect to the distribution of vegetation and life. Water vapour exists all the time in the atmosphere but with varying degree of amount depending upon the season (temperature condition) and the supply of water for evaporation and evapotranspiration. Air is hardly completely dry. In summer, the water holding capacity of the air is large as the temperature is high while in winter it is low. Availability of sufficient amount water on the earth surface or water body in an area witness greater vapour while less availability of avoidance of the same shows low vapour. Examples may be taken as equatorial region rich in water bodies (high vapour) and subtropical hot desert region with less to no water availability (low vapour). Though, vapour and air both are in gaseous form, their mixing and movement are quite natural but the same homogeneity it not seen. At any particular point of time, the amount of vapour is not more than four present of the total volume of atmosphere. It is found in the troposphere only and its concentration is in the lower level. About 90 percent of the total vapour lays below six km. It is estimated that the about 50 percent is within two km of height.

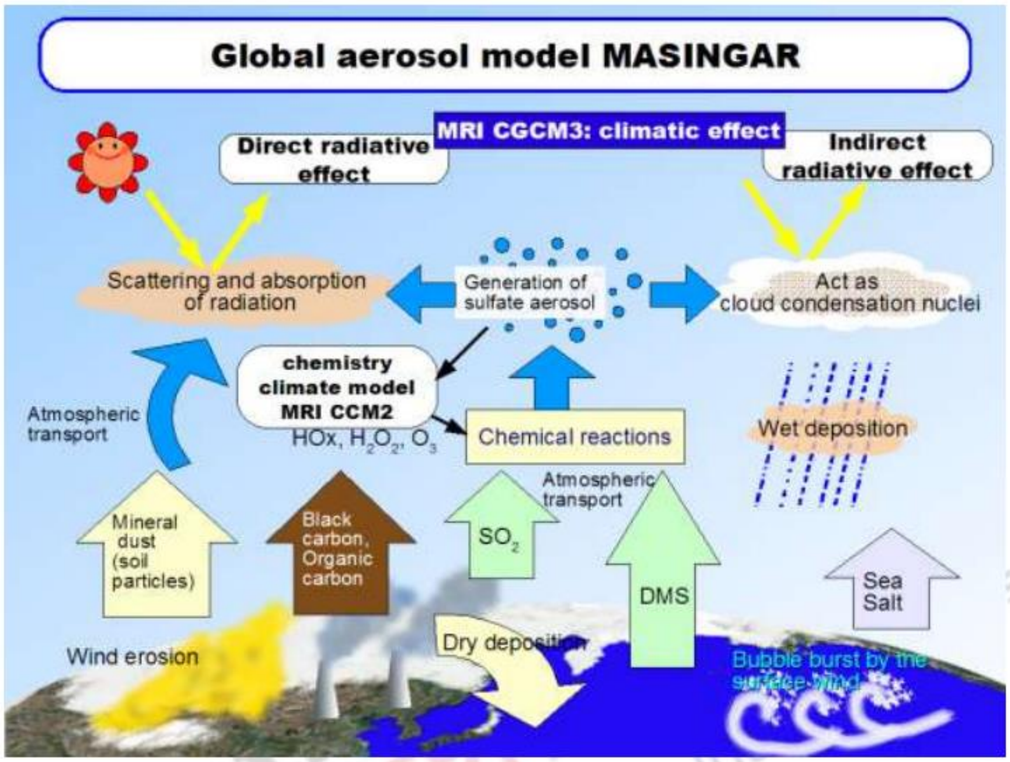
Water vapour plays a vital role in keeping the earth warm as it has greenhouse characteristics.

3.4.8 Dust Particles

Huge amount of dust particles are available in the lower layer of atmosphere in a suspended form. These dust particles are solid substances generated from various sources and being carried by winds. Greater velocity wind have greater amount of dust particles. It is not only a matter of suspended solid particles, they are transported to great distances as well. They varies widely in sizes. They may be big sized suspended only when the drafting ability of the wind is great, but settles swiftly when the carrying capacity of the wind is reduced. You must have observed yourselves too during gales/ storms. Huge number of microscopic dust particles are suspended even in completely calm air. Dust particles are variable and it is more during dry seasons as the soils are loose and easily carried by winds, but reverse is the case when it is rainy season when they are settled and compacted. Over the globe, it is less in equatorial and polar areas while more in subtropical hot desert areas. Minute dust particles are found several km above the surface while the coarse sized are abundant near the surface. Microscopic particles are nuclei for condensation and precipitation and they have a great importance in this respect.

3.4.9 Aerosols

Aerosols are extremely fine-sized solid particles or liquid droplets which continue to be in suspended form in gas for very-very long time. They could be seen when their concentration is more otherwise they are invisible. Aerosols themselves are non-gaseous microscopic substance released in the atmosphere from various sources – natural and human created. They could be pollen, minute earthly dust, sea salt, carbon soot from burning fuels, volcanic dust etc. Human activities also help the aerosols to enter the atmosphere. Their concentration is more over the industrial and urban areas. Burning of fossil fuels and generation of smoke also pump the aerosols in the air. Therefore, the source of aerosols are both natural as well as human generated (Figure 5). They are grouped into two – hygroscopic (moisture absorbing and retaining) and non-hygroscopic (moisture non-absorbing). Hygroscopic aerosols form the nuclei for condensation and in this way, they help in precipitation. From the above description, it is fairly obvious that our atmosphere is made up of innumerable minute molecules of several gases about which a discussion has been presented above. Apart from that several non-gaseous substances are also available in the air which are part and parcel of the atmosphere. They have their own significance and play very essential role for the earth to be a liveable planet.



Source: http://www.mri-jma.go.jp/Project/1-21/1-21-1/aerosol.en.png

Figure 5: Different Sources of Aerosols

3.5 Structure of Atmosphere

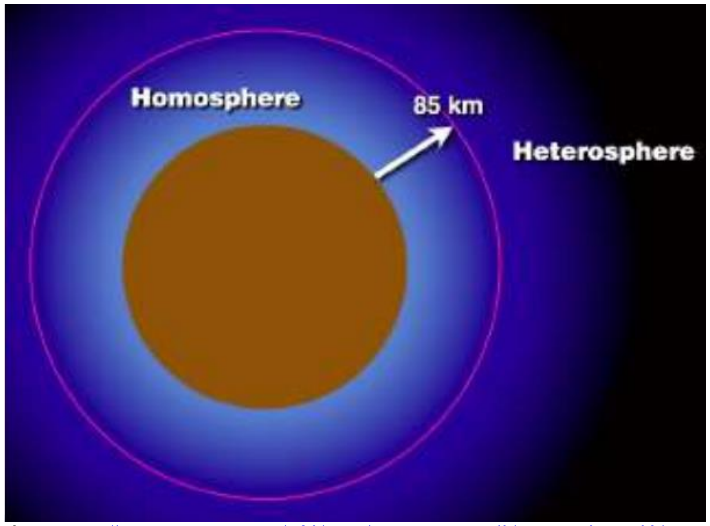
Structure means the arrangement of different part into one. In another words, it is the skeleton or organization or anatomy of a whole by looking at the relationships with its parts. According this background, the study of different parts of the atmosphere and the relationship with its parts is said to be the structure of the atmosphere. Vertically, the atmosphere is divided into different layers/ parts. Therefore, the study of different layers is known as structure of atmosphere.

Based on chemical composition, the atmosphere is classified into two. They are **homosphere** and **heterosphere**.

3.5.1 Homosphere

Homosphere is that part of atmosphere where the chemical composition of the air is uniform or similar. It is the lowest layer in terms of chemical composition. It extends from the earth's/ ocean surface to about 85 km (Figure 6). The density of the air changes very rapidly with increasing altitude but the proportion of the major gases found there remain alike throughout this layer with the exception of water vapour, pollutants, ozone and some trace/ very minor gases.

On the basis of the changes in temperature, the atmosphere is divided into five layers (Figure 7) out of them, three lower layers falls under homosphere (i.e. within 85 km of altitude). They are troposphere, stratosphere and mesosphere.



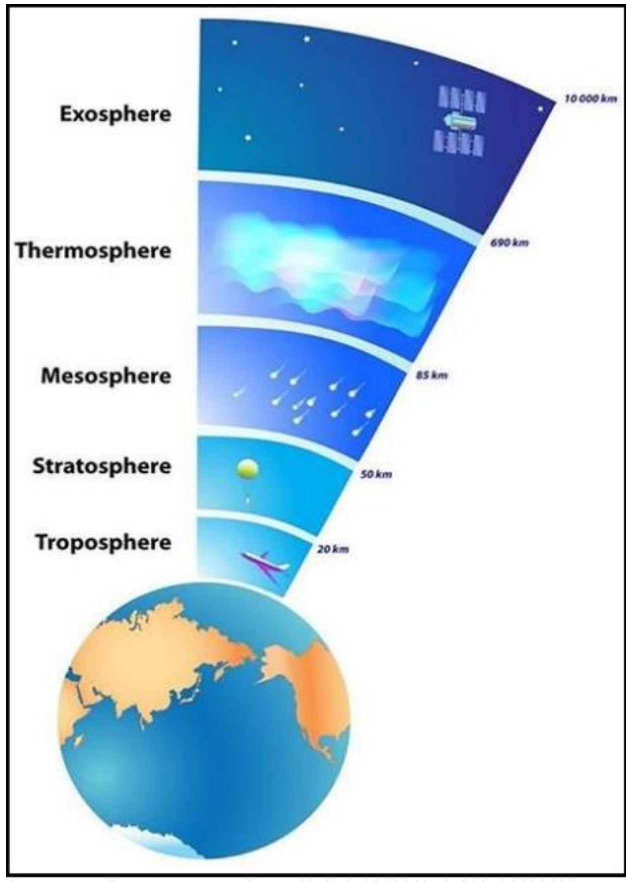
Source: http://class.atmos.ucla.edu/AS3/scrns/atmocompstruct/01intro.aos3.web.021.png

Figure 6: Homosphere and Heterosphere

3.5.1.1 Troposphere

It is the lowest and densest layer of the atmosphere. It extends till a height of about 8 km over pole but over equator, it is 18 km. About 80 percent of the total mass of the atmosphere lays in this layer. With increase in height, the temperature keeps on declining till the limit of this layer. On an average, the decrease in temperature with height is 60Celsius par km. The upper boundary is known as troposphere laying between 8 and 18 km. At this level, the average temperature reaches to minus 500 to minus 600 Celsius (Figure 8). Water vapour is found in this layer in abundance and about 99 percent of the total atmospheric water vapour is concentrated here but wide variation is seen in terms of height and longitudes.

Vapour plays very vital role in regulating the temperature of the earth by creating greenhouse effect. All weather phenomena are occurring in this layer only. Troposphere is the home of all types of clouds, atmospheric turbulence and mixing of the air. Both horizontal and vertical mixing is quite prominent here. In fact, the term troposphere is derived from the Greek word 'tropos' means 'turn'. Sphere is signifying 'ball' or a structure which is round in shape attaining a three-dimensional space. Therefore, the troposphere is a three-dimensional object with turning or mixing characteristics. Every sort of living life is confined to the biosphere which include land water and air. The upper limit of troposphere is tropopause which is a transition zone another upper layer known as stratosphere.



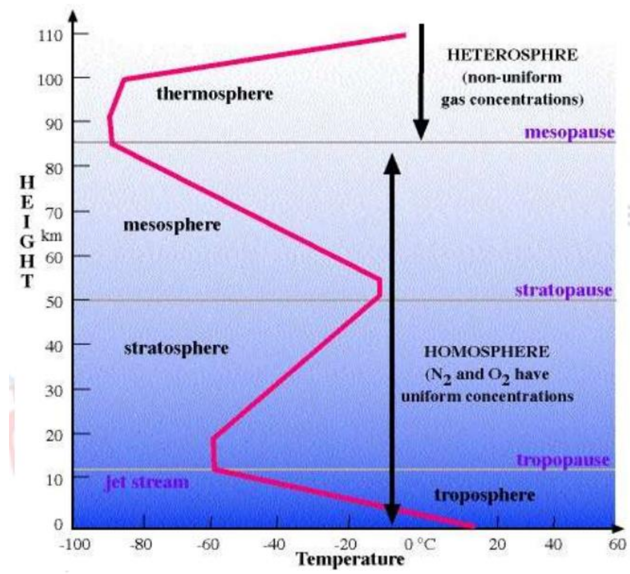
Source: http://www.imgrum.org/media/1537253008910545060_3446446857

Figure 7: Different Layers of Atmosphere

3.5.1.2 Stratosphere

Stratosphere is the upward second layer as well as middle layer of the homosphere. It starts from tropopause to approximate height of 50 km. The temperature at the tropopause remains almost constant till the height of 20 km. After that, it starts increasing and continue the trend till the height of 50 km (Figure 8). At this level, the estimated temperature is about minus 100 to minus 150 Celsius. Though the temperature is on rise, but there is no atmospheric turbulence. This layer is completely free from clouds and other weather conditions. That is why, it has an advantage for flying long-distance supersonic jets/ aeroplanes through this layer. The increase in temperature in this layer is caused by absorption of solar radiation by ozone (O3). Ozone is abundant in this layer and its 90 percent is concentrated (found between 15 km to 50 km) in this layer only. The upper limit is stratopause which is a very narrow strip of transition zone beyond which mesosphere is found.

Stratosphere is also termed as ozonosphere, a layer made up of ozone. This layer protects the living world of the planet from the harmful effects ultra-violet rays. The ozone depletion and hole over Antarctic was discovered in 1985. Since then, we have observed that this layer has reached to a dangerous level of depletion of ozone. The main ozone depleting substances are received from the release of chlorofluorocarbon (CFCs), hydro-chlorofluorocarbon (HCFCs) and carbon tetrachloride. When the molecules of chlorine atom come into contact with ozone (O3), it turns O3into O2 which is normal oxygen. One chlorine atom can destroy more than a lakh atoms of ozone. Therefore, the chain of depletion is very serious. O3turned into O2, an ordinary oxygen molecule is not capable to absorbing ultra-violet rays.



Source: http://apollo.lsc.vsc.edu/classes/met130/notes/chapter1/graphics/vert_comp.free.gif

Figure 8: State of Temperature in Different Layers of Atmosphere

3.5.1.3 Mesosphere

Mesosphere is the third but the upper-most layer of the homosphere. After this layer, heterosphere starts. The literal meaning of mesosphere is the middle sphere. It is separated by tropopause below from troposphere and mesopause on the top from thermosphere. It is extended from 50 km to 85 km from the earth's surface (Figures 7 and 8). The air pressure is very low. It is 1 millibar at the lower limit whereas it is 0.01 millibar at the highest limit. This layer is characterised by decreasing temperature and the coldest/ lowest atmospheric temperature is recorded in this layer. The lowest temperature estimated near the mesosphere is around minus 130 0Celsius. It is colder that the lowest temperature recorded over Antarctic. Between 75 to 85 km from the earth, noctilucent clouds are normal affairs in the summer nights between 500 to 700 north and south latitudes. Its literal meaning is night shining. It is a deep twilight seen only when the sun is on horizon but the sunlight is still falling at that height. The seen clouds are made up of ice crystals. Meteoric dust particles work like nuclei for ice crystallization which are falling as well as produced due to burning of meteor caused by friction.

Figure 9: Noctilucent Clouds

Source: http://www.astrofotografen.se/gallery/nightscapes/GS_20140728_NLC_7647_Pan.jpg

3.5.2 Heterosphere

The atmosphere laying beyond the homosphere is termed as heterosphere. The term itself is self-explanatory and it is used for that part of atmosphere where the air is not uniform. In this part of atmosphere, the air is rare and the molecules are wide apart. Relatively heavier gas molecules are concentrated in the lower part whereas the lighter are forced to be above. Beyond 85 km height, the composition of the atmosphere with increasing altitude vary significantly. The mixing of the gases are not possible as the turbulence is not happening there. Different layers of prominently different gases are nitrogen layer, oxygen layer, helium 14 layer and hydrogen layer are differentiated. However, the heterosphere, is divided into two main spheres – thermosphere and exosphere.

3.5.2.1 Thermosphere

This sphere extends from mesopouse i.e., 85 km to about 650 km from earth. The temperature is on rise in this layer due to absorption of solar radiation by small amount of oxygen molecules present. It is highly dependent upon the solar activities. The temperature reaches beyond 12000C at an altitude of about 350 km but by 650 km it may even rise to 20000C. This much high temperature is primarily defined by average speed with which molecules are moving. Because of this, the temperature may be high. The effectiveness of this temperature is not that great. Its exposure to astronaut, if they are coming out from the capsule, is not affecting at all. The Aurora is conspicuous phenomena observed in this layer. It is a striking display of light and are maximum between 10pm to 2am in the magnetic polar region of northern and southern hemispheres. It is known as Aurora Borealis (Figure 10) in the northern and Aurora Australis in southern hemisphere. They are referred as northern and southern lights. Charged particles coming from the solar flare reaches to the earth's upper atmosphere. These charged particles collide with nitrogen and oxygen molecules present there in rarity. The collusion results into innumerable little surges of lights. The scattering of these lights seen is very beautiful and magnificent.

Figure 10: Aurora Borealis over Alaska, 16 February 2017, Poker Flat Research Range

Source: https://www.nasa.gov/sites/default/files/thumbnails/image/img_7440.jpg

3.5.2.2 Exosphere

Exo means external. Therefore, exosphere the external or the outer most layer of the atmosphere. Its lower boundary starts from the thermopause (650 km) to the limit from where the void space begins. This limit is estimated to be about 10000 km. This much distance is little less than the diameter of the earth. It is really a very big size of the limit of the atmosphere. In exosphere, very light gases are traced and they are hydrogen and helium. Their molecules are spaced very widely. Beyond the upper limit of exosphere, the space is considered to be void.

3.6 Importance of the Atmosphere

Atmosphere is very crucial for every types of lives surviving on the earth. Without atmosphere, there is least possibility of survival of living organisms. In very brief, following are the importance of atmosphere.

Atmosphere is made up of several gases. These gases are important for the living world. Oxygen available in the atmosphere is the life of all animals including human beings for breathe. Carbon dioxide gas helps in photosynthesis by plants which is food for many animals. Without food, they are unable to live. Photosynthesis is not possible without the humidity of the air and soils. Hence, availability of water is also very important and it is partly also found in the air in the form of vapour. The atmospheric vapour is distributed and redistributed all through the globe by hydrological cycle but not uniformly. Nitrogen is equally very vital for making proteins through nitrogen fixation to plants and to all animals. It is the building blocks for the growth of the body of all animals.

Ozone is a protective layer of the atmosphere which traps harmful ultra-violet rays coming from the solar radiations. Its trapping in the ozonosphere ensures good health of all flora and fauna of the earth particularly in the higher latitudes. Carbon dioxide, methane, nitrous oxide, fluorinated gases, water vapour etc. are responsible for keeping the earth warm. Solar energy is reaching to the ground directly from the sun by short wave radiations. But when the earth radiates back the received energy to space, it is being trapped by greenhouse gases. They keep the earth liveable and maintain proper temperature. Without greenhouse effect, the average temperature would fall to minus 180C whereas at present the average temperature of the earth is 150C. The difference between the two is of 330C.

We are able to hear any sound because of the presence of air in the atmosphere. It behaves like a medium to transport the sound waves. Flying of aeroplane is possible because of air as it helps in floatation and marching forward the plane.

References

Adapted from E-PG Pathshala, Geography, Climatology, Module 3 Composition and Structure of the Atmosphere and Environmental Science, Atmospheric Processes Module 2 Structure of Atmosphere.

Unit 4: Atmospheric Heating and Cooling

Unit Structure

4.0 Learning Objectives

After studying this module, you will be able to:

- name the source of heat for the earth and its atmosphere,
- explain the mechanism of heating and cooling of the atmosphere,
- explain the terms radiation, conduction, convection, advection etc.,
- discuss the mechanism of latent heats and their release,
- elaborate upon the distribution of energy surplus and deficit,
- describe different types of lapse rates, and;
- explain various factors affecting the heating and cooling of atmosphere

4.1 Introduction

You must have observed while taking tea that it is very hot when poured in the cup to sip. Can you dare to sip immediately? Probably not. Hopefully, you would wait for a few minutes to get the heat of the tea lowered. What happens when you leave the tea for a few minutes? The place where you are sitting to sip the tea is cooler than the tea. The tea is not so hot now, as it was when poured in the cup. Where the heat escaped? As a matter of fact, heat released from the cup spreads to your surroundings. Take another example, why do you prefer to drink cold water from your refrigerator during hot weather? Suppose, you are putting the refrigerated cold water on your table for some time, say an hour or so. What will happen to the cold water after an hour? Will it remain at the same low temperature or its temperature will rise? If the temperature is rising, what is the process to warming? Its condition will be equal to room temperature. In both the above examples, the heat/ temperature of tea and cold water is altered. In the first case, the heat is lowered while in the second case, it is increased. All depends on the heating/ cooling conditions of the objects and its surroundings. The radiant energy coming from the sun is the main cause of heat on our earth. The atmosphere is primarily heated by the long wave radiation emitted by the earth surface. Heating and cooling of the atmosphere are affected by several regional and global factors. In this module, an attempt is being made to understand the heating and cooling process of atmosphere within which we are living in.

4.2 Source of Heat

The source of heat on the earth and for earth's atmosphere is almost completely governed by the energy received from the sun. Little heat reaches to the surface and atmosphere by earth's cooling, hot springs, and volcanic eruption. Volcanic eruption is confined to certain belts/ pockets on the globe. Primarily these sources are very meager keeping the size of whole of the earth as well as huge mass ofsurroundingatmosphere. It is the solar energy which is responsible for the distribution of heat/ energy all over the globe. The distribution of this energy is again affected by numerous factors. Those factors will be dealt later in this module.

4.3 Mechanisms of Heating and Cooling

Heating and cooling of the atmosphere is performed by following processes:

- Partial absorption of solar radiation by atmosphere
- Conduction
- Terrestrial radiation
- Convection
- Advection
- Latent heat of condensation
- Expansion and compression of the air

4.3.1 Partial absorption of solar radiation by atmosphere

The solar radiations are coming to the earth surface directly from the sun. It is in the form of short-wave radiation. They are so energized that atmospheric gases are unable to trap them. But the presence of some dust particles and water vapour in the lower level of troposphere are capable of holding some energy directly coming from the sun.

About 20% of the total incoming solar energy is trapped by the dust particles and vapour in the atmosphere. Approximately, half of the total absorbed energy is done so within two km of the height from the earth's surface. It is this layer where the amount of dust particles, fire shoots/ smokes and water vapour are available in large quantities. However, the quantity of these particles decreases sharply with increasing height.

You must have also observed that when the patches of clouds are there between you and the sun in day time, you feel cool even when the temperature is very high. It is so, because the concentrated water vapour (clouds) acts as an intervening obstruction by holding some part of solar energy between sun and the earth. In this process, the air is heated where it contains vapour, dust particles and fire shoots. But the heating of air over certain height through these obstructionsdoes not increase the surface temperature in that particular region. Since, these areas are receiving relatively less energy on the surface, the surface is cool as otherwise it would have been. Because of more cloud cover in equatorial regions, relatively less energy is received at the earth surface in these regions. On the other hand, the sky is clear over subtropical belt, hence the energy received in the surface areas of these belts is quite high.

4.3.2 Conduction

The literal meaning of the term conduction is passing on something by a medium without any perceptible movement by itself. It is the transfer of something from one part to the other without any physical movement.

You must have observed, while vegetable is cooked in a pan and a metallic spatula is used to turn the vegetable, it gets heated up while its handle is outside the pan. It happens so, because the heat received by the pan from the burner and the spatula is touching the pan. The received heat of the pan is transmitted to spatula which is warmed up and thus it burns our hand if left for a little more time in the pan.

Air is a very poor medium of heat conduction. It is a very slow process of transferring heat in a mass of air. By this method, air is heated, but its importance is not that great. Because, the air is in the gaseous state and its particles (molecules or atom) are not very solidly compacted. A very thin layer which is very close to the earth surface is heated by conduction method (Figure 1). Once the air atom is heated, it becomes lighter and less dense and ultimately moves upward. Therefore, conduction has a very insignificant role in heating the atmosphere. It is almost negligible in comparison to other methods. Practically speaking, majority of the meteorologists and climatologists prefer to neglect the conduction method of atmospheric heating.

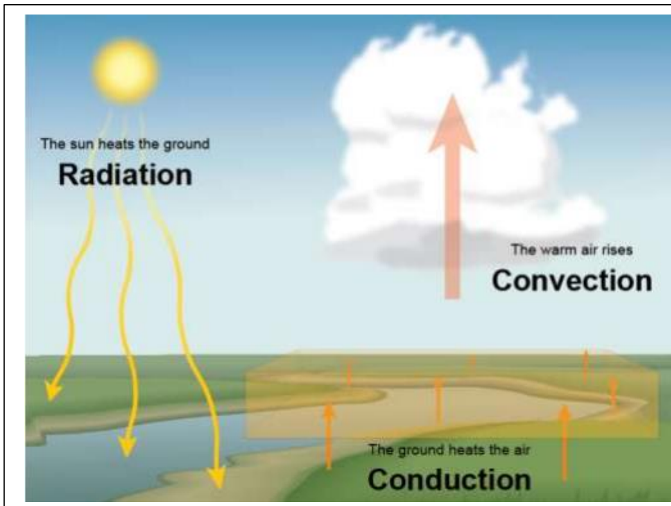


Figure 1: Atmospheric Heating Methods
Source: http://www.srh.noaa.gov/jetstream/atmos/heat.html

4.3.3 Terrestrial Radiation

The terrestrial radiation is the most important method of atmospheric heating. Out of the total solar electromagnetic radiations reaching at the top layer of the atmosphere, approximately 49% reaches to the earth's surface. Out of this, 5% is reflected back to the space without heating the atmosphere. About 20% is absorbed by the atmospheric substances including water vapour. Therefore, 45% (49-5=45%) plus 20% (total 65%) is available for heating the atmosphere (Figure 2).

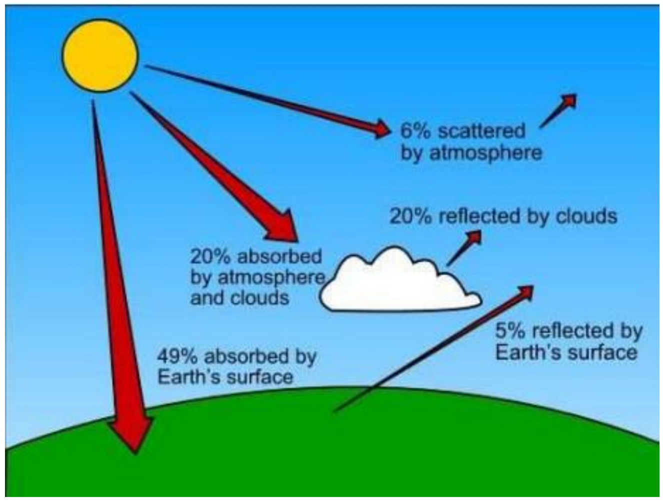


Figure 2: Solar Energy at the Earth and in its Atmosphere

Source: https://i.pinimg.com/736x/18/49/48/184948e5fedb1895388ec7b1026b8fd0--greenhouse-effect-greenhouse-gases.jpg

All the above mentioned energy is reaching the earth surface in the form of short wave electromagnetic radiations from the sun. The heated earth radiates back the same but in the form of long wave electromagnetic or infrared radiations. The atmosphere gains the heat radiated through long waves from the earth surface (Figure 2 and 3). Most of the short wave radiations are not being trapped by the atmospheric gases, as they are not capable of.

Terrestrial radiations are a continuous affair all 24 hours throughout the year. During day time when sun is in the sky, the solar short wave incoming energy is greater than the energy lost from the earth surface (land and water). Since there in no incoming solar energy during nights, the day time received energy is radiated back to the atmosphere. There may be addition or subtraction of energy on day to day basis depending upon the seasons, but on annual basis, the incoming and outgoing energy is balanced and a static temperature of the earth is maintained.

Greenhouse gases and water vapour are transparent for incoming radiation but they trap the outgoing long wave radiations. You must have observed that the cloudy day keeps us cool while cloudy night makes us warm. It does not make any difference, whether the taken examples are of summer or winter day and night. The reason is that the cloud reduces the incoming radiations and traps the outgoing radiations. It behaves like greenhouse gas. It has very important role to make the earth livable otherwise in the absence of greenhouse effect, the earth's average temperature would have gone down to minus 17^0 C.

It is also very true that there is a gradual decrease in temperature with increasing altitude within the troposphere. Greater temperature is recorded at the ground surface as the earth is heated first and then the heating of atmosphere starts. The addition of heat is distributed and finally results into a cooling. The process of cooling at one level is the cause of heating at another level. It is nothing but the transfer of energy from one to another. In the same way, heating is possible because the energy is again distributed or gained from where it has more. All the time, the energy is transferred from the high level of concentration to the lower level.

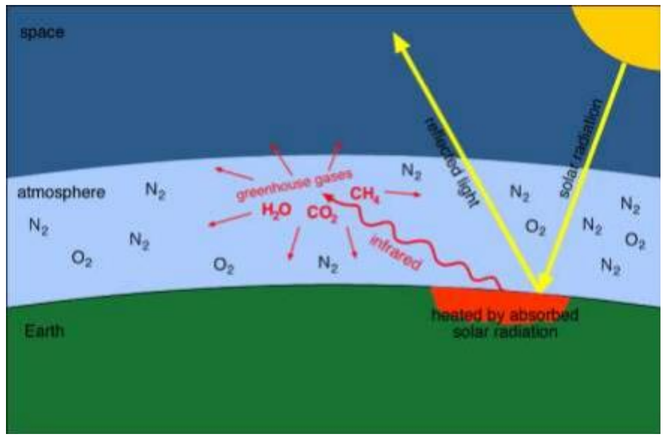


Figure 3: Heating of Earth and its Atmosphere

Source: https://i.pinimg.com/736x/18/49/48/184948e5fedb1895388ec7b1026b8fd0--greenhouse-effect-greenhouse-gases.jpg

4.3.4 Convection

The earth's surface is heated with incoming solar energy. The air in contact with the surface is in gaseous form. Earth's surface heating results in heating of the air in its contact. But the air

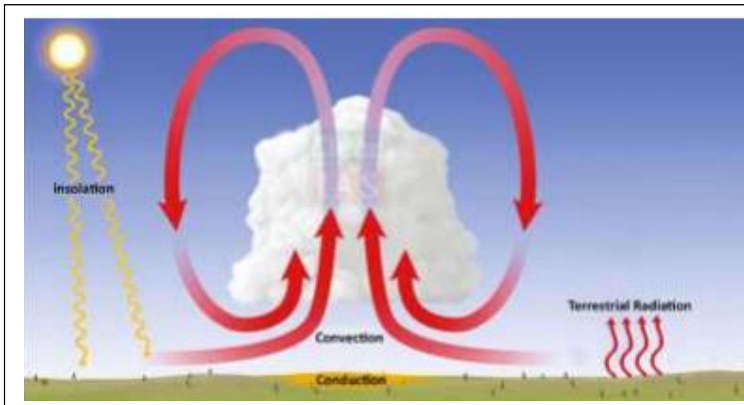


Figure 4: Convectional Heat Transfer in the Atmosphere

becomes less dense by heating. It further results into rising of the warmed/ expanded air molecules upward. Upward moving air molecules in large quantity create a convection. The removed air by expansion at the lower/ ground level results into creation of low pressure. Therefore, nearby air from relatively cool air starts moving to fill the gap created by upward lifting of air. The heat is also transferred upward with vertically moving air. This convection may occur at a local level as well as at much larger regional level. The occurrence of Hadley cell, Ferrel's cell and Polar cell are examples of atmospheric convection. Therefore, convection transfers the heat energy received from the sun to the surface and from the surface to the atmosphere. The Figure 4 very clearly explains this.

4.3.5 Advection

The meaning of advection is transfer of something from one place to another especially in horizontal direction. Atmosphere is a huge body of air and it has differences in terms of its pressure depending on several affecting factors. Due to varying pressure at local, regional and global level, atmospheric gases are continuously on move. A local level horizontal movement of air (advection) can be seen from Figure 5. The monsoonal air current movement is the example of regional advection while planetary permanent wind system signifies the global advection. All of them are transferring the heat from one area to another. Transfer of energy is not only done by atmospheric advection, but also by hydrospheric advection. There is movement of water also from the low latitude to high latitude in the form of ocean currents. The ocean currents also redistribute the received energy from high concentration to low concentration zones. It is also a fact that the ocean currents are also affected by the adventive movements in the atmosphere.

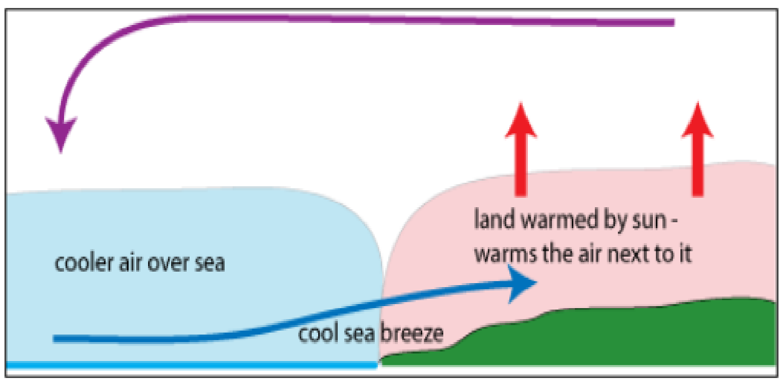


Figure 5: Process of Advection and Horizontal Air Movement

Once the air is on move horizontally, physical transfer of air, associated heat and other related properties of the mass of air are transferred. In this process, the heating of the atmosphere is the result. It is caused by the differences in air pressure and temperature. In fact, these two characteristics of air are primary factors in the movement of the mass of the air.

If the net radiation at global level is calculated for the atmosphere, it is established facts that there is positive budget between incoming and outgoing energy between 400 north and 350 south latitudes. This fact is very clear from the Figure 6. It is also apparent that there is negative budget beyond 400 north and 350 south latitudes. Overall the total budget of the earth is almost neutral. The positive received radiation is diverted to the higher latitude areas by advection. Therefore, higher latitude areas are releasing more energy to space than they receive as it is transported from low latitude areas. Contrary to this, the low latitude areas are releasing less energy than they directly receive from the sun as remaining is transported to the high latitude areas. The same information is very clearly presented in Figure 6.

4.3.6 Latent Heat

Heat absorbed or released due to change of the state of any matter is known as latent heat. During this process, there is no change of temperature of that matter. In another words, it is the heat that is required to change the matter to a higher state of matter. You may be well aware, when water changes from one state to another, for example, water vapour to liquid water and liquid water to solid water (ice), it absorbs or releases heat. The energy involved in this process is

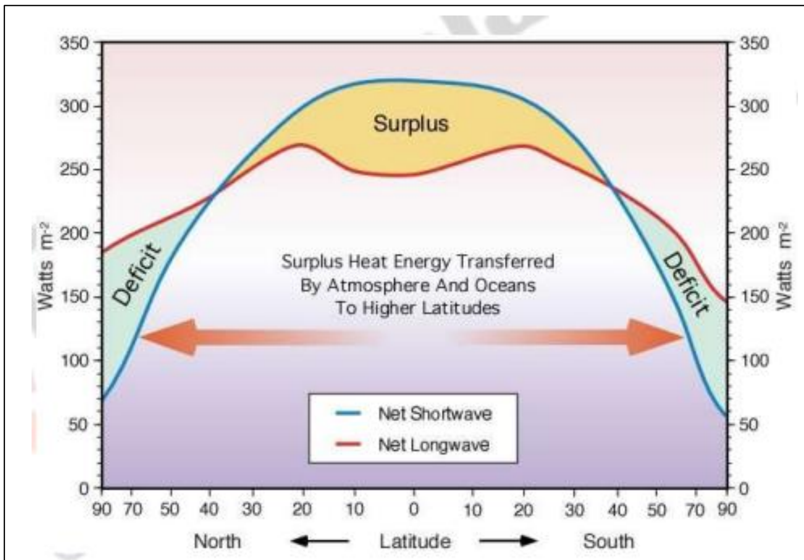


Figure 6: Surplus and Deficit Zones of Radiations
Source: http://www.physicalgeography.net/fundamentals/images/rad_balance_ERBE_1987.jpg

known as latent heat, popularly meant for 'hidden' heat. Water vapour transports the energy from one region to another.

When water is heated, vapour is generated and in this process heat is absorbed. The same vapour when condenses, releases the absorbed heat during vapourization. Generally, it is measured in calories. One calorie is the aggregate amount heat needed to raise the temperature of one gram of water by one degree Celsius.

Suppose one gram of ice is melted, it releases 80 calories of heat and turns into water. If the same one gram of water is evaporated, it requires 540 calories. Therefore, the said calories are known as latent heat. In the same way, when the condensation is taking place, conversion of vapour into one gram water releases 540 calories and it reaches to the atmosphere and heats it. When one gram water turns into ice, 80 calories is released what it was consumed while melting the ice. Sublimation is the process in which ice turns into vapour (it releases 540+80=620 calories) or vapour turns into ice, (it releases 540+80=620 calories). In both the cases, latent heat is either released or utilized Figure 7.

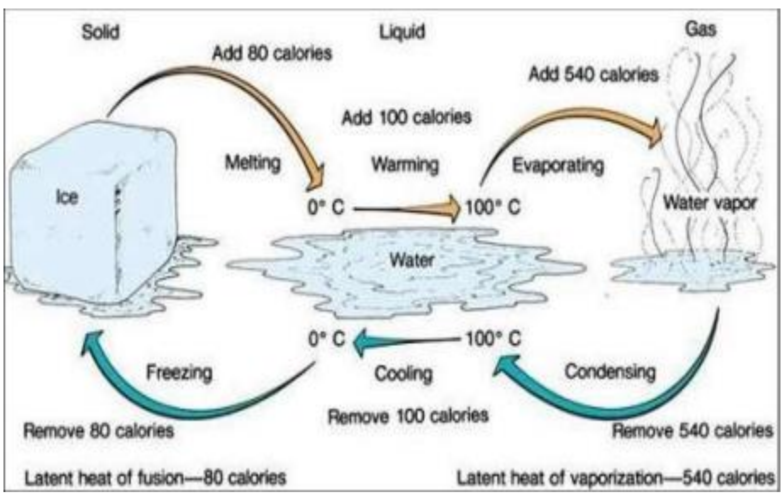


Figure 7: Latent Heat: Absorption and Release

Source: https://qph.ec.quoracdn.net/main-qimg-36a6e3973562f9f51f02b4c061f940e2-

From the above discussion, it is quite apparent that the latent heat plays a significant role in heating and cooling of the atmosphere. When the heat is utilized in turning the state of matter from lower level of heat to higher level, cooling is evident. But when it is in descending order, i.e., from higher level of heat to lower level, it releases the latent heat and heating of the surrounding atmosphere is the result.

You may even feel cool when the sweat is removed from your skin either by moving fan or the use of air conditioner. Removal of sweat by transpiration/ evaporation is associated with latent heat, and hence we feel comfortable. When condensation takes place, it leads to release of the same latent heat and causes the air to warm up at the level (generally upper level of atmosphere) of condensation. The same thing happens with freezing and sublimation.

i) Latent Heat of Condensation: It is the amount of heat energy released to the atmosphere when condensation takes place. As mentioned above, when one gram vapour is changed to water 540 calories is released, it is called latent heat of condensation, because it is reaching to the atmosphere due to the process of condensation.

ii) Latent Heat of Vapourization: It is the amount of heat energy needed to evaporate water and it is taken from the surroundings. When one gram water turns into vapour, 540 calories is utilized. This amount of heat is called latent heat of vapourization.

iii) Latent Heat of Sublimation: It is the amount of heat required to change solid (ice) directly into vapour without turning into liquid (water) or vice versa. This amount is 620 calories for changing one gram of ice into vapour or one gram of vapour to ice.

iv) Latent Heat of Freezing/ Melting: It is the amount of heat required to change one gram of water into ice or one gram of ice into water. This amount is 80 calories per gram of water/ ice.

4.4 Expansion and Compression of the Air

We have already discussed that the air pressure keeps on declining progressively with increase in height. Consequently, the mass of air is lesser with increase in height. The mass is greater downward. It is due to this reason, any parcel of air, if it rises, going upward is expanded. Because the rising air is entering in the zone of less dense air, it results in expansion. Therefore, the expansion is a natural event in this case. Contrary to this process, when any parcel of air descends, it enters in the zone of more dense air. This results into the compression of the descending air. Rising air expands and the intermolecular space is expanded and it causes the cooling in the air as well. It is also known as adiabatic cooling. That means, the cooling is caused by simply expansion of the volume of air. There is no exchange of heat with the rising air and its surroundings.

4.5 Lapse Rate

Lapse rate is observed change in temperature when moving upward in the troposphere. It is generally counted as drop in temperature with per km ascent in the atmosphere. We know that the mountains are colder than plains if the latitude remains the same. It is due to the lesser effectiveness of the long wave radiation with height.

4.5.1 Environmental Lapse Rate

It is a simple drop in temperature. We are simply climbing the height and we feel the drop in temperature. It is known as environmental lapse rate. The average environmental lapse rate is 6.50C per km. This rate is applicable only in the lower atmosphere (troposphere). It happens due to two reasons, fall in atmospheric pressure and decrease in greenhouse gases (carbon dioxide and water vapour).

4.5.2 Adiabatic Lapse Rate

In adiabatic lapse rate, the parcel of the air is lifted and the lifting air is forced to expand. Expansion leads to drop in temperature. In this case, air itself is rising whereas in environmental lapse rate the air was static but someone is going up and feels the declining temperature. Adiabatic lapse rate is categorized into two – dry and wet.

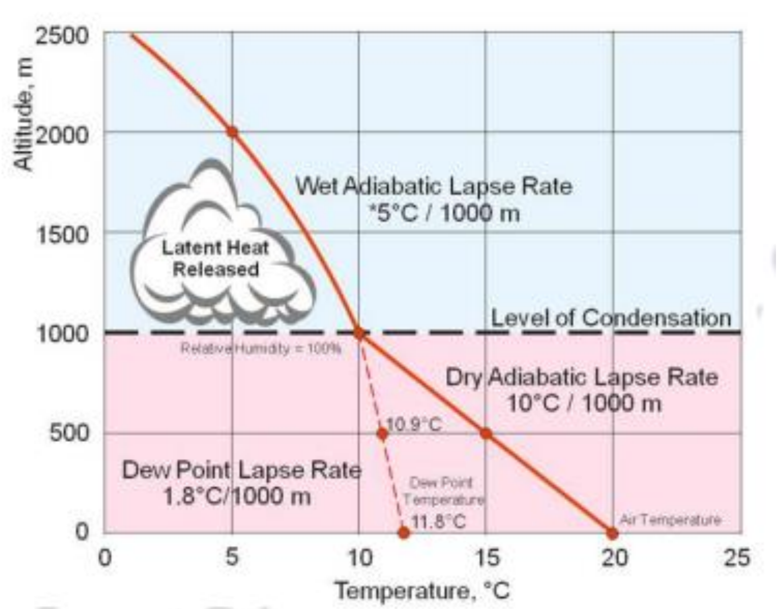


Figure 8: Dry and Wet Adiabatic Lapse Rate

Source: https://i0.wp.com/www.nandyradiotelephony.com/wp-content/uploads/2015/09/CloudFormation.gif

4.5.3 Dry Adiabatic Lapse Rate

When the air is dry or having very less moisture in it and it rises, the temperature will fall more sharply. Since there is less possibility of condensation, the decline in temperature is at higher side and it is about 100C per km (Figure 9). In this case the air is almost stable and in general represents high pressure conditions.

4.5.4 Wet Adiabatic Lapse Rate

When the air is moist, it is unstable. The capacity to hold more moisture in the air is less. There is greater possibility of condensation with rise of air parcel. Once it is fully saturated and the condensation takes place, the latent heat of condensation is released. The released heat is utilized to warm the surrounding air. Therefore, the decrease in temperature is lowered. On an average, the drop in temperature is about 5 0C per km (Figure 8).

4.6 Factors Affecting Heating and Cooling of Atmosphere

The earth is a sphere and the atmosphere is encircling around it. The distribution of energy on the earth surface and in atmosphere is varying to a great degree particularly with respect to latitude. The distribution of heat is affected by several factors important among them are:

- Latitude
- Altitude and nature of earth's surface
- Differential heating and cooling of land and water
- Nature of ocean currents
- Transparency of the sky
- Slope aspects

4.61 Latitude

The light energy of the sun reaches to the earth's surface to a maximum limit to 1800 of angle. You know it very well that the earth is a sphere. The angle of incidence keeps on reducing poleward from the equator. Reduction in angle of incidence reduces the energy received per unit of the area. It happens because a beam with vertical or near to vertical will spread to a smaller area while greatly inclined rays will spread over a large area. Therefore, energy received by vertical or near to vertical rays will be greater in comparison to the greatly inclined rays (Figure 09). Sun rays are vertical in equatorial region while in polar region, it is greatly inclined. That is why, the low latitude areas are warmer and high latitude areas are colder. On the other hand, high latitude areas are much colder because of less effective heating.

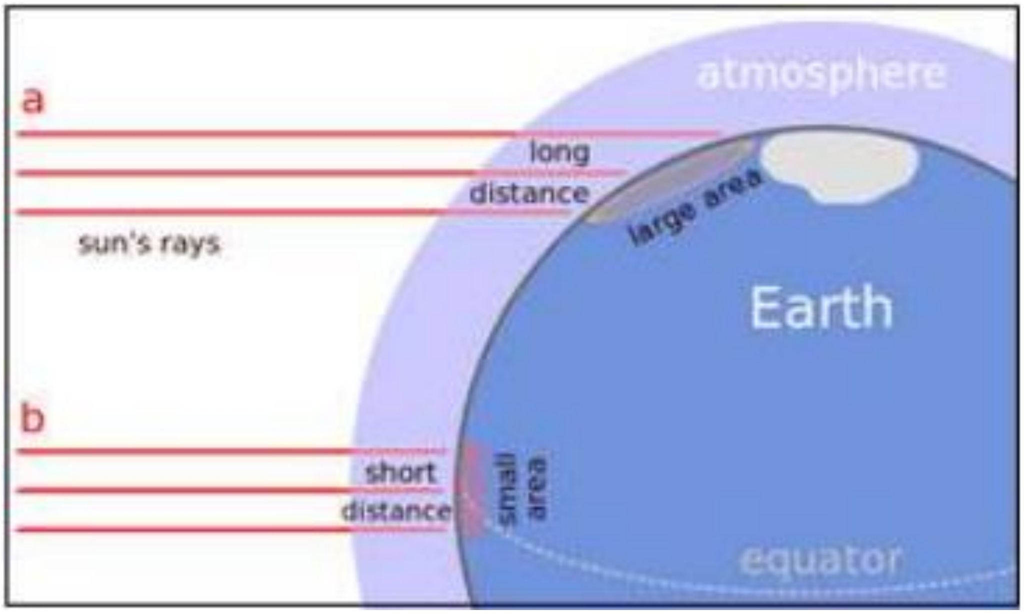


Figure 09: Decreasing Effectiveness of Solar Energy with Latitudes

Source: https://upload.wikimedia.org/wikipedia/commons/thumb/e/e6/Oblique_rays_04_Pengo.svg/800px-Oblique_rays_04_Pengo.svg.png

4.6.2 Altitude and Nature of Earth's Surface

You know it very well that, in general, the mountains are cool and the plains are warm/ hot if the latitude is the same. Plain possess thick layer of atmosphere and the mountain has a small thickness of it. Air is greatly compressed on the plains in comparisons to the mountains. The atmosphere is normally warmed by the longwave terrestrial radiations. Hence, low altitude area has more temperature than the high altitude areas.

The nature of the rock also affects the atmospheric heating and cooling. The areas possessing bare rocks have more intense heating by the sun's energy. That type of area also radiates back more and more received energy and the result is quick heating of the air laying there. On the other hand, the area possessing more and more vegetative cover, the heating is moderate as some of the energy is released from the earth surface in the form of latent heat with evapotranspiration. Vapourazitation form any area keeps it cool. That is why, the forested or grasslands are cooler than the hot deserts. Its effects are also seen on the air/ atmosphere of the area.

4.6.3 Differential Heating and Cooling of Land and Water

The earth surface is covered by land and water bodies. However, the absorption of heat energy to both of these surfaces are markedly different. The land is an opaque to the incoming solar radiation while water is translucent (Figure 11). Whatever the heat energy reaches to the land body, it is utilized to heat a thin layer of the land surface while the same amount of heat energy reaching to the water surface is penetrating to much deeper depths. Apart from that, evaporation also reduces the effectiveness of heat on water surface as a part of its energy is removed by latent heat of evaporation. That is why, we find equalizing climatic condition on the sea coast while the interior part of the continent reflect harsh climate i.e. very cold or very hot. Accordingly the heating and cooling of the air of that region is affected.

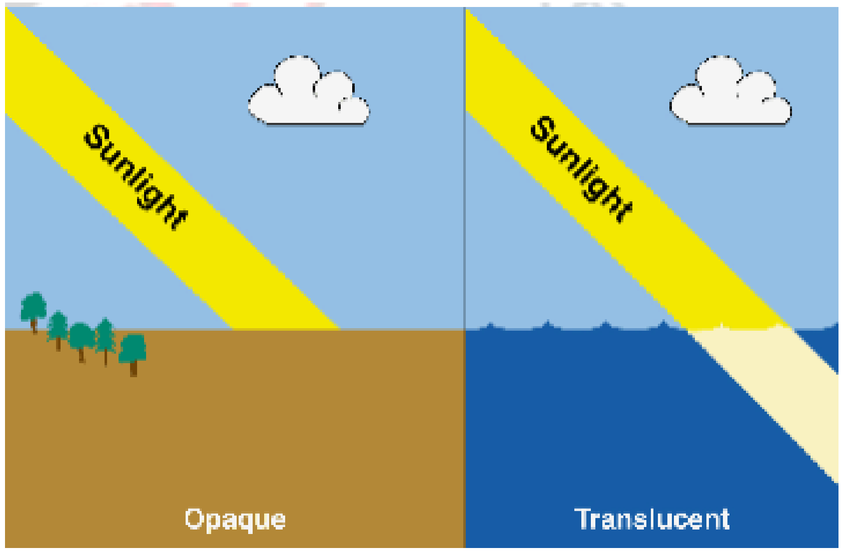


Figure 10: Differential Heating of Land and Water

Source: http://www.shsu.edu/~dl_www/bkonline/131online/CourseGraphics/GraphicsMaster/G030.gif

4.6.4 Nature of Ocean Currents

Heating and Cooling Low latitude areas are warmer while the high latitude areas are colder. The temperature of the ocean water is also affected by the temperature distribution over the globe. Ocean currents are flowing under the influence of planetary wind system as well as the regional shape of the sea coasts. Since the ocean currents are very important medium of heat transfer through advection from low latitude to the high latitude. Depending upon the nature and temperature of the ocean water, currents are categorized into two – warm and cold. Wherever those currents are reaching, they are influencing the areas accordingly. That is way, the north-western European coasts are warmer but the north-eastern coast of North America is chilled during winter though both of them lie on the same latitude.

4.6.5 Transparency of the Sky

Apart from the gases, several other minute suspended particles and water vapour constitute the atmosphere. Though the gases are almost uniformly distributed, but other substances are varying at local and regional level. Their availability and quantity is season dependent also. These substances are obstructing, reflecting and absorbing the solar radiations and affecting the heating and cooling of the atmosphere.

4.6.6 Slope Aspects

Slope of the any region or mountain has direct bearing on the heating or cooling of the air. The south facing slope of northern hemisphere and north facing slope of southern hemisphere receive more energy than their counterpart. Therefore, they are warmer and support more rain resulting in dense vegetation cover. When it is the reverse case, it is colder, less moist and retarded growth of vegetation. The examples can be had from the Himalayas (Figure 11).

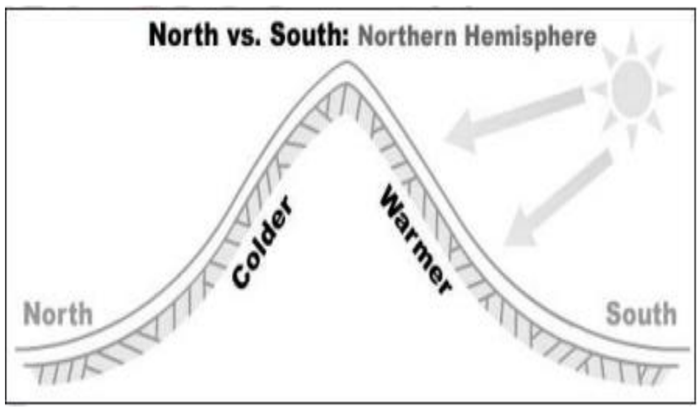


Figure 11: North-South Slope Aspects

Eastern and western slope also have bearing on the heating and cooling of the air along them. Eastern facing slope receive less energy as the temperature is not that effective. Therefore, it is cool on the

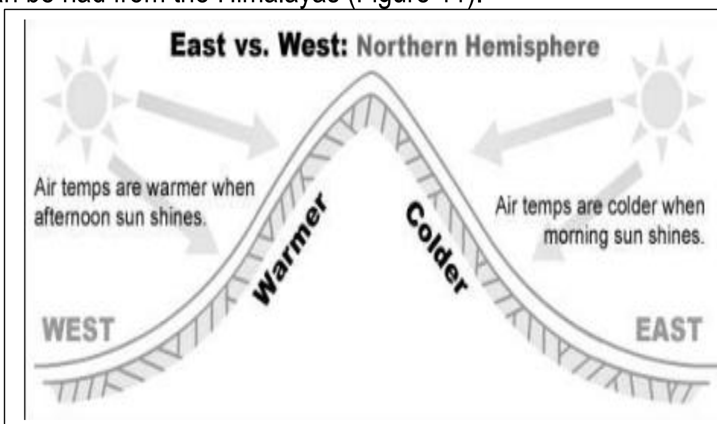


Figure 12: East-West Slope Aspects

eastern slope. On the western facing slope, more temperature is recorded and hence, it is warmer. This type of example can be had from the two slopes of the Rockies and the Andes (Figure 12).

4.7 Summery and Conclusions

The major source of heat on the earth as well as on the atmosphere is sun. Sun's energy reaches directly to the earth by shortwave radiations. Once the earth is heated, it releases received energy through longwave radiations. This radiation heats the atmosphere as it is capable of catching the energy, which it is not the case with the shortwave radiations. The atmospheric heating is possible by different ways. Important among them are absorption of incoming solar radiations, conduction, terrestrial radiations, convection, advection, latent heat transfer and heating and cooling by expansion and contraction. Heating and cooling of earth's atmosphere may keep on changing on day-to-day or seasonal basis, but on annual basis it is neutral. It means, the total incoming and outgoing radiations are balanced and the entire earth and its atmosphere maintain uniform temperature conditions.

The heating and cooling of the earth and its atmosphere is controlled by several factors. The important among them are the latitude. Since the earth is a sphere, the angle of incidence of sun rays differs with changing latitudes. Therefore, the distribution of energy on the earth is not uniform. It is more in the low latitudes and less in high latitudes. Depending on the distribution of insolation, the heating and cooling of the atmosphere is affected. Other controlling factors are altitude, distribution of land and water, ocean currents, transparency of the sky and the slope. All of them are affecting the temperature conditions on the atmosphere.

References

Adapted from E-PG Pathshala, Geography, Climatology Module 4, Atmospheric Heating and Cooling.

Unit 5: Global Energy Balance

Unit Structure

5.0 Learning Objectives

After completion of this unit you will be able to:

- define and discuss heat and temperature
- Explain distribution of temperature and factor influencing distribution
- describe heat absorption, emission, reflection and re-radiation;
- explain different controlling factors of temperature;
- explain the vertical temperature distribution and its inversion and
- discuss different types of temperature inversions.
- define and distinguish heat budget and heat balance

5.1 Introduction

The meaning of heat is condition of being hot or existence of degree of hotness in the form of temperature. But have you ever thought that wherefrom the heat is coming from or what is the source of heat, for earth-atmosphere system? You must have observed that the days are hot and nights are cool. It is quite obvious that the sun is the prime source of energy on our earth. Though a little energy reaches to the earth surface or to the atmosphere when there is volcanic eruption. Some energy is also released by the endogenic forces creating irregularity like plate movement or mountain building. But these are very-very scanty in comparison to the energy received from the sun. Therefore, predominantly the sun is responsible for energizing earth atmosphere system.

During peak summer days you must have heard people saying that 'it is too hot' or during peak winter days you might agree, people saying 'it is too cold'. Too hot or too cold is referred to heat while people mean it temperature. The quality of hotness or coldness refers to the state of the air which we call 'heat'. Heat is basically the transfer of thermal energy from one substance to another. This transfer happens due to difference in hotness or coldness. Temperature is different from heat. But sometimes we use heat and temperature as synonyms which is not fair. Temperature of any substance is the degree or intensity of heat available in that body. In fact, temperature is a measure of average heat or thermal energy of the particles in a substance. Its most popular measure is in either degree Celsius or Fahrenheit. You have already studied about the heating and cooling of atmosphere and distribution of insolation over the globe in Module 4 and 5. You must be well aware that the temperature vary substantially. The global distribution of temperature is directly and very closely associated with the distribution of insolation. There are several factors affecting them. The main concern in this module to study the factors controlling the temperature and its global distribution in both horizontal and vertical perspectives.

With this background in our mind, here, an attempt has been made to study the heat budget, heat balance and the conditions of the atmosphere which keep the earth livable. The livable conditions are basically associated with the warming of the surrounding. So, an evaluation is also tried to see, how natural greenhouse effect is good for the earth or how bad the human enhanced greenhouse effect is.

5.2 Source of Energy on the Earth

The prime source of energy for the earth surface is the sun. It comes in the form of electromagnetic radiation in different wave lengths or bands of electromagnetic spectrum. Some of these bands. Some of these bands (thermal and visible) are heating the earth surface as well as its atmosphere. Another source of energy i.e. geothermal energy from earth's interior also reaches the surface but its role in temperature distribution is negligible. Therefore, we will discuss about the distribution of temperature received only from the sun.

5.3 Heat and Temperature

Heat is a form of energy. It measures the total energy in a volume of a substance retained by all the molecules which we call total kinetic energy. Its measuring units are joule or calorie. The standard unit for the rate of heat transferred is watt, generally defined as one joule per second. Temperature is a measure of degree of hotness or coldness of a substance. In other words, heat represents the molecular movement of particles of a substance while the temperature is the measurement of degree of hotness of the substance. It is the measure of average kinetic energy of the molecules of the substance we are referring to. Refer to the Figure 1A. The water in two containers – a bucket and a cup has the same temperature 250C. The same amount (total energy) of heat (50,000 joule) is provided to both the containers. The water in the cup gets heated more in comparison to the bucket, though the energy given was same (Figure 1A). Remember the definition given above, heat is total energy retained by all the molecules of the substance (water), while the temperature is the average kinetic energy of the substance.

The movement of heat depend upon the temperature difference between two bodies (Figure 1B). Heat always moves from a body of higher temperature to that of lower temperature.

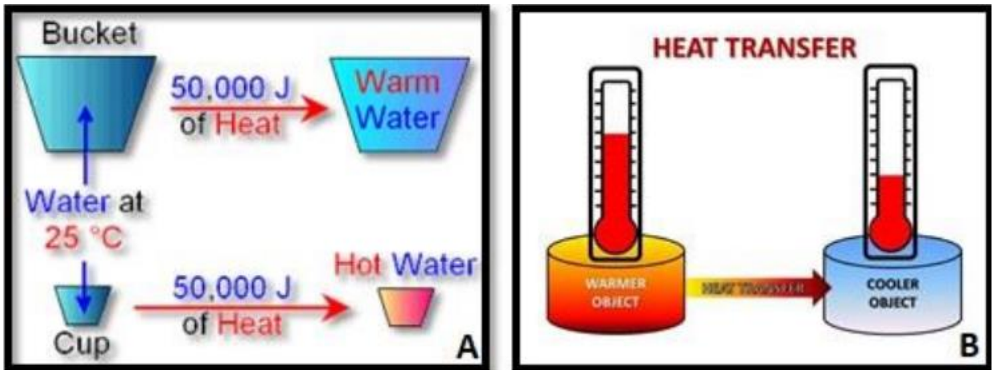


Figure 1: Difference between Heat and Temperature (A), Heat Transfer (B)

Primarily, it is measured in kelvin (K) unit in the study of physical sciences, but most commonly measured in Celsius (C) or Fahrenheit (F) in day to day uses. They are denoted as ^{0}K, ^{0}C and ^{0}F.

Temperature in 0C or 0F would be taken into account while describing its distribution and not the kelvin scale of measurement.

5.4 Global Temperature Distribution

The global temperature distribution is explained in two ways – horizontal and vertical. But before coming to the direct distribution of temperature over the globe in these two perspectives, it is important to study the factors which control the temperature. The temperature on the earth surface and in its atmosphere is not alike, but it varies significantly. The variation is controlled by various factors. Some of the important factors are:

- Latitude
- Altitude
- Length of the day
- Continentality
- Wind and ocean currents
- Aspect
- Topography and vegetation

5.4.1 Latitude

Latitude is one of the most important and primary factors affecting the unequal heating of the earth surface and its atmosphere. The intensity of heating determine the degree of temperature on the earth and so is its distribution. Overall annual maximum energy is received on or near the equator. Away from the equator towards poles, the received energy from the sun decreasesand hence the temperature also keeps on declining. The low latitude areas receive more solar radiation due to two reasons:

a. Effect of Atmosphere: In low latitude particularly near equator, the solar beam of light travels for lesser distances in the atmosphere. Hence, less reflection, less obstruction and less absorption is observed in the atmosphere. This results in greater amount of solar energy receiving on the earth and records higher temperature. On the other hand, in the higher latitude particularly in the Polar Regions, the reverse conditions prevail and hence, less temperature is recorded (Figure 2).

b. Angle of Incidence: In the low latitude areas, the incidence of sun rays is vertical or near to vertical, and hence the beam of rays (energy) is concentrated to smaller areas. Therefore, the heat received per unit area is higher and thus more temperature is recorded.But in the higher latitude areas, the incidence of sun rays is oblique, and hence, beams of rays spread over larger areas. This leads to less energy received per unit of area, leading to less temperature in the higher latitudes or polar areas (Figure 2).

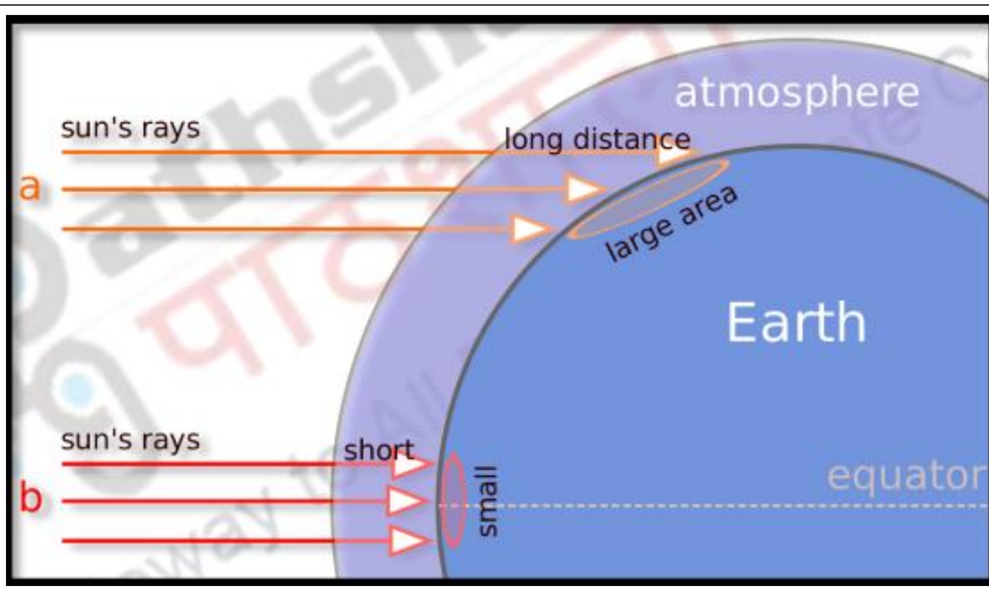


Figure: The Greenhouse Effect
Source: https://upload.wikimedia.org/wikipedia/commons/thumb/7/75/Oblique_rays.svg/2000px-Oblique_rays.svg.png

5.4.2 Altitude

Temperature is inversely correlated with altitude. Increase in altitude shows decrease in temperature. You might be remembering (module on insolation) that sun energy heats the earth surface first. The air in its contact is heated and finally the atmosphere gets the heat by different methods. Another reason for more temperature in the lower atmosphere is the presence of more dust particles, water vapour, aerosols, and other solid minute substances in the lower level of the atmosphere. They are also absorbing the incoming solar radiation as well as the terrestrial longwave radiation. In this process, lower atmosphere is relatively warmer in comparison to upper atmosphere which is clean and free from minute solid substances.

5.2.3 Length of the Day

With change in season, length of the day changes and it is due to apparent departure of the incidence of sunrays. In general, more duration of sunlight results into greater amount of energy received. When it is summer time in northern hemisphere, it is winter time for southern hemisphere. During June, places in northern hemisphere have greater duration of day hours (Figure 4). The sun is vertical on and near the Tropic of Cancer. Therefore, higher temperaturesare recorded around the Tropic of Cancer in June than at the equator. The

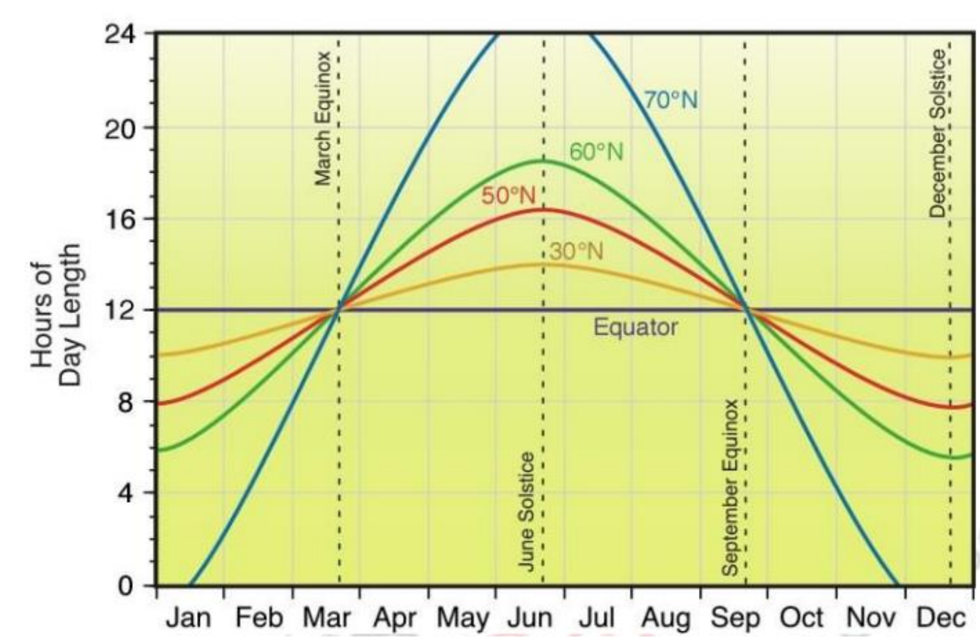


Figure 4: Duration of Day Length in Northern Hemisphere

Source: http://www.physicalgeography.net/fundamentals/images/daylength.jpg duration of day at 300N latitude is about 14 hours, while at 500 N, it is more than 16 hours. It is also worth mentioning that that greater acute angle of sunrays in polar areas does not increase temperature effectively even though the duration of days are more than 24 hours. When it is summer time for southern hemisphere, it is winter for the northern hemisphere. During January, it is the reverse case of what it has happened during June.

5.4.4 Continentality

Continentality refers to control of landmass on temperature and its range and it depends on distance from sea. As the distance from sea or water bodies' increases continentality increases it means range of temperature increases. In coastal areas due to maritime influence range of temperature is low. These variations are related to nature of surface or to differential rates of heating and cooling of land and water.Refer to Figure 5, two stations – Dollas (320 51'N) and San Diego 320 44'N) of USA which are situated on the same latitude. San Diego, near the sea coast, has moderate temperatures (not very high and not very low)

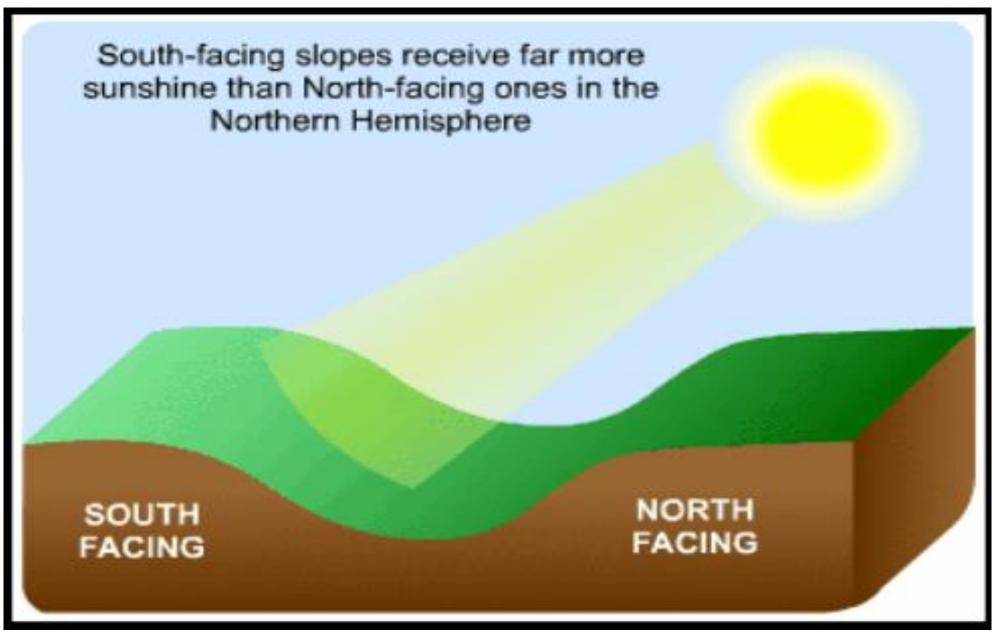


Figure 5: South and North Facing Slopes with Respect to Sun

Source: http://www.s-cool.co.uk/gifs/g-geo-climat-dia02.gif

while Dollas, situated in the interior, has extremesof temperatures (very high in summer and very low in winter). Therefore, the annual range of temperature at San Diego is only 90C while it is 240C at Dollas. The reason is condition of continentality.

5.4.5 Winds and Ocean Currents

Winds and ocean currents affect the temperature of any region. Winds are the horizontal movement of air from high air pressure region to low pressure. Ocean currents also transport the heat energy from one region to another. The prevailing winds blowing towards land from the oceans modify the temperature. For example, winds blowing from the warm ocean (tropical region) keep the coast warm while winds blowing from cold (polar region) surface make the coast cold. The same thing happens with the ocean currents because, they also affect as per their characteristics.

5.4.6 Aspect

The temperature at local or regional level is affected by the aspect of the area. Aspect refers to the direction of the place or area especially to the angle of the sunrays it faces (Figure 5). Due to inclined axis of the earth and its rotation, the sway of the sun is apparently seen between Tropics of Cancer and Capricorn. Beyond these limits, east-west laying mountain's northern slope in north hemisphere and southern hemisphere in southern hemisphere do not get direct sunlight even at the noon. They have shadows of the mountain while the southern facing slope in the north hemisphere gets direct and almost vertical sun's rays. In southern hemisphere, northern facing slope gets bright and effective sun's energy and the temperature is high on the sun facing slopes. The slope away from sun faces chilled conditions during winter as winds coming from poles are very cold. Sun facing slope is protected from cold winds. Sun facing slopes have very good condition for photosynthesis and have very dense vegetation while theon surface away from sun, theideal condition for photosynthesis lacks and so does the vegetation (Figure 6).

5.4.7 Topography and Vegetation

The term topography refers to the appearance of the surface of any particular area in terms of differences in height like nature created mountains, hills, plains, plateaus, or human created different cultural features. Therefore, various features found on the earth's surface also affect the temperature as per interactions with incoming solar radiation. The differences in temperature is amplified by the topography, if you compare hot desert with that of vegetative areas or rainforest or grasslands. In the same way, types of soil or vegetation affects the temperature a lot. The alteration of the land cover also alters heating and cooling process in a changed situation. Hence, changes in the soil and vegetation are reflected on the distribution of temperature.

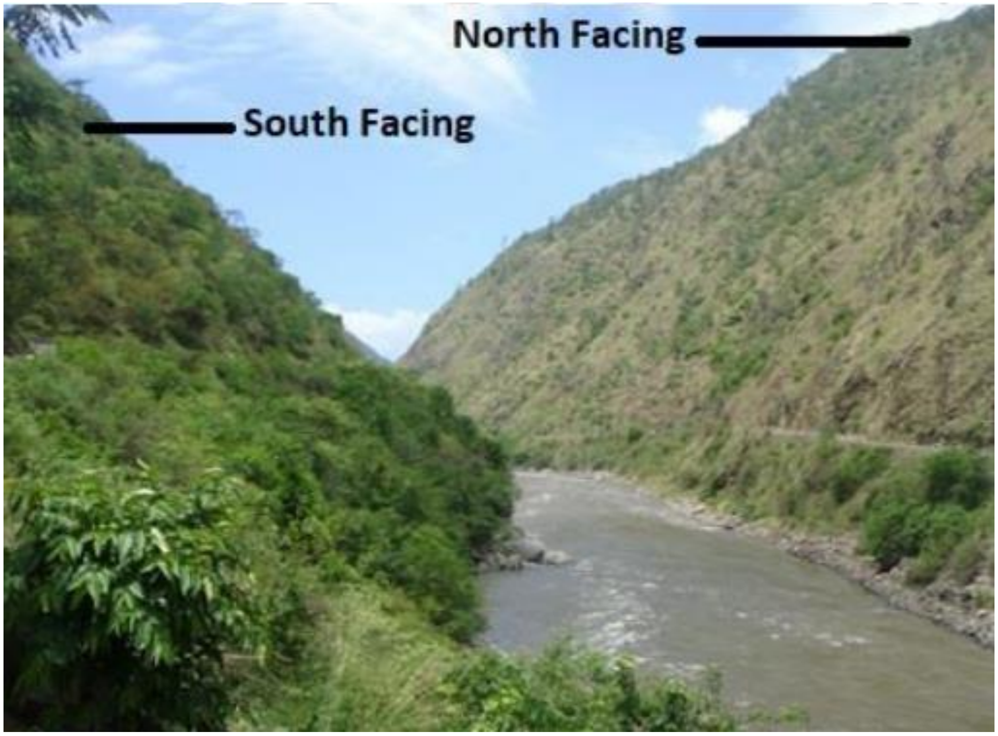


Figure 6: South and North Facing Slopes in Eastern Bhutan Himalaya
Source: Source: Photograph by Author (Dr. R. Prasad) at Trashigang along Dangme Chu River, Eastern Bhutan

5.4.8 Horizontal Temperature Distribution

The energy coming from the sun is not uniform all through the globe which we have already pointed out in discussion about factors affecting temperature. Due to the effects of several factors, incoming energy and temperature are widely varying over the surface of the earth. In general, equatorial region is hot and its temperature is high throughout the year. Generally, from equator to polewards, temperature keeps on declining. The lowest temperature is at and near the pole. In other words, the average annual temperature has a gradual decrease towards pole in the beginning from the equator, but after tropical zone, the decrease is accelerated. After the temperate zone, the declining trend in temperature is drastically enhanced (Figure 7A and B). It is all due to locational disadvantages of the poles, far away from the sunlight associated with other factors as explained a little while ago.

Since the sun is almost vertical in the tropical zone, the annual average temperature varies between 220C to 260C. The 220C is at Tropic of Capricorn, laying in the southern hemisphere. Along Tropics of Cancer, the annual average temperature is 240C (Figure 7B). The reason behind the difference is that, southern hemisphere has more water bodies while

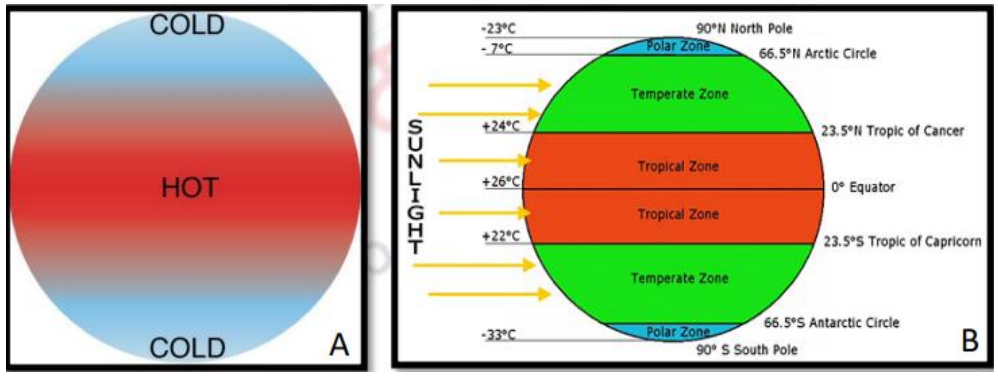


Figure 7A and B: Trends of Temperature Decline
Source A: http://www.physicalgeography.net/fundamentals/images/hotcold.jpg
Source B: http://jrohnerweatherandclimate.weebly.com/uploads/4/3/7/1/43713345/9198026_orig.gif

northern hemisphere has relatively more continental areas (Figure 8). As explained before, land areas record higher temperature than water bodies. It is due to this reason, temperature difference is observed.

To represent distribution of temperature isotherms are used. Isotherm is an imaginary line joining the places with same temperature. If we draw the isotherm of certain time over the world map, we would be in a position to have spatial pattern of the distribution of temperature. Let us study them with respect to two positions – (i) when the sun is overhead at Tropic of Cancer and (ii) when the sun is overhead at Tropic of Capricorn.

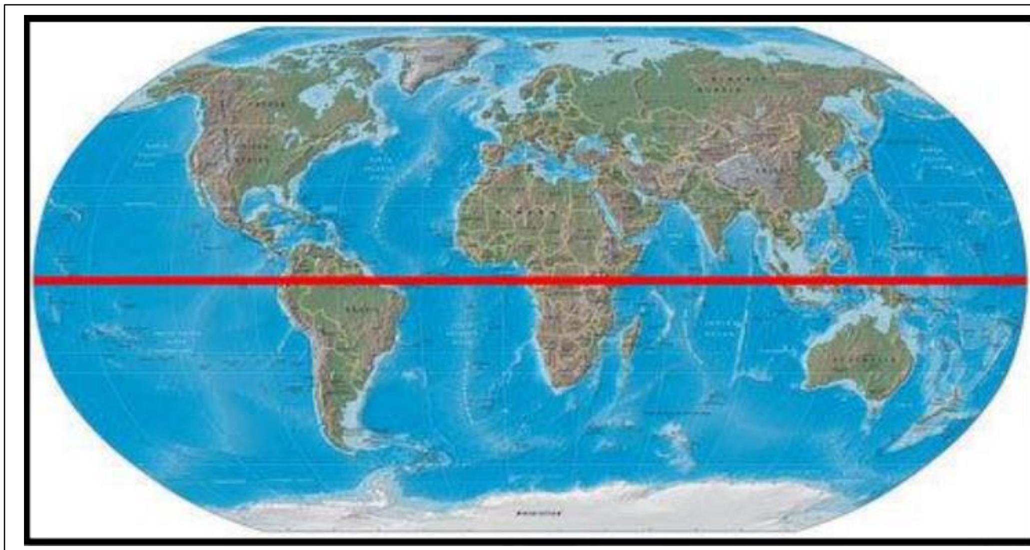


Figure 8: Land-Water Distribution over the Globe
Source:http://s3.amazonaws.com/kidzworld_photo/images/2015826/0c3f5852-fba9-4fcb-963b-94907603b6bf/map-equator.jpg

Sun Overhead on the Tropic of Cancer (July) The sun is overhead at the Tropic of Cancer by the end of third week of June (June 21st) at 23.50N. Entire northern hemisphere witnesses bright sun, greater insolation leading to high temperature throughout. But the maximum average monthly temperature is not recorded in June, but it so in July. Therefore, case of July is taken to study ideal summer month for northern hemisphere. The highest temperature is recorded over large chunk of area comprising Sahara desert of northern Africa and desert parts of west central Asia. This belt runs from Sahara desert, via Arabia to Thar. The high temperature zone is extended to the Indo-Gangetic plain as well as Tibetan plateau. This zone attracts the monsoon winds as it has intense low pressure due to high temperature. This low pressure zone is characterized by inter tropical convergence zone (ITCZ). From this belt, the temperature is declining northward as well as southward. By the

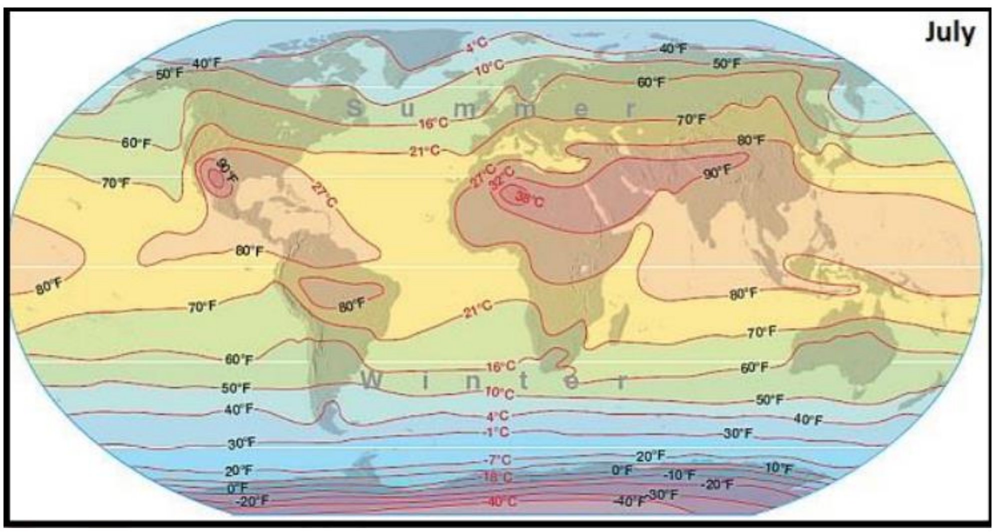


Figure 9. Temperature Distribution during July

Source:http://mgh-images.s3.amazonaws.com/9780321871770/508902-4-9ISQ2.png

northern end of the Asiatic landmass, the average recorded air temperature is around 4 0C (Figure 9).

During northern hemisphere summer days, the isotherms turns towards northward over land as it is hotter than water. The condition is reversed on the oceans as the water bodies are not that hot as the land is. Hence, the isotherms turns southward on the oceans of the northern hemisphere. Another low pressure system is developed over the northwestern Mexico and southwestern USA due to more intense record of temperature (Figure 9). The same pattern of isotherms are seen on North American landmass.

Overall, pattern of isotherm is reversed in southern hemisphere, particularly with reference to the direction of bending isotherms on land and water. One very remarkable observation is seen on the isotherm map of July in southern hemisphere. During this period, incidence of sunrays is acute and hence, insolation is less. It is the winter season for southern hemisphere. Isotherms are almost parallel to each other with very narrow spacing. The isothermal gradient is very steep (Figure 9). It is more so over the Antarctic landmass where the temperature is very low. Sun Overhead on the Tropic of Capricorn (January)

The sun is overhead at the Tropic of Capricorn by the end of third week of December (December 21st) at 23.50S. Entire southern hemisphere witnesses bright sun, greater insolation leading to high temperature throughout. But maximum average monthly temperature is not recorded in December, but it is so in January. Therefore, case of January is taken to study ideal summer month for southern hemisphere. Both major continents – South America and Africa are tapered towards south. There is no wide and large landmass in southern hemisphere as compared to the northern. The effects of ocean can be seen very clearly. Relatively, the temperature is recorded less. The maximum mean temperature of January is about 320C over a small area of western Australian desert. Over South America and Africa, it is around 270C. The area bounded by the 270C isotherm is wide over continents as well as on the Indian Ocean. The same is narrow over western Pacific. Eastern Pacific is cool due to the cold ocean currents. Over the Atlantic Ocean, warm area is confined to small and narrow belt enclosed by 270C isotherm. Both Pacific and Atlantic is are open

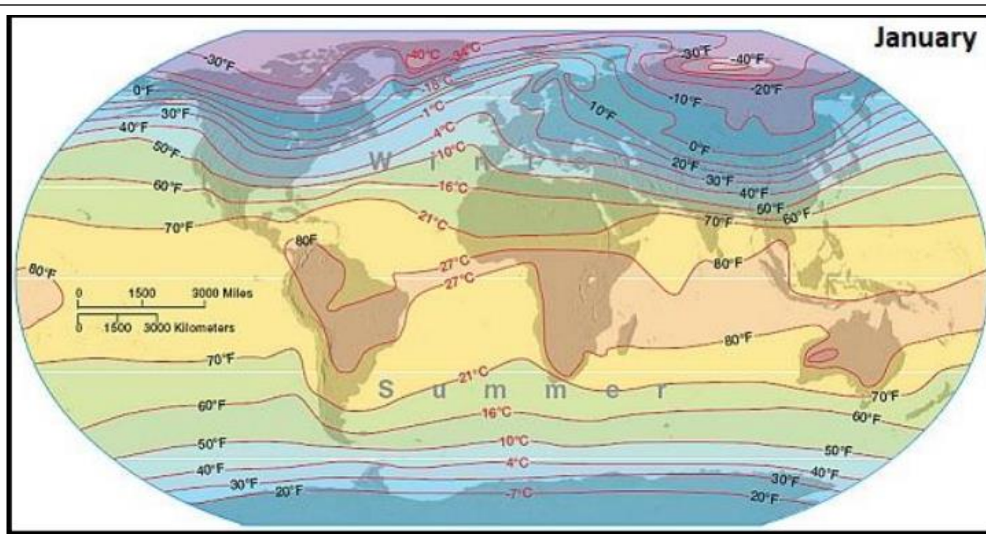


Figure 10. Temperature Distribution during January

Source: http://mgh-images.s3.amazonaws.com/9780321871770/508902-4-9ISQ1.png oceans in comparison to the Indian Ocean. Hence, wider warm belt is seen on map **(Figure10)**. From this zone, there is declining trend of temperature in both the directions – north and south. The isotherm of 210C covers a large part of the globe. Beyond this isotherm in both hemispheres, isotherms are coming closer and keeps on declining towards both poles (Figure 10). The temperature gradient is increasing. It is greater in the northern hemisphere particularly over the large landmass of Asia and North America. The lowest temperature around -400C is recorded on the polar region of Canada, Iceland and Asian Siberia. Over the northern oceans, isotherms are turned towards pole whereas on landmass their bends are towards south. It is because of the transport of heat from equatorial region to poleward through prevailing winds and ocean currents.

5.5 Annual Mean Temperature over the Globe

We have already discussed about the distribution of temperature for summer and winter seasons represented by two months – July and January. Since sun is always apparently on move due to rotation of the earth on the inclined axis, there is continuously change in the

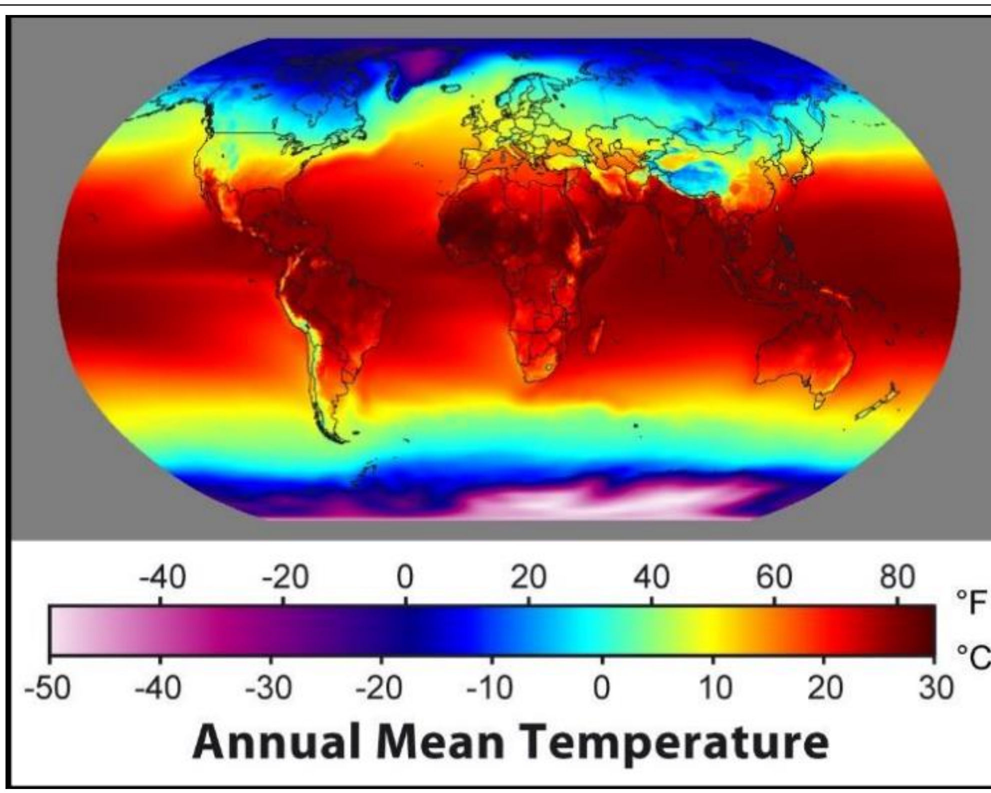


Figure 11: Annual Mean Temperature over the Globe
Source: https://upload.wikimedia.org/wikipedia/commons/a/aa/Annual_Average_Temperature_Map.jpg

distribution of temperature on the globe. If we calculate annual mean temperature of the earth and plot the same on the map, it would appear as it is shown in Figure 11. From this figure, it is vivid that the decline of temperature is almost symmetrical in distribution from equator towards poles with slight modification by the prevailing winds and ocean currents.

Average Annual Temperature Range Average annual range of temperature is the difference between mean monthly temperatures of the hottest and the coldest months. We have already discussed about distribution of temperature of two seasons – summer and winter. If the difference is computed between these months, that would give you the difference. Those values are plotted in Figure 12. The values shown with the isotherms are written in degree Celsius. From this figure, it is evident that annual range of temperature is very low in low latitude areas. It is less than 30C or less. This is a narrow belt across Africa and South America in the equatorial region. This belt is much wider on ocean surfaces. As long as we keep on marching towards poles, the annual range of temperature is increasing very sharply. This trend is very drastic in the northern hemisphere. This is due to presence of large landmasses and associated high thermal ranges.Over the large landmass of Siberian region, it reaches to about 600C (Figure 12). The same case is observed with Canadian big landmass but with lesser intensity. But in southern hemisphere, it is not that much great

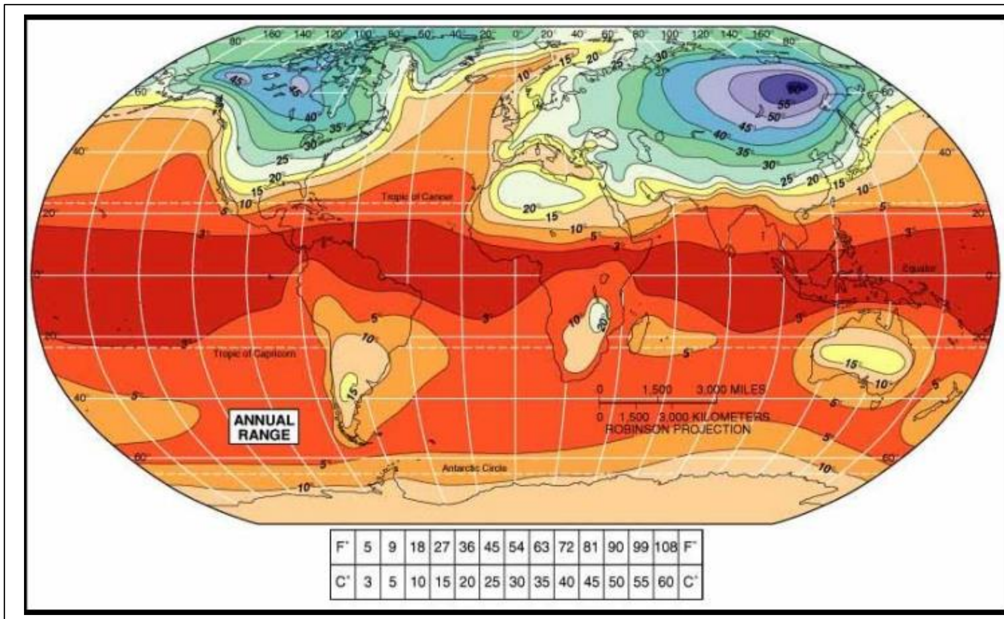


Figure 12: Average Annual Temperature Range

Source: https://ncache.ilbe.com/files/attach/new/20161108/377678/4164420490/9009480854/9df553b4c5edfe2f5f2a9035930c643c.jpg

Vertical Distribution of Temperature You might have already studied about composition and structure of atmosphere in Module 3 and insolation in Module 5. Here, our concern is to study vertical temperature distribution but only within the troposphere. We would not discuss the distribution of temperature beyond this limit.

In general, temperature declines upward from surface of the earth in troposphere till its upper limit – tropopause. This decreasing temperature is termed as lapse rate. Generally, it is called normal lapse rate in which air keeps on laying at its place and someone or thermometer moves upward. In this way temperature is measured. This drop is 6.50C/km of ascent. It is also termed as vertical temperature gradient. The normal lapse rate is not always the same but it differs depending upon height, season, latitude or other numerous local factors. Inversion of Temperature In certain conditions, temperature is not always declining with increasing altitude but it rises. This situation is known as inversion of temperature. The term, inversion, means opposite to the normal. Since normal is fall in temperature with altitude, under inversion, it rises with increasing height (Figure 13). It happens when the air near surface is cooler than upper air.

5.6 Temperature Inversion

Normally temperature decreases with increasing altitude which is at an average rate of 6.50 per 1000 m and this is called as lapse rate. However, under special circumstances this rule of temperature decre4as with increasing height is reversed and temperature starts increasing with altitude up to a few kilometers and is known as negative lapse rate.

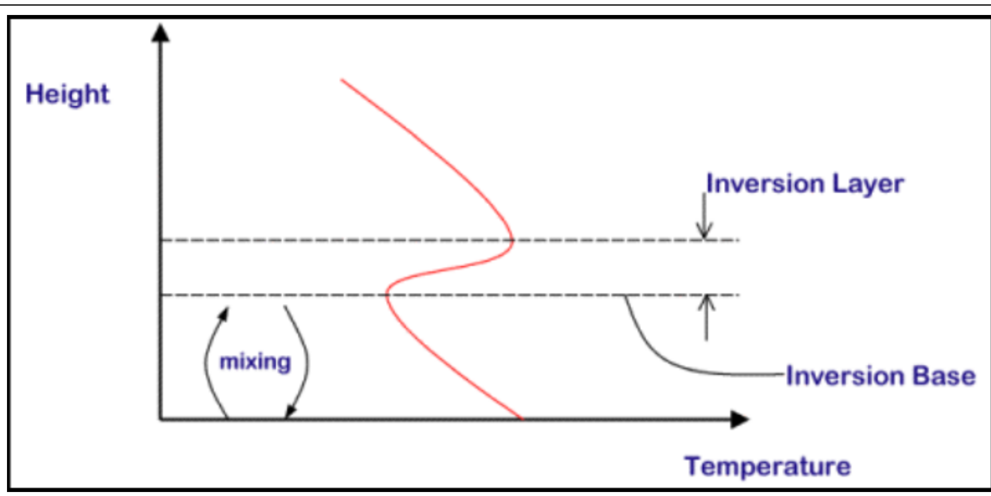


Figure 13: Inversion of Temperature

Therefore, in this condition warm air mass lies over the cold air mass. This phenomenon is meteorologically known as **temperature inversion**. This situation may occur near eath's surface or in greater heights in the troposphere. The duration of temperature inversion near surface is of very short time whereas in the higher heights it last for longer duration.

5.6.1 Ideal Conditions for Temperature Inversion

Temperature inversion takes place only under certain conditions. Important among them are:

- There has to be long and cool nights so that earth radiates received solar energy.
- There has to be clear sky so that terrestrial radiation escapes.
- There has to be calm and stable air so that vertical motion in the air is absent.

5.6.2 Types of Temperature Inversion

Primarily, there are several types of inversion of temperature. Important among them are:

- Ground inversion,
- Valley inversion,
- Subsidence inversion and

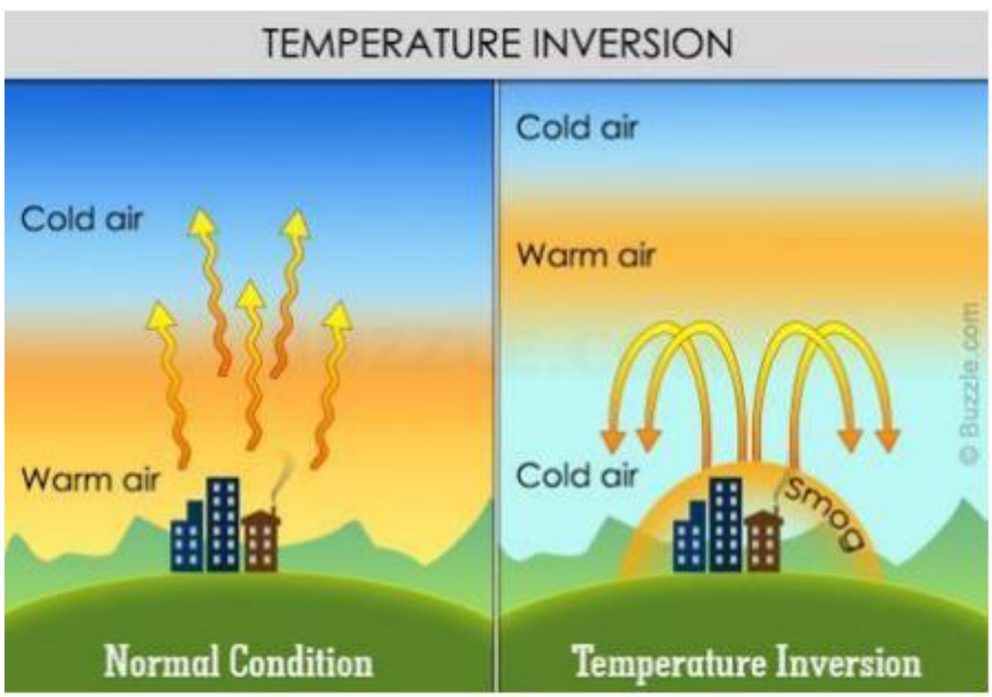


Figure 14: Inversion of Temperature on the Ground
Source: http://media.buzzle.com/media/images-en/buzzle/450-temperature-inversion.jpg

• Frontal inversion.

5.6.2.1 Ground Inversion

Ground inversion occurs when the surface is cooled rapidly by earth radiation under clear sky. In this way, temperature above the ground is still warmer than air near the ground. When temperature near surface reaches to dew level, the possibility of fog formation increases. Ground inversion is very common in the higher latitude areas or during winter in the plain even in the tropical regions (Figure 14).

5.6.2.2 Valley Inversion

Valley inversion takes place on the rolling topography, particularly in hilly areas. In such situation, mountain slope becomes cool in the night and the air with its contact gets cooler. Cool air creeps downward along the slope and occupies the valley. The warm air of the valley is pushed up and thus the inversion of temperature is evident (Figure 15).

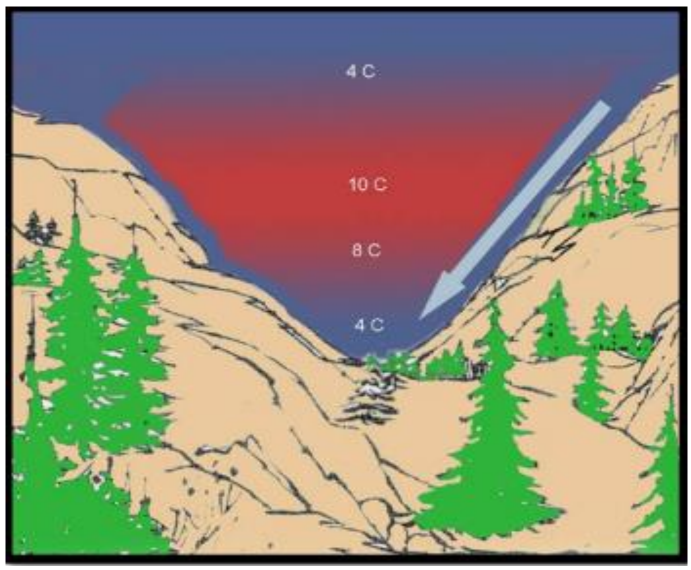


Figure 15: Inversion of Temperature in a Valley
Source:http://www.islandnet.com/~see/weather/graphics/photos1112/valleyinversoin.jpg

5.6.2.3 Subsidence

Inversion Subsidence inversion takes place mostly in subtropical high pressure belts or leeward side of the mountain where air subsides. In either of the cases, subsiding air gets warmed in this process while the lower level preexisting air is cooler. The warming is achieved about 100C per km of descending air. Therefore, lower level air seems to be cooler than the plunging air from above. In this situation, the subsidence inversion of temperature is caused (Figure 16).

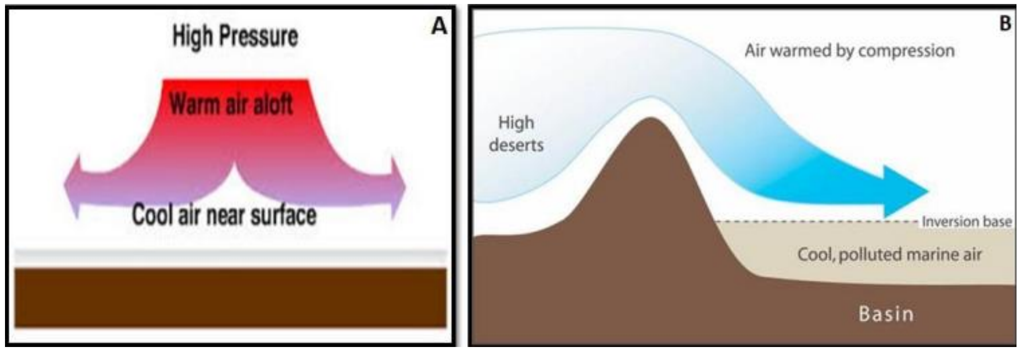


Figure 16: Inversion of Temperature due to Subsidence
Source A:http://www.earthonlinemedia.com/ebooks/tpe_3e/temperature/subsidence_inversion.png
Source B:http://doorstoarrival.com/wp-content/uploads/2015/08/regional-subsidence-inversion.jpg

5.6.2.4 Frontal Inversion

As the name suggests that this type of inversion of temperature takes place under the frontal formation of two different air masses. When cold and heavier air mass undercuts warm sector occupied by warm air mass, the warm air is lifted up. The ground is occupied with cold air, and thus, inversion is observed (Figure 17).

5.7 Concept of Heat Budget

Simply the meaning of budget is an estimate of your income and the expenditure of the same over a certain period of time. Heat is a sort of energy which our earth receives from the sun. Therefore, the energy received (your income) from the sun and its utilization (your

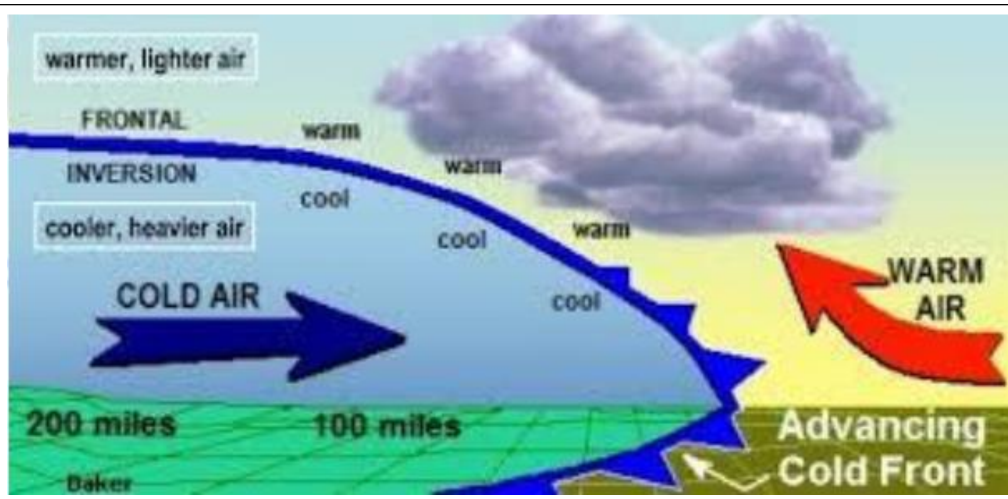


Figure 17: Frontal Inversion
Source:https://www.iasmania.com/wp-content/uploads/2016/02/Frontal-Inversion.jpg

expenditure) by/in the atmosphere as well as the surface (land and water surface) of the earth is basically heat budget. In this context, the heat budget has two main components incoming shortwave solar radiation and outgoing longwave terrestrial radiation. Let us study them in brief:

5.7.1 Incoming Shortwave Solar Radiation

By now, you must have studied the topics on insolation in which its factors and distribution has been explained. The uppermost atmosphere of earth receives about one part of energy out of two billion parts radiated from the entire sun's surface. This much tiny energy is the cause of various interactions in the atmospheric systems. Now, let us through some light on the processes involved with incoming radiations: There are three processes operating with the incoming solar radiation. They are:

- Reflection
- Diffusion and scattering
- Absorption

5.7.1.1 Reflection

The meaning of reflection is returning something back from where something was coming. You also know it well, as you bring a mirror to the sunlight, a bright beam of light is thrown away from the surface of the mirror. The angle of the reflection of light is dependent on the angle of the incidence. Refer the Figure 18 and you find that the angle of incidence and angle of reflection is equal. The smooth surface like a mirror or relatively smooth surface

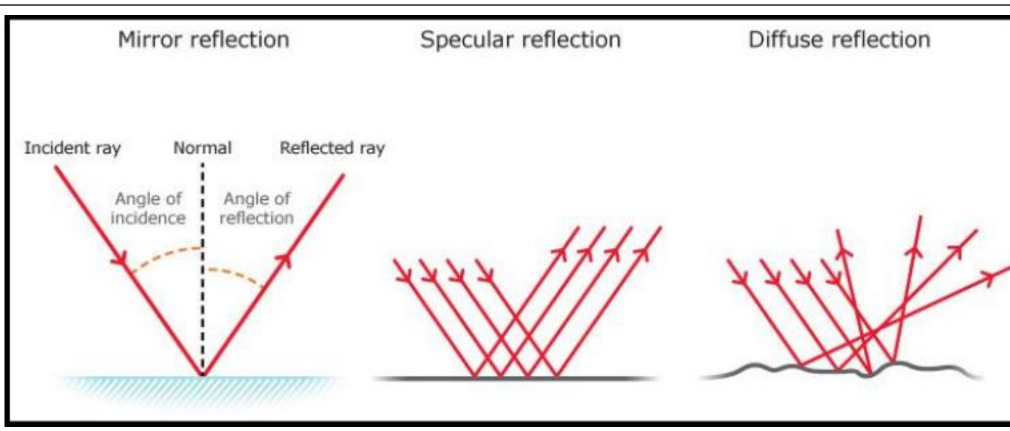


Figure 18: Reflection and Diffuse Reflection on the Surface

shows specular reflection while on rough and undulated surface, it is diffused reflection. The certain amount of incoming energy is lost and it does not participate in the heating process of atmosphere or the earth's surface. It is generally expressed in percentage of the incident radiation reflected. It is also called as albedo or coefficient of reflection.

5.7.1.2 Diffusion and Scattering

The term diffusion refers to the spreading of something more widely from its centre to all directions. In scattering, sun energy or light is forced to deviate from the direction of propagation. When the sun energy passes through the atmosphere, it has to travel through numerous solid minute particles of aerosols and gases. In this process of passing through, the energy and light is diffused and scattered.

Refer to the Figure 19. The smaller suspended particles in the atmosphere also reflect and diffuse the sun's electromagnetic radiation. Because of this reason, we find the twilight before the sunrise or even after the sunset. More and more scattering and diffusion is possible when the wavelength is smaller. Violet visible rays have much smaller wavelength than the red visible light. The blue colour of the sky is due to selective scattering of sun light. Before dawn or after the sunset, the sky is red and it is due to diffusion and scattering of red visible light.

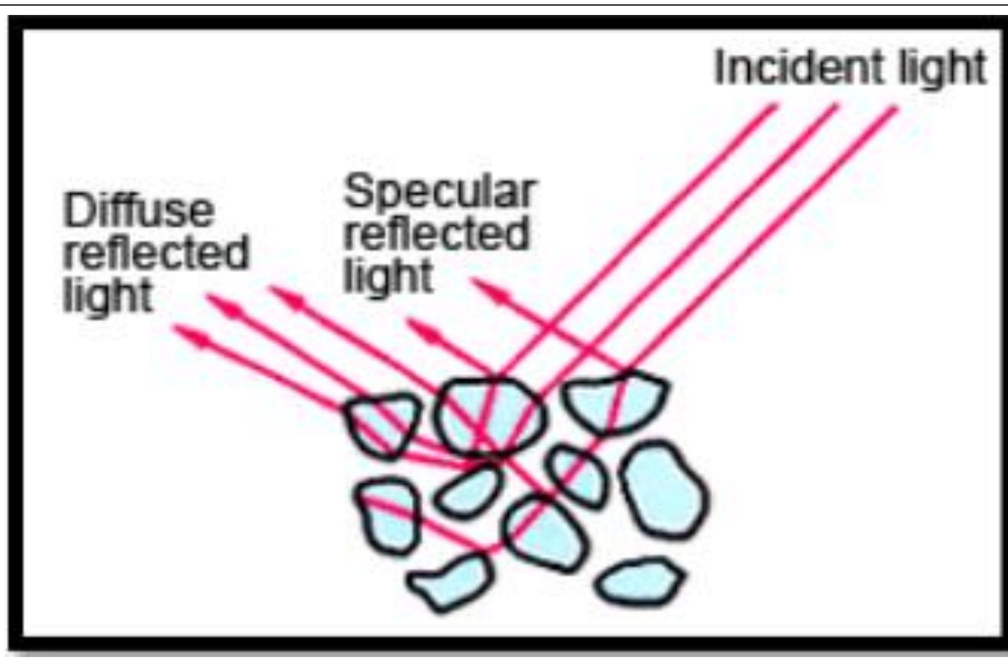


Figure 19: Reflection and Diffuse Reflection in the Atmosphere

5.7.1.3 Absorption

The term absorption refers to a state of being engrossed or being captivated. Therefore, it is a process by which something is absorbed by another thing. With reference to the absorption of solar radiation, it is done so by the atmosphere or the earth surface. Incoming solar radiation is absorbed by the different elements of atmosphere present at a particular point of time. These elements are gas molecules, water vapour, smoke and dust particles. They trap a part of solar energy during transmission through the atmosphere. In fact, the absorption is a function of the nature of the absorbing particles/ surface and the wavelength of the energy. For example, shortwave radiation is absorbed by oxygen and ozone but for relatively longer waves, they behave as transparent body.

5.7.2 Outgoing Longwave Terrestrial Radiation

The received energy from the sun heats the earth surface. Heated earth surface is not that hot hence, it re-emits the energy. This remittance energy is in the form of longwave radiation. In this process, the longwave energy is absorbed by the atmosphere. And the atmosphere is warmed up. Now, let us study the heat budget by different heads of incoming (income) and outgoing (expenditure) radiations.

The received energy by the earth as well as by the atmosphere is re-emitted back. It happens through different processes. Therefore, the outgoing energy involves following processes:

- Latent heat transfer
- Sensible heat transfer
- Emission by vapour and clouds
- Longwave radiation

5.7.2.1 Latent Heat Transfer

Latent heat is the energy absorbed or released from a substance due to changing phases. For example, when solid to liquid or from liquid to gas or even from solid to gas and vice versa. If a substance is changing from solid to liquid, it absorbs the energy from the surroundings so that its molecules are spread out. If the liquid is again changing its state to gas, it further requires more energy for the same reason. When the process is reversed, the energy utilized for changing the state of the substance, the same amount of energy is returned to the surroundings. Figure 20 undoubtedly explains the changing state of water and energy retained or released.

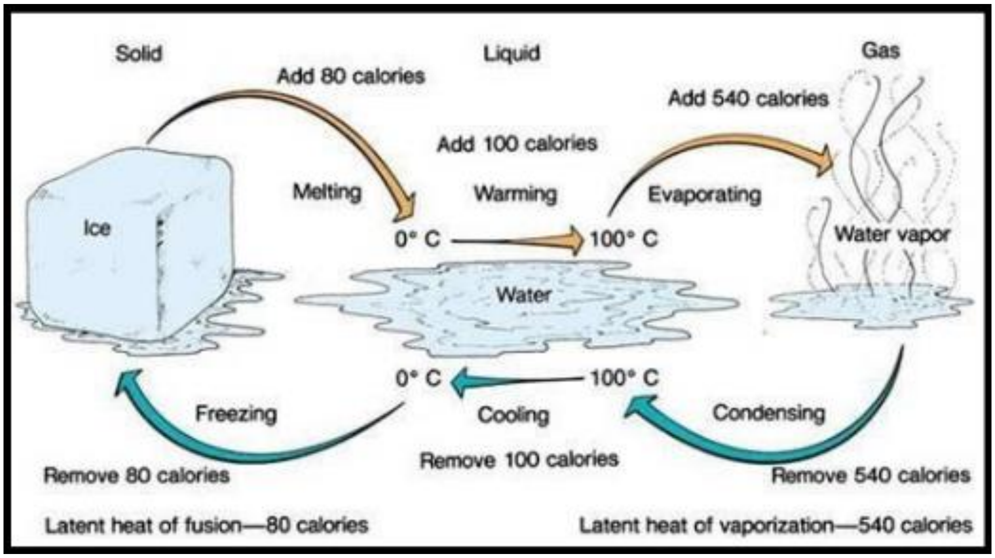


Figure 20: Relationship of Changing State of Water and Energy Use or Release

Source: https://qph.ec.quoracdn.net/main-qimg-36a6e3973562f9f51f02b4c061f940e2-c

5.7.2.2 Sensible Heat Transfer

Sensible heat is the energy needed to alter the temperature of a substance without any change in the state. It is possible by absorption of sunlight by the land surface or even the air is warmed up by gaining heat. Release of latent heat or the cool air coming in contact of warm air also cause the temperature to rise. Therefore, both the methods latent and sensible heat are responsible for gain or release of energy in the atmosphere.

5.7.2.3 Emission by Vapour and Clouds

Emission means discharge or release of something. Huge amount of terrestrial energy is released through the vapour and clouds. In fact, the energy due to which the atmosphere was heated up, in general, is released through vapour and clouds as well.

5.7.2.4 Longwave Radiation

Little amount of energy is directly released to the space by direct longwave radiation. It means that this amount of energy is not trapped by the atmosphere.

5.8 Heat Budget

The ideal heat budget of the earth is supposed to be a perfect balance between the incoming solar radiation and outgoing terrestrial radiation. Therefore, no negative or no positive between the two has to be maintained. In other words, it has to be a zero outcome of the two.

The total incoming shortwave radiation reaching at the top of the atmosphere is considered to be 100 percent. The distributed and re-distributed of this 100% or 100 units energy is termed as heat budget of the earth. Out of these 100 units, 17 units are reflected back to the space by cloud cover. Air molecules scatter 8 units of the energy back to the space. Energy reached on earth surfaceis also reflected by some surfaces like show cover, deserts or other bright surfaces. Their contribution in reflection is 6 units. Hence, the total reflection, from atmosphere (17 units), from air molecules (8 units) and from surface (6 units) is 31 units.

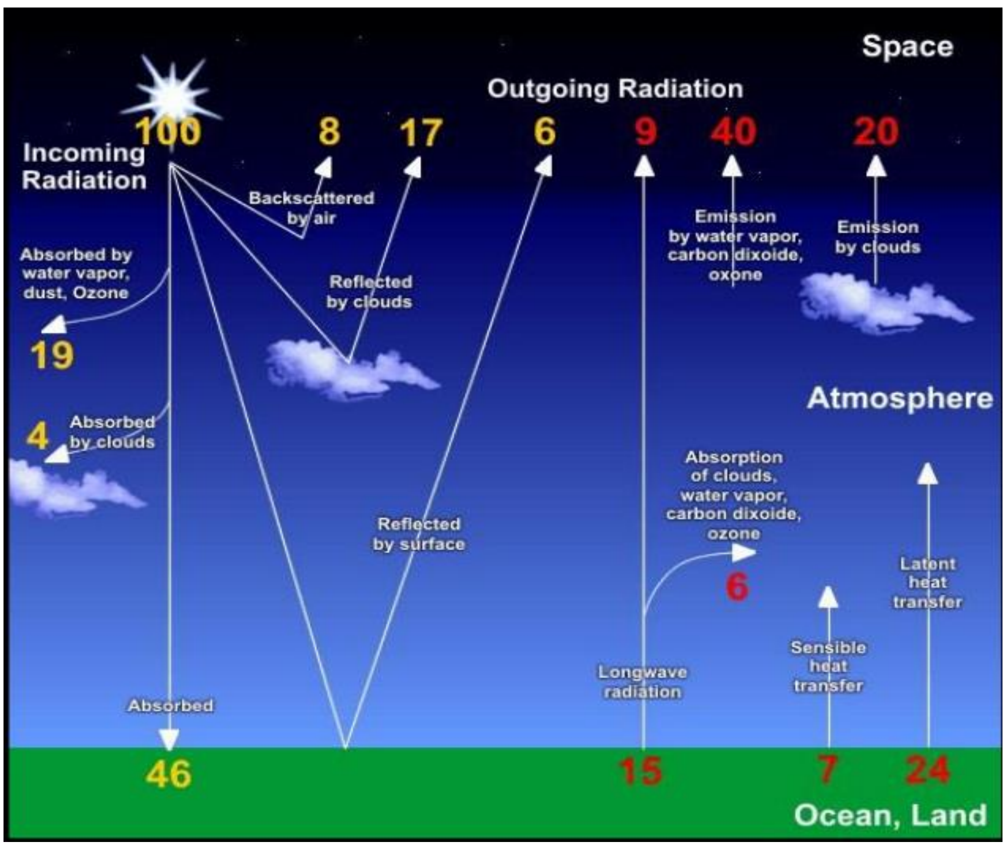


Figure 21: Heat Budget of the Earth

Source: http://www.geocoops.com/heat-budget--insolation.html

This much of energy is not at all used in the heating of the atmosphere or the earth surface. Refer to Figure 21.

Remaining 69 units are involved in heating of the atmosphere and the earth surface. Out of these 69 units, 9 units are trapped by the water vapour, dust particles and ozone and heats up the atmosphere. Four units are absorbed by clouds and the rest 46 units reach directly to the earth surface. The 31 units directly reflected back to space, 23 units utilized in the atmosphere and 46 units reaching the earth make the total 100 units of incoming solar radiation. Out of 46 units received by the earth, 9 units are directly released back to space by longwave radiation without heating the atmosphere. Six units of the longwave radiation are absorbed by clouds, water vapour, carbon dioxide and ozone. The total energy used up in heating the atmosphere is 60 units; 37 units released by the earth surface (7 units – sensible heat; 24 – units latent heat and 6 units absorbed by clouds, water vapour, carbon dioxide and ozone) and 23 units already absorbed during transmission of the solar energy (19 – units absorbed by water vapour, dust particles and ozone and 4 units – absorbed by clouds).The details of the heat budget of the earth are compiled in Table 1.

Table 1. Heat budget of the earth

Unit	Sector	Incoming solar radiation
		Incoming solar radiations (100 units)
17		Reflected by clouds
8		Backscattered by air
6		Reflected back by earth surface
	31	**Returned to space (Albedo)**
19		Absorbed by water vapour, dust particles and ozone
4		Absorbed by clouds
	23	**Incoming energy absorbed in the atmosphere on the way to earth**
	46	**Reaches to the earth surface**
	100	**Total incoming radiation**
		Outgoing terrestrial radiation(46+19+4=69)
9		Escaped to space by longwave radiation
6		Absorbed by clouds, water vapour, carbon dioxide and ozone
7		Transfer by sensible heat
24		Transfer by latent heat
	46	**Returned to atmosphere and space**
	37	Re-emitted energy from the earth heating the atmosphere
	23	Incoming energy absorbed in the atmosphere on the way to earth
	60	Total energy utilized in heating the atmosphere

The total energy released to the space after being utilized by atmosphere as well as the earth is 69 units. So these 69 units as well as 31 units directly returned to space make 100 units and that was the total incoming radiation. The sectoral heat budget and their description are presented in Table 2.

Table 2: Sector-wise Description of Heat Budget

Units	Detail description
	Incoming solar radiations (23+8+23+46=100)
17+6=23	Reflection
8	Diffusion and scattering
19+4=23	Absorption
46	Received at the earth surface
	Absorption by atmosphere (both incoming and outgoing; 19+4+6=29) *
19	Incoming by water vapour, dust particles and ozone
4	Incoming by clouds
6	Outgoing by clouds, water vapour, carbon dioxide and ozone
	Released by the earth but atmosphere is heated (6+7+24=37)
6	Longwave radiation absorbed by clouds, water vapour, carbon dioxide and ozone
7	Sensible heat transfer, utilized in the atmosphere
24	Latent heat transfer, utilized in the atmosphere
	Outgoing total energy from the earth and atmosphere(9+20+40=69)
9	Directly released to space by the earth
20	Emission by clouds
40	Emission by water vapour, carbon dioxide and ozone

5.9 Heat Balance

Heating is the process of transfer of energy from a body of higher temperature to another body of lower temperature. The distribution heat energy is not uniform over the earth surface. It has numerous factors to affect, about which you have already studied in earlier toppics. Its distribution is most affected by the curvature of the earth/ incidence of sun rays. Therefore, the maximum energy is received near the equator throughout the year. The seasonal variations of energy received are considerable with increasing latitudes.

5.9.1 Latitude-wise Temporal Variation in Received Energy

Refer the Figure 22. On vertical axis, the energy is increasing upward. You can very well observe that the grey line is on the top showing very high received energy in all months (throughout the year) and it is equator. Blue lines are for different latitudes of northern hemisphere. Sun is vertical in the northern hemisphere from third week of March and reaches on peak in the third week of June. Hence, from January to June the energy received on the northern latitudes increases. After that, it keeps on declining and the lowest most reaches in December/January. The reverse case is seen in the context of southern hemisphere. The latitudes of southern hemisphere are shown in green colour. The complete reversal of the distribution of energy is primarily caused by the change in incidence of sun rays in an annual cycle.

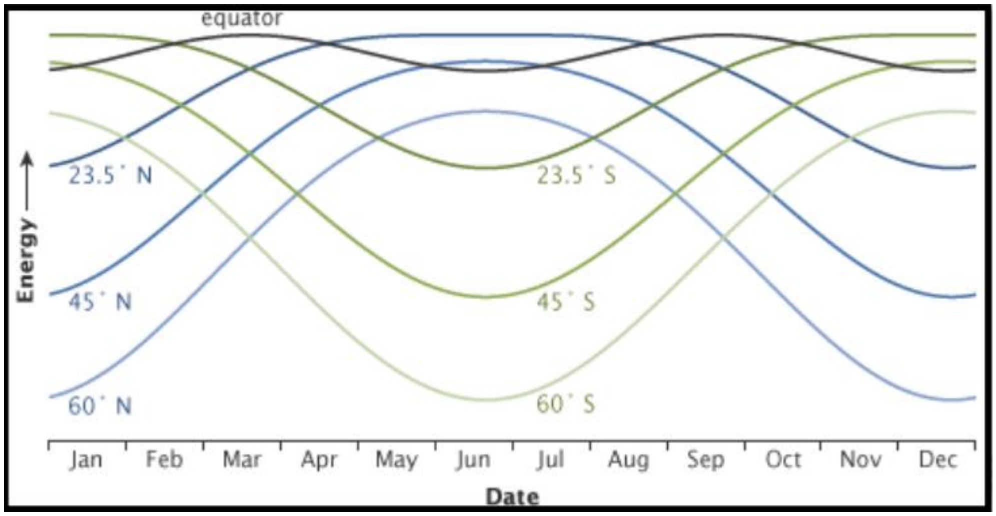


Figure 22: Selected Latitude-wise Trend of Daily Received Energy at Local Noon
Source: https://earthobservatory.nasa.gov/Features/EnergyBalance/page3.php

5.9.2 Diurnal and Horizontal Variations in Irradiance

The maximum irradiance (flux of radiant energy per unit area) from the sun is when the incidence of rays is vertical or near to vertical. It happens around noon at any place on the earth. Inclination of sun rays causes the variations. In general, it is the highest at the equator and lowest at the poles. At equator, it is perpendicular to the propagation of sun rays. With progressive increase in latitudes, the angle of solar illumination reduces, consequently, the solar irradiance decreases. It is demonstrated in Figure 23. It shows the relationship between latitudes, time and solar energy during the equinoxes. Five recorded times are taken here for the illustration from 6am to 6pm at the interval of three hours.

The length of shadow of the objects shows the inclination of sun light and the intensity is affected by the duration of the day. The shadow of the objects decreases from sunrise to the noon. When the sun is directly overhead along the equator, there is no shadow. After the noon, it keeps on increasing until the sunset. At this time, the shadow is the longest as it happens at the sunrise. Further after that, the sun goes beyond the horizon.

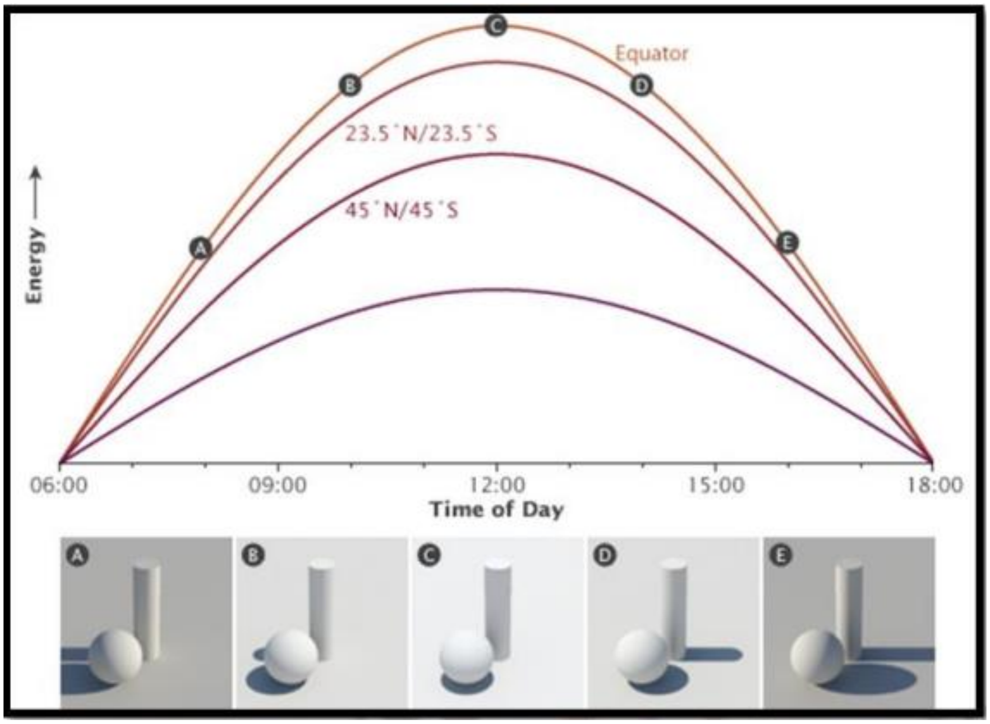


Figure 23: Diurnal and Horizontal Variations in Irradiance during Equinox
Source: https://earthobservatory.nasa.gov/Features/EnergyBalance/page2.php

5.9.3 Variations in Reflected Solar Radiation

During June in northern hemisphere and during December in southern hemisphere, days are longer over poles and due to this reason polar areas get more sunlight. Polar areas are cold with huge accumulation of ice. Long duration sunshine is also not very effective because of greater reflectivity of the areas. Hence, the heating in the polar areas is very low. During the same months, but in reverse hemispheres, the sunshine is absent in the polar areas. Overall, the tropics receive more sunshine and consequently greater energy. The greater reflection means less energy available for heating the surface and lesser reflection signify the greater energy availability for heating the surface. Therefore, if other things remain the same, higher reflecting zones are cooler and lesser reflectance is associated with more heating. Refer to the Figure 24. The amount of sunlight absorbed on the earth surface depends on the reflectiveness of the atmosphere as well as the earth surface. From this figure, it is obvious that the amount of solar radiation (in watts per square meter) reflected by clouds is high, at equinox, in tropical areas. The cloud free deserts also reflect substantial amount of energy. During September for which this map is, the poles are not getting sufficient sunlight, the reflectance is less and darker blue colour is assigned. Reflected solar radiation is the function of the state of atmosphere as well as the nature of the surface of the earth.

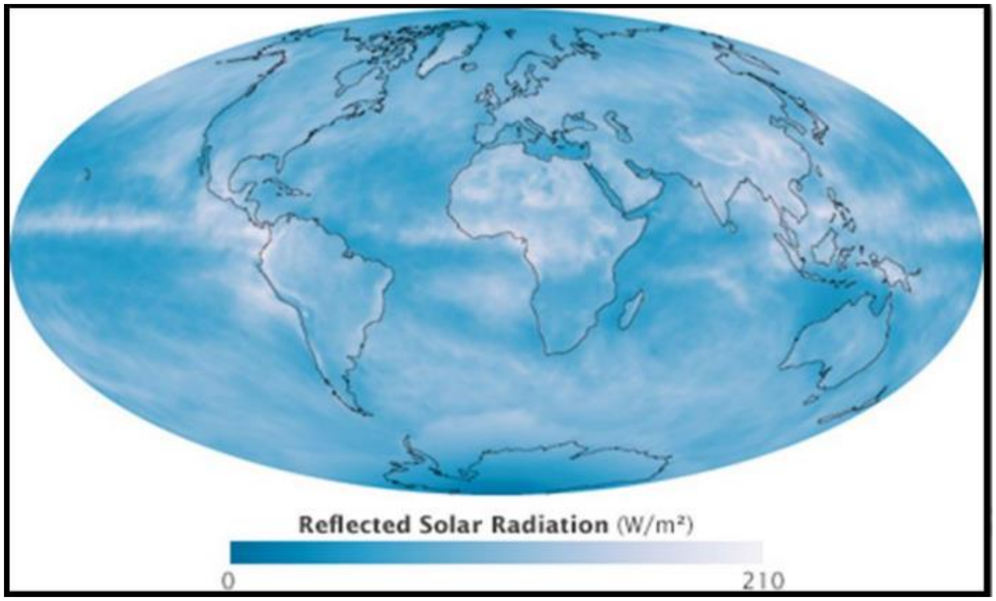


Figure 24: Variations in Reflected Solar Radiation during September 2008
Source: https://earthobservatory.nasa.gov/Features/EnergyBalance/page3.php

Net Radiation The difference in reflectiveness and solar illumination over the earth determines the heating imbalances. These imbalances give birth to several changes and variations in the earth systems. As discussed above, the net radiation is the result the difference between the amount of incoming energy and the amount of the energy radiated back to space. In the tropics, there is a surplus energy because the amount of sunlight absorbed is more than the amount of heat radiated. Contrary to this, the higher latitude areas have annual energy deficit as the amount of absorbed energy is less than the radiated energy. Refer to the Figure 25. It is quite obvious that during equinox, the net radiation is more in the tropics but the higher latitude areas have deficit radiation. At this time the sun is overhead at the equator. On entire earth, the days and nights are almost equal. Poles are getting oblique sun rays and that are not effective. On the other hand, during solstice in December, the sun is vertical in the southern hemisphere and therefore, gets very high net radiation. During the same period, the northern hemisphere is away from the sun and gets less net radiation. During June, when the sun is vertical in the northern hemisphere, its net radiation is very high and while the southern hemisphere gets very low net radiation.

The positive values on the map denote that the received energy is more than the radiated. Conversely, the negative values of net radiation show that the terrestrial radiation is more than incoming solar radiation. Dark green and bluish shades towards higher latitudes reflect increased intensity of this trend.

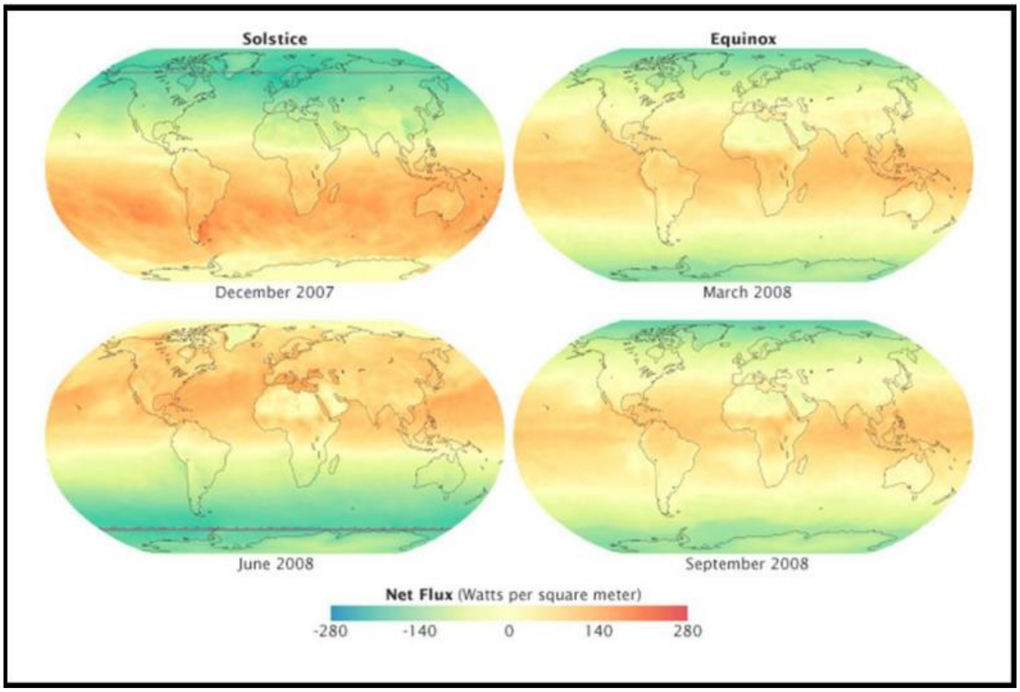


Figure 25: Net Radiation during Solstice and Equinox

Source: https://eoimages.gsfc.nasa.gov/images/imagerecords/77000/77849/netflux_cer_2007-08.jpg

5.9.4 Incoming and Outgoing Radiation across the Latitudes

You are well aware that the maximum solar radiation is received in the tropics. The heat from the tropics is transported to the higher latitudes by atmospheric circulations (prevailing winds, cyclones and air masses) and oceanic circulations (mainly ocean currents. From Figure 26, it is evident that approximately between 350 N and 350 S latitudes, the energy received is surplus. More energy is received (shortwave) than lost (longwave). Blue colour line represents the incoming radiation while red colour line shows the outgoing. The areas with higher incoming and lesser outgoing radiation are shown as heat surplus areas and reverse situation represents heat deficit areas. Because of the transport of radiation in the form of heat energy, higher latitudes are relatively warmer than what they wouldhave been otherwise. Heat is also lowered in the tropics due to transport, and hence, it is relatively cooler than what it wouldhave beenin the absence of latitudinal heat transfer.

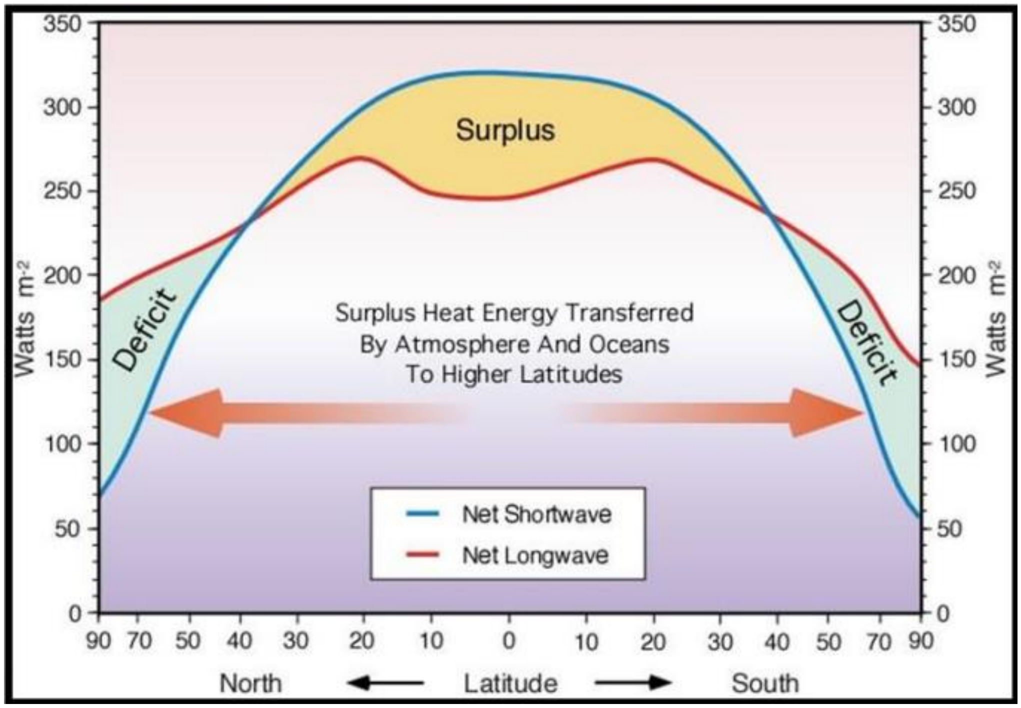


Figure 26: Latitudinal Variation of the Radiation Balance

Source: http://www.physicalgeography.net/fundamentals/images/rad_balance_ERBE_1987.jpg

5.9.5 Greenhouse Conditions

Major gases in the composition of the atmosphere are nitrogen and oxygen accounting for nearly 99 percent share of the total. These gases are transparent to both incoming as well as outgoing radiation. As against this, gases such as carbon dioxide, methane, water vapour and other trace gases are opaque to several wave lengths of thermal radiation.They allow solar radiation to come but when the earth re-emit the same energy by longwave radiation, they do not allow to escape. They behave like a house made up of glass which allows the sun energy to enter but holds back when the house itself releases the energy. The result is the rise of the temperature of the glass house (Figure 27).

Atmospheric gases absorb only some wavelengths of energy but are transparent to others. The absorption patterns of water vapor (blue band) and carbon dioxide (pink band) overlap in some wavelengths. The carbon dioxide is not as strong a greenhouse gas as water vapor, but it absorbs energy in wavelengths (12 to 15micro meters) which water vapor does not. As such, atmospheric window, in this zone, is partially closed through which heat radiated by surface would normally escape to space.

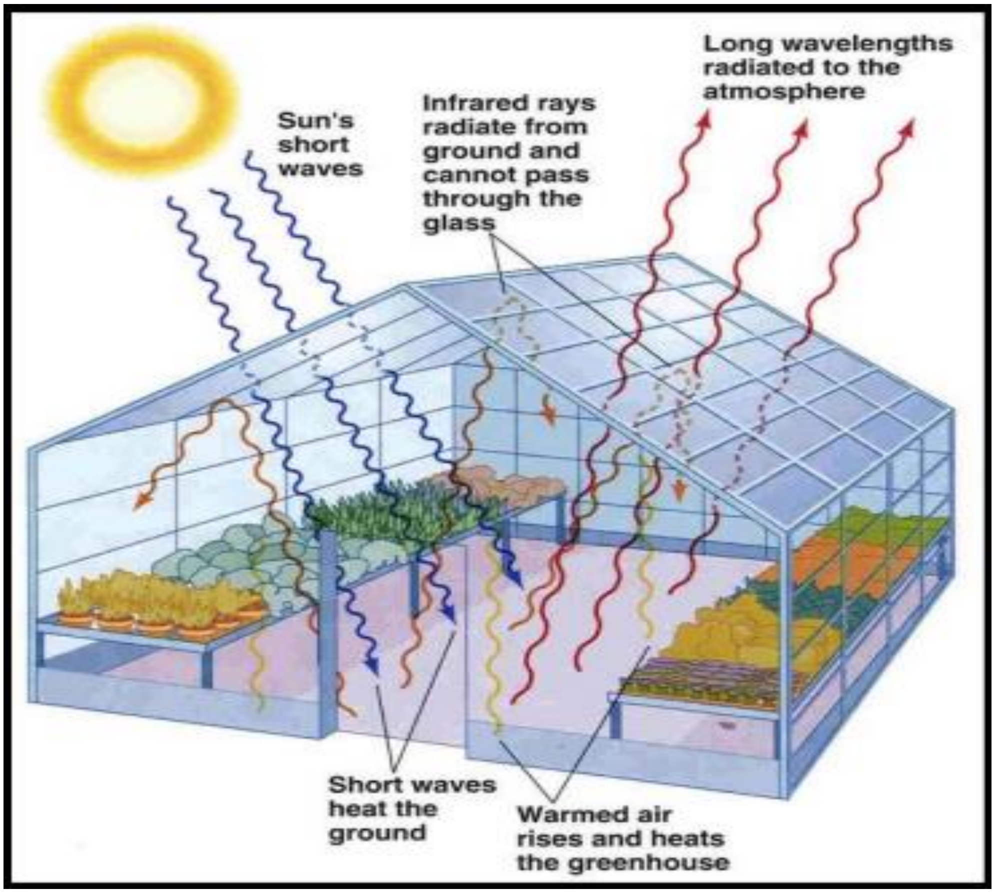


Figure 27: House made up of Glass Creates Greenhouse Condition
Source: http://www.earthlyissues.com/images/greenhouse.jpg

Temperature rises when molecules of greenhouse gas absorb thermal infrared energy. These gases radiate thermal infrared energy in all directions. The upward radiated heat continues to encounter greenhouse gas molecules which also absorb the heat, resulting in temperature rise. The net result is that the amount of radiated heat increases. It is well known that atmosphere thins with altitude. The concentration of greenhouse gases is also in the lower troposphere. Since greenhouse gas molecules radiate infrared energy in all directions, some of it spreads downward also and ultimately returns to Earth's surface, where it is absorbed. The Earth's surface temperature is higher than it would have been only by direct solar heating. The additional heating is due to the effect of greenhouse conditions (Figure 28).

Since the earth is covered by a blanket of atmosphere that allowsshort wave solar radiation

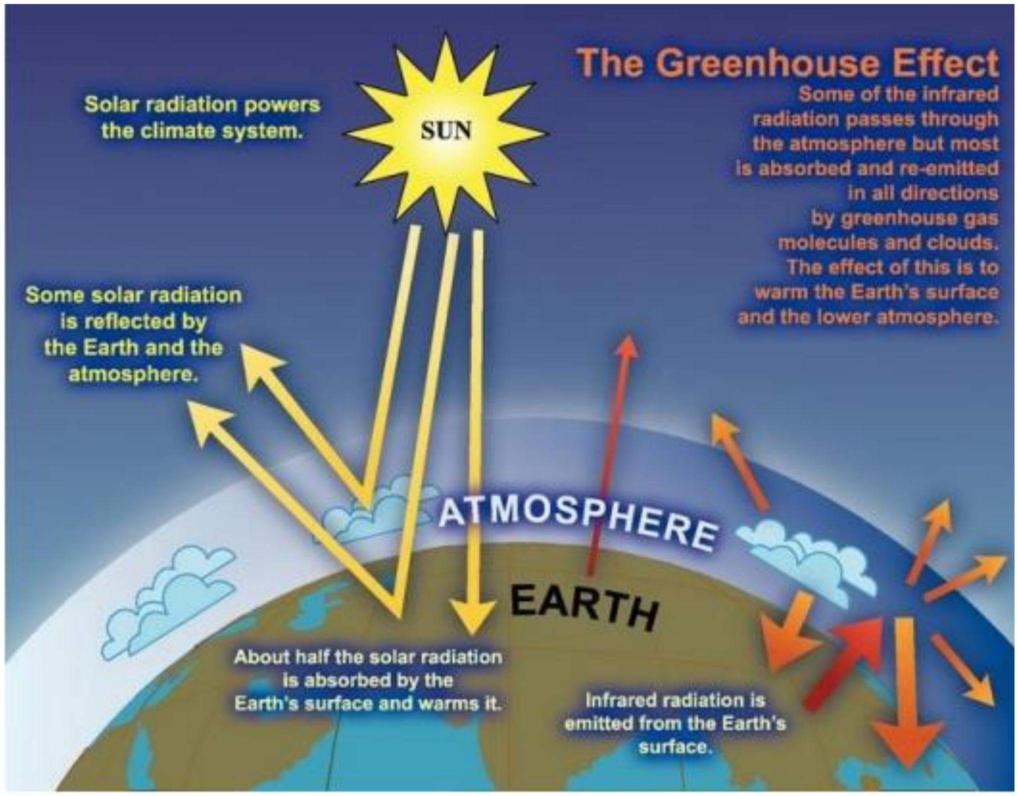


Figure 28: The Greenhouse Effect

Source: http://www.earthontheedge.com/wp-content/uploads/2014/10/greenhouse_effect_AR4.png

to enter and slows the rate of the long wave infrared radiation emitted by the Earth leaves. In addition, it is important to note that ozone (O3) in Stratosphere absorbs ultra violet rays and thus keeps Earth free from the harmful effects of UV radiation. It was detected in 1980s that ozone layer is depleting fast over poles. Montreal Protocol (1987) was signed to check the problem. Recent researches have shown that the ozone layer is improving because of the concerted cooperative efforts of the international community.

5.10 Balancing Act

The temperature on the globe remains almost constant. It happens because the incoming and outgoing energy is almost equal on an annual basis. The high energy receiving areas transfer to the low receiving and thus, uniformity is almost reached. That is why the low latitude areas are relatively cooler by transferring the energy to the deficit areas, in comparison to what it would have been otherwise. Apart from the transfer of energy, some atmospheric gases are of the nature which holds the energy released by longwave radiation. It causes the temperature to rise and maintain a moderate temperature of the entire earth which makes it habitable. In the absence of the greenhouse effect of the atmosphere the earth's temperature would have been 330C lower than present. Therefore, without the absorptive gases in atmosphere human life and other life forms would do not have been possible.

Summary and Conclusions

The source of almost all energy on the earth's surface and its atmosphere is sun. The incoming solar energy serves as the basis for transforming energy into heat. The distribution of heat varies significantly from equator to poles; from low altitudes to higher altitudes and from shallow to greater depths; and in land and oceans. Motions such as winds, currents, waves and processes such as conduction, convection and advection serve as the basis for the redistribution of heat in different parts of the earth surface. The absorption of heat by different surfaces gets modified under the influence of reflection, refraction and re-radiation. Heat balance is an extremely important factor in maintaining a fairly stable temperature on the earth surface. Global heat budget is the balance between incoming and outgoing solar radiation. Incoming solar energy varies at different times of year and for different locations across the globe. Insolation is the solar radiation received at the earth surface or in its atmosphere.

The maximum solar radiation is received in the tropics and the lowest around the poles and their surroundings. Heat is always transferred from high heat concentration to the lower one. In another words, the cold is also transferred from high cold concentrated areas to low heat concentration. Therefore, the transport of energy is from the high concentration zone to low concentration zone. In this way, a sort of balance of heat is maintained by transfer particularly through winds and ocean currents.

Major gases in the composition of the atmosphere are nitrogen and oxygen accounting for nearly 99 percent share of the total. These gases are transparent to both incoming as well as outgoing radiation. As against this, gases such as carbon dioxide, methane, water vapor and other trace gases are opaque to several wave lengths of thermal radiation. Temperature rises when molecules of greenhouse gas absorb thermal infrared energy. The net result is increase in heat. Since greenhouse gas molecules radiate infrared energy in all directions, some of it spreads downward also and ultimately returns to earth's surface, where it is absorbed. The earth's surface temperature is higher than it would have been only by direct solar heating. The additional heating is due to the effect of greenhouse conditions. Therefore, greenhouse effect of the atmosphere is required for different life forms on earth but 'enhanced' greenhouse effect due to anthropogenic activities is a challenge.

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Unit 6: Ocean- Atmosphere Interaction

Unit Structure

6.0 Learning Objectives

After completion of this unit you will be able to:

- identify the forces responsible for ocean - atmosphere interaction,
- analyze the operational aspects of these forces,
- discuss different atmospheric cells operating in different parts of the world,
- describe different type of motions in oceanic waters,
- explain the causes of shifting of wind and pressure belts,
- analyze the role of moist and dry winds in ocean-atmosphere interaction, and

- describe the role of warming and cooling of oceanic water.

6.1 Introduction

The major driving force of ocean - atmosphere interaction is solar heating. It is greatest near equator and keeps on declining towards poles. Ocean - atmospheric circulation transports energy from higher received region to lower. The resultant is the declining temperature gradient from equator to poles. Ocean and atmosphere are in constant exchange of heat, water and momentum. The interaction of the ocean and atmosphere adds rhythms in the structure of the world climates. This is the result of buoyancy of warm air rising from the equator to troposphere. As it is pushed upwards by air rising from below, cooling begins at high altitude. The sinking of air near subtropics and equator ward return near the surface completes the cycle. The oceanic interaction transports moisture in the atmosphere in the form of water vapor. Cold currents originating in the poles flow towards equator while warm currents originating in equator flow towards poles. Thus, currents play a vital role in transporting heat and moisture. Condensation of water vapor results in the cloud formation that takes place in the atmosphere. Precipitation and its distribution over the world is the result of ocean atmosphere interaction. Meteorologists have developed models to explain the complex interaction.

Solar radiation is the ultimate driving force for all motions in the ocean and atmosphere and gives rise to the pronounced and regular diurnal and seasonal cycles throughout the world. Climate not only displays repeating and regular cycles of solar radiation, but also displays variability that is not correlated with solar radiation. An attempt has been made to study the ocean and atmosphere interaction and its resultant outcomes.

6.2 Forces Responsible for Ocean - Atmosphere Interaction

The motions of the earth with reference to sun are responsible for the generation of energy and its distribution in different parts of the earth. Earth's rotation results in causing day and night. The variation in the length of day results in the receipt of solar energy, its absorption and transmission. 5 Earth's revolution results in causing the seasons and developing situations for the promotion of life forms. Solar energy, the basis of interaction within and among different spheres of the earth, i.e., hydrosphere, lithosphere atmosphere and biosphere, is constantly transmitted to the earth in differential proportions. Tropics receive proportionately higher quantity of solar energy compared to temperate and polar areas. The transfer of energy takes place through radiation, convection and conduction. The transmission of solar energy is received variously by different surfaces in varying quantities depending upon the angle of incidence and absorption characteristics.

The absorbed energy is emitted to atmosphere and space from land, oceanic and biospheric surfaces through the processes of air circulation, reflection, evaporation, evapotranspiration and sublimation. In its return from atmosphere, energy is transferred through condensation, precipitation and descending air circulation.

6.3 Processes and Factors Responsible for Ocean-Atmosphere Interaction

There are several processes such as radiation, conduction and convection that are responsible for the transfer of energy from source. Similarly, energy transferred is subjected to several other processes that interfere and modify the impacts. In terms of factors such as wind, waves, currents and air are responsible for interaction between ocean and atmosphere. Salt from oceans and superfine dust and sand particles from land masses are ejected to the atmosphere by winds and waves. The medium of transfer of energy takes place though various processes.

Medium of Interaction: The energy received from the sun is in a systematic circulatory pattern. It is from sun to earthsurface (land and water), from land and oceanic surfaces to atmosphere and return flow from atmosphere to land and oceanic surfaces. The cycle of interaction is augmented by processes such as radiation, conduction and convection. The energy so transferred is subjected to modification by the processes such as reflection, refraction and re-radiation. While basis of energy transfer from sun to earth is radiation. In the course of transfer of energy, various surfaces such as atmosphere, land and oceanic areas behave differently. As such, role of reflection, refraction and re-radiation becomes significant in modifying the reception of energy at various surfaces. Air, winds and salt aerosols are the interacting agents in a different ways.

6.3.1 Air

The air and the ocean are continuously exchanging heat. As the ocean has a higher heat capacity, it takes longer to adjust to changes in incoming radiation, and therefore, tends to change the temperature slower. This means that the surface of the sea is usually a different temperature to the air immediately above it, and heat is transferred between ocean and the atmosphere.

6.3.2 Winds

The movement of wind from ocean to land is an important factor in transferring the moisture towards land areas. There is a marked difference between the response of a large land mass and oceanic surface to heat received from the sun. During summer, the wind over continents 6 is much warmer and less dense compared to the oceans. Most of the solar energy received at the ground by the continents is confined to a thin layer of the earth. More and more solar energy received on the land surface is used in heating the nearby air parcel. On the other hand, solar energy is able to penetrate much greater depths of the oceans because of the stirring. It is mostly operational under the action of winds. Consequently, a smaller part of the solar heat is available for heating the air. Apart from that, more and more evaporation is taking place from the ocean surface with which, a good amount of energy is carried away in the form of latent heat. The overall result is that the rise in temperature during summer is much less over the oceans than over the continents.

Evapotranspiration is taking place by plants and animals by which moisture is expelled to the atmosphere. Large quantity of moisture is, thus, transferred to atmosphere through the processes of both evaporation and evapotranspiration. Because of intense insolation in tropics, convection currents are formed transferring moisture from oceanic surfaces to atmosphere. During the course of upward transfer, air expands and pressure decreases. At this stage of air ascend, not only air pressure decreases but temperature also falls down resulting in the gradual process of cooling. Consequently, relative humidity increases leading to saturation. Condensation occurs in the form of cloud formation culminating in precipitation, expressed as snowfall in higher altitudes and latitudes and rainfall in lower altitudes and tropical and temperate regions. These facts have been demonstrated in Figure 1.

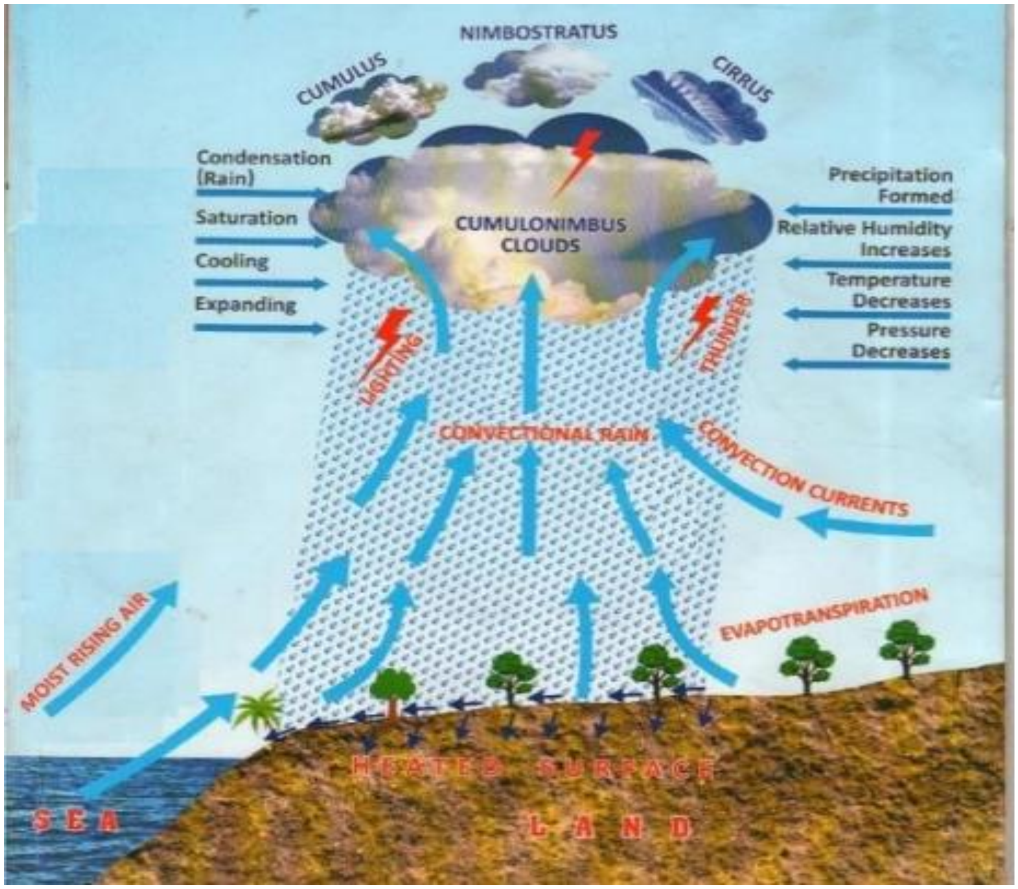

Figure 1: Process of Heating and its Resultants
Source: Goh Cheng Leong (2014), p.108.

6.3.3 Salt Aerosols

Meteorologists are of the opinion that very large quantities of salt particles in the form of aerosols are injected into the atmosphere by the breaking of sea waves. When waves strike the coastal regions of a large land mass, they release a large volume of spray. Millions of minute salt particles are injected into the free atmosphere in this manner, and they act as a store house of nuclei for condensation. Salt is continuously brought into the oceans by the rivers by draining off the continents. They carry minerals by dissolving from the rocks they run over, and deposit the same in the ocean floor. Water evaporating or freezing at the ocean's surface leaves the remaining water saltier, but rain, which is not salty, dilutes the salt concentration of the ocean.

6.4 Feedback mechanisms

There are many feedback mechanisms between the oceans and the atmospheres. For example evaporating water can condense in the atmosphere to form clouds. These reflect both incoming and outgoing radiation. It is because of this mechanism that cloudy nights are

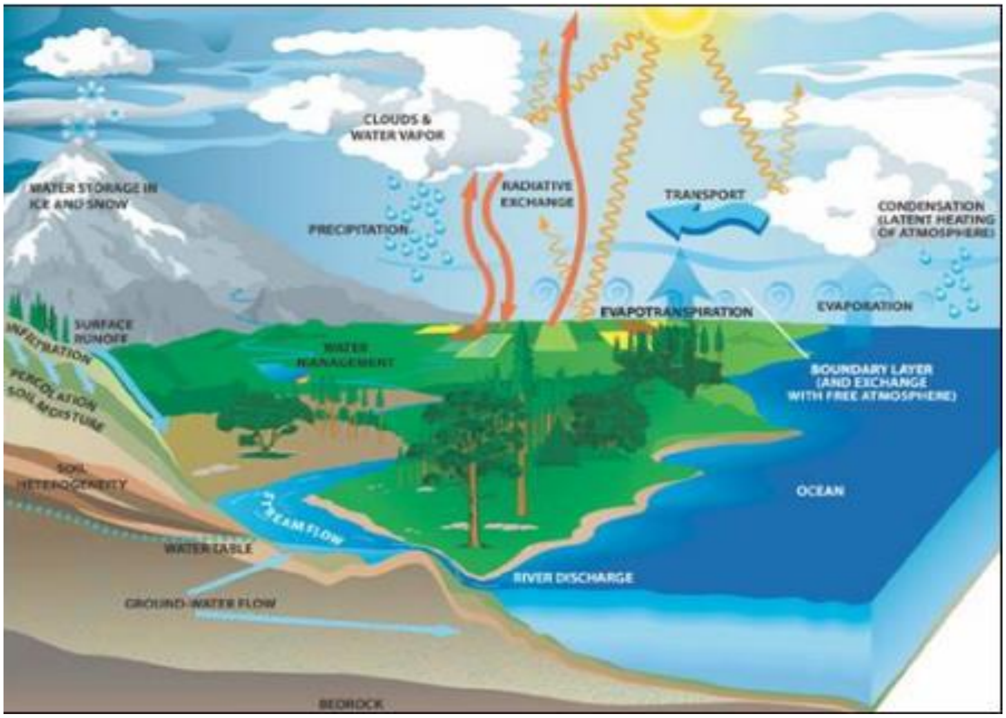

Figure 2: Processes of Exchange and Storage of Heat and Moisture
Source: https://smd-prod.s3.amazonaws.com/science-red/s3fs-public/mnt/medialibrary/2010/03/31/water_cycle.jpg

warmer than clear ones. The system, thus determines the temperature of the ocean surface. Surface air and air aloft are in opposite motion and thus, form a circle. It helps in transferring heat and other objects to upper surface. For example moisture from oceans helps in cloud formation and precipitation. Air and water masses behave in accordance to solar energy transmitted to the surface. Such a system is well developed in tropics and gets gradually less pronounced. The most famous among such climate variations is the atmosphere's Southern Oscillation (Walker, 1924) and its oceanic counterpart El Niño.

6.4.1 Walker Circulation

The interaction between oceanic water and atmospheric winds are closely related. Sir Gilbert Walker was the Head of the Indian Meteorological Service (1904-21). Based on observations and experiments during the course of his assignment, Sir Gilbert Walker has developed a conceptual model of air circulation in the tropics in lower atmosphere (troposphere). According to this model, parcels of air follow a closed circulation in the zonal and vertical directions. Walker 9 circulation is also known as 'Walker cell'. It is the result of a difference in surface air pressure and temperature over Western and Eastern Pacific Ocean. A pressure gradient from east to west causes surface air to form high pressure in Eastern Pacific to low pressure in Western Pacific (Figure 3). A line differentiating cold water layer with warm water layer is known as thermocline. The rising branch of Pacific Cell of the Walker Circulation follows on as this warm pool moves east.

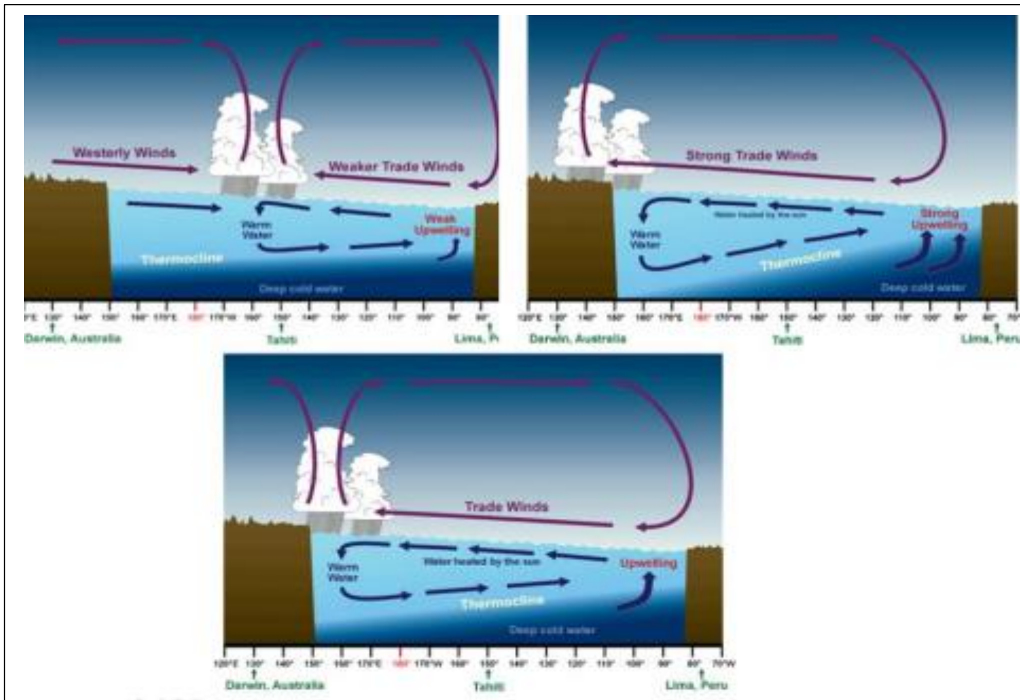

Figure 3: Change in Thermocline Level and Trade Winds
Source: http://www.weather.gov.sg/wp-content/uploads/2015/03/climate2.png

Sir Walker discovered a significant relation between monsoon rain over Indian peninsula and South American pressure in April – May. He opined that overall effect of energy received from the sun was to set up impulses or natural oscillation in the atmosphere. The normal Walker circulation is represented diagrammatically in Figure 4. Accordingly Eastern Pacific

Ocean remains cooler with high air pressure. The surface winds blow in east-west direction while winds aloft move in west-east direction, thus, completing the circulation cycle. On the contrary, Western Pacific Ocean becomes cool and the air over this area is denser. A high pressure is created in the Western Pacific Ocean. At the same time the Eastern Pacific becomes warmer and the air over this area is lighter and hence a low pressure is the result. Thus, the winds are in west toeast on the 10 surface and east to west in the upper air motion. Such a situation is known as El Nino which is responsible for a weak summer monsoon in northern hemisphere. It is very clearly represented in Figure 4.

6.4.2 Atmospheric cells in Ocean-Atmosphere Interaction

Because of rotation and differential heating of the surface of the earth, air motion takes the form of cells. The air motion of the cells on the ground is opposed to the air motion aloft as it completes the cycle. The operating cells from equator to poles are three. A brief account of these cell and there role in ocean atmosphere interaction is explained below briefly.

6.4.3 Hadley Cell

It is named after George Hadley (1735). There is one primary circulation cell known as Hadley Cell (Figure 5) and two secondary circulation cells at higher latitudes, known as Ferrel Cell, and Polar Cell, respectively (Figure 6). Hadley suggested that the distribution of solar heating would lead to rising motion in the equatorial regions and sinking motion near the poles. To compensate for the upper flow from the equator to the pole, Hadley envisaged a return flow from pole to the equator at lower latitudes. It can consist from 30 to 40 degrees north and south and is mainly responsible for the weather in the equatorial regions of the world. The Hadley Cell is a tropical atmospheric circulation that features air rising near the equator, flowing pole ward at 10-15 kilometers above the surface, descending in the subtropics and then flowing equator ward near the surface. The circulation creates the trade winds, tropical rain belts and hurricanes, subtropical deserts and the jet streams.

6.4.4 Ferrel Cell

William Ferrel in 1856 has pointed out the effect of earth's rotation, or the Corialis force, on large scale movement of air. Ferrel has pointed out that Hadley's model does not take into

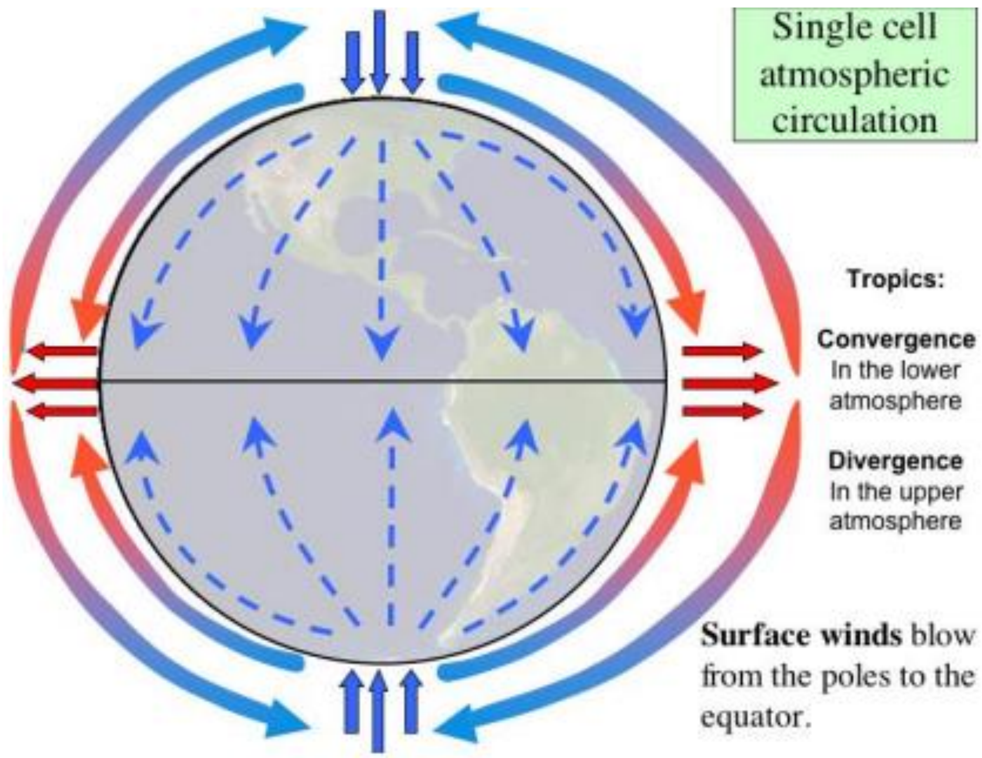

Figure 5: Single Cell Circulation

Source: http://montessorimuddle.org/wp-content/uploads/2011/04/Atm-circ-02.png

Figure 4: Walker Circulation during El Nino and Normal Condition

Source:https://weatherworksinc.com/sites/default/files/Walker%20Circulation%20Schematic.png

account the relative loss of heat from upper layers of the atmosphere. He has explained that towards higher latitudes loss of energy by long wave radiation exceeds incoming radiant energy from the sun. The loss is equivalent to a cooling of the atmosphere by about 1o to 2oC per day. There is then a middle cell between 30o N to 60o N. in which there are westerly winds at the earth's surface and easterly winds aloft. This is known as Ferrel Cell. The location of tropopause in this cell region is about 10 kilometers from the surface.

6.4.5 Polar Cell

Between 600N and the pole, there lies a polar cell. The surface winds in this case are easterly and the upper winds are from a westerly direction. The Polar tropopause is located at about 8 kilometers above the surface. The model is shown schematically below in Figure 5. Thus the effect of heating and convective currents is dominant in tropics while cooling and subsiding currents dominate towards polar areas. Ferrel cell is significant as it balances the two opposite systems of air circulation.

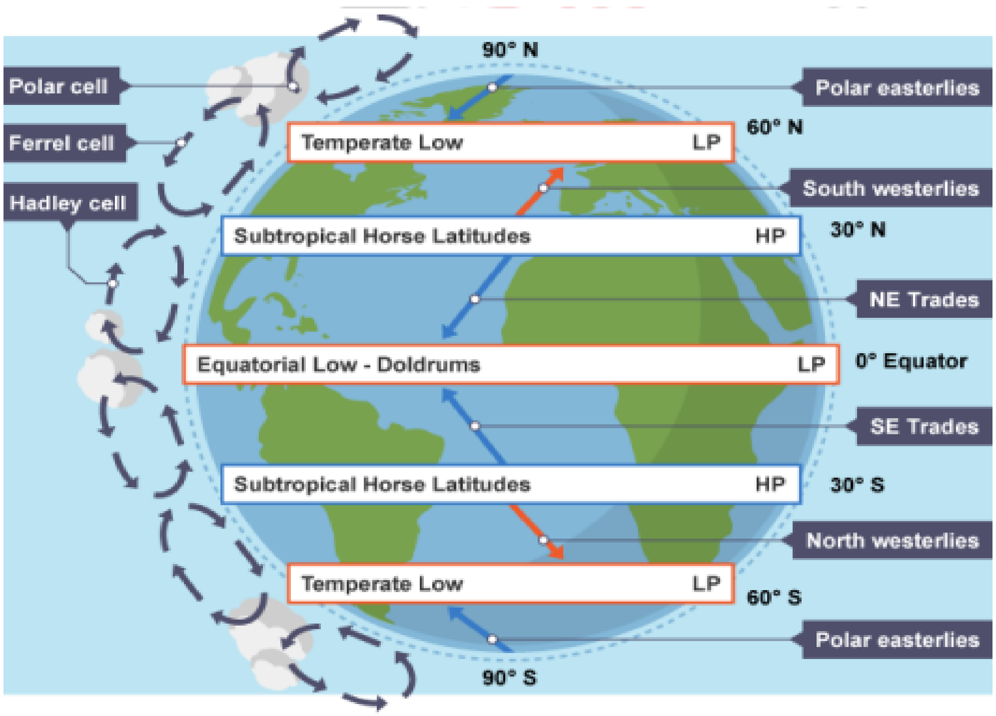

Figure 6: Atmospheric Cells and their Interactions with Oceans
Source: https://bam.files.bbci.co.uk/bam/live/content/zyb2n39/large

6.5 Jet Streams in Ocean Atmospheric Interaction

These are narrow meandering upper air high speed winds. They play a decisive role in accelerating the dynamic situations that are conducive to transfer of energy and moisture to the atmosphere. A brief account of polar and subtropical jet is explained below:

6.5.1 Polar jet

The jet stream operating in polar areas modify the weather conditions significantly because of lower altitude and velocity (130 km/hour). During spring and summer season polar jets transfer energy to atmosphere effectively (Figure 7).

6.5.2 Subtropical jet

Popularly known as westerly jet operate in subtropical and temperate regions. The normal speed of subtropical jet ranges between 160 to 190 km/hour. It significantly improves the weather condition during winter and spring seasons in the region. The shift of subtropical jet results in improving the prospects of monsoon in tropics.

6.5.3 Easterly jet

These winds operate in tropical zones at a speed of 190 to 220 km/hour. Easterly - jet operate over a relatively higher altitude and also cover a larger areal extent as compared to

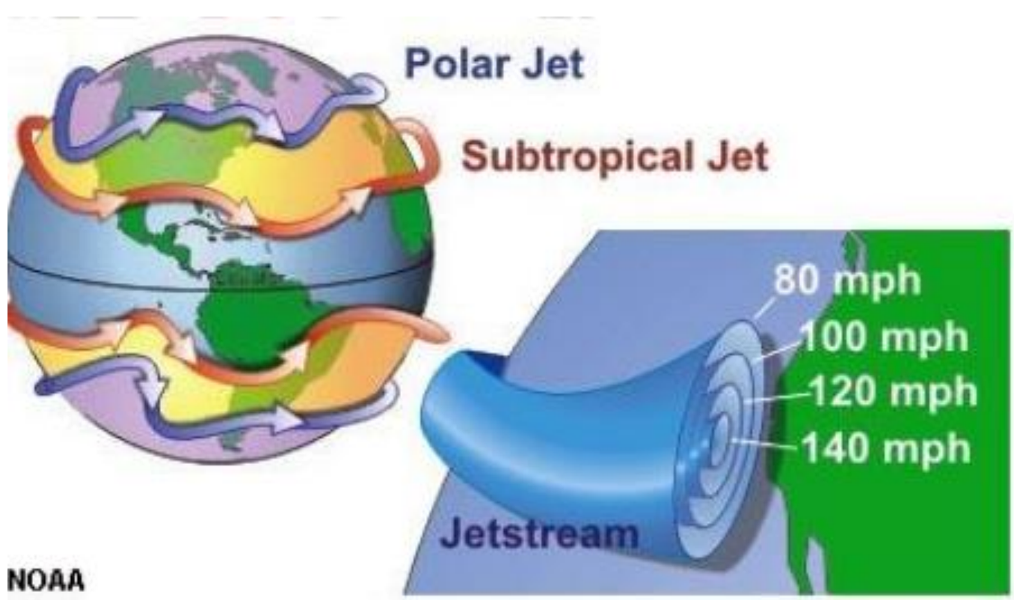

Figure 7: Jet Streams and Ocean - Atmosphere Interaction
Source: http://gotbooks.miracosta.edu/oceans/images/jet_streams.jpg

subtropical and polar jets. They are significant in causing descend of easterly winds near subtropics during winter and south westerly monsoon winds near ITCZ during summer. As a consequence high pressure conditions develop in oceanic zones in tropics. It results and in improving the status of south west monsoon.

6.5.4 Rossby Waves

C.G. Rossby (1939), a Swedish meteorologist, suggested that upper easterly winds in the middle cell are wiped out by frictional drag exerted by upper westerly winds to the north and south of the middle cell. There are many problems in the general circulation of atmosphere whose answers are not yet known. Rossby waves are also known as planetary waves. They are caused by the earth's rotation as a natural phenomenon in atmosphere and oceans. Rossby waves are the subset of inertial waves. On the earth, these waves are giant meanders in the high altitude winds that exercise major influence on the weather. Rossby waves are associated with pressure systems and jet streams. Oceanic Rossby waves move

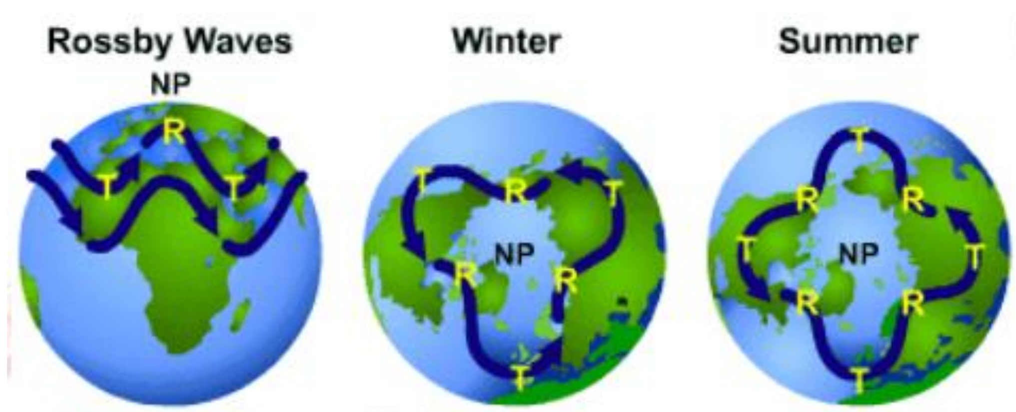

Figure 8: Rossby Waves in Normal, Winter and Summer Situations.
Source: http://www.s-cool.co.uk/gifs/a-geo-weacli-dia14.gif

along a thermocline. The conditions vary significantly from summer to winter season particularly in tropics. An example of temperature conditions in Indian Ocean and resultant flow of oceanic currents during summer and winter season is demonstrated through maps (Figure 8).

6.6 Ocean Waves and Currents

Oscillating waves continuously transfer moisture and salt particle to the atmosphere. Similarly, ocean currents transfer water, heat, and large quantities of marine biological products from equator to poles and poles to equator. In the process ocean - atmosphere maintain balance in the exchange of heat, energy and moisture. For example ocean currents in Indian Ocean flow from west to east during summer strengthening south - west summer monsoon (Figure 9). Thus, prospects of rain increase significantly during summer.

On the contrary ocean currents, in Indian Ocean, flow from east to west during winter season. Ocean currents in eastern coast of India coincide with the direction of north - east trade winds. As a consequence, Tamil Nadu region and its vicinity records (Figure 10) sufficient rainduring winter season while it remains dry during summer season.

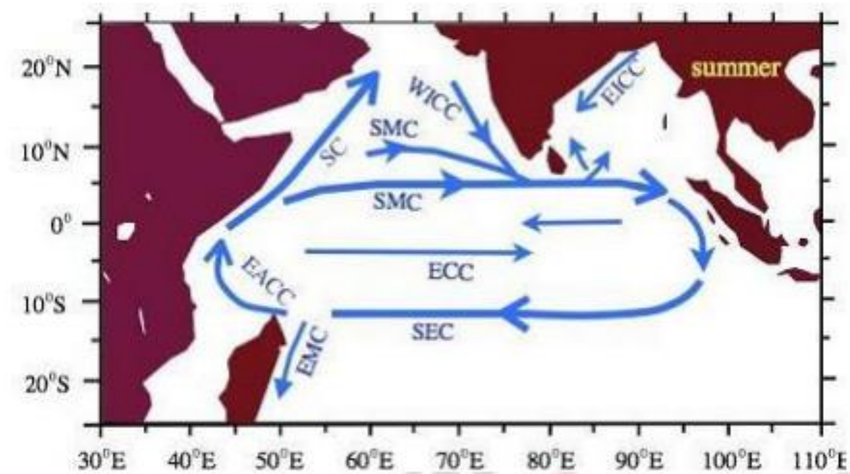

Figure 9: Indian Ocean Currents during summer andthesummer Monsoon

Source: http://www.nptel.ac.in/courses/119102007/basic%20meteorology%20and%20oceanography/images/fig33.1.JPG

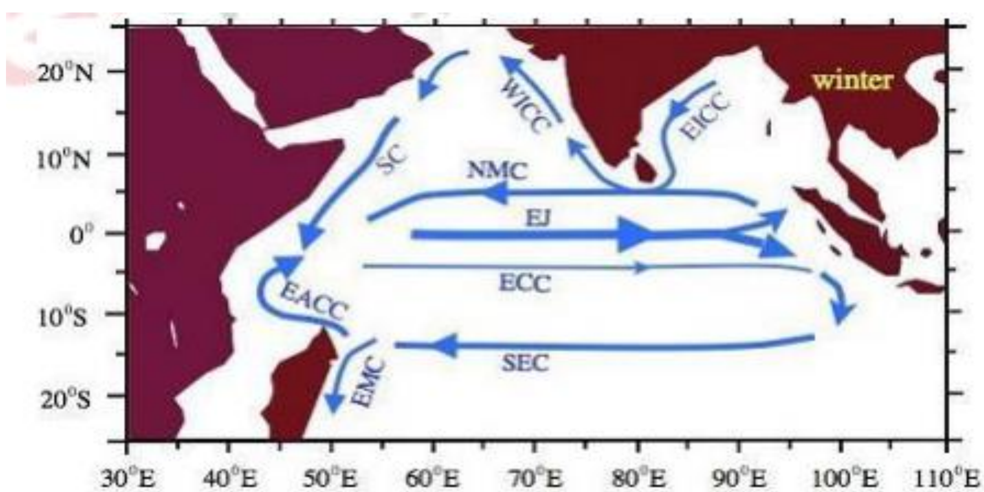

Figure 10: Indian Ocean Currents during winter and prospects for winter monsoon

Source:http://www.nptel.ac.in/courses/119102007/basic%20meteorology%20and%20oceanography/images/fig33.jpg

6.6.1 Land and Sea Breezes

These are location specific breeze systems. They blow from sea to land during day time as land area gets heated quickly due to solar radiation and develops low air pressure. Sea surface, on the contrary, records high air pressure during day time because of its slow heating process. As a consequence, winds blow from sea to land and are known as 'sea breeze'.During night, land area loss heat quickly and develop a high air pressure whereas sea surfaces remain comparatively warmer and, thus, develop a low air pressure (Figure 11). As a consequence, winds blow from land to sea during night and are known as 'land breeze'.

Figure 11: Land and Sea Breeze in a natural setting of Day and Night
Source: http://media1.britannica.com/eb-media/69/62669-004-5211C2BA.gif

6.6.2 El Nino Phases

Ocean atmosphere interaction is studied in terms of occurrence of El Nino and Southern Oscillation. The two concepts have been put together to be known as ENSO. There are 17 two basic concepts related to ENSO phenomenon. These are: sea surface temperature (SST)and sea level pressure (SLP).The term El Niño refers to the extended episodes of anomalous warming of the ocean off the coast of Peru. The term Southern Oscillation refers to a sea level pressure (SLP) swing between Darwin, Australia and the island of Tahiti in the central tropical Pacific (Figure 12). Bjerknes (1969) recognized that El Niño and the Southern Oscillation (ENSO) are in fact just two different aspects of the same phenomenon, and demonstrated a remarkable correlation between Darwin atmospheric pressure and water temperature off the coast of Peru, two locations separated by the vast span of the Pacific Ocean.

Thus, ocean–atmosphere interaction is at the heart of the ENSO phenomenon. An initial change in the ocean could affect the atmosphere in such a manner that the altered atmospheric conditions, would in turn, induce oceanic changes that reinforce the initial change. The atmosphere will respond by reducing the east–west gradient of SLP, and consequently relaxing the strength of the easterly trade winds. The relaxation of the easterly winds in turn, causes an eastward surge of warm water along the equator, positively reinforcing the initial warm SST anomalies. The positive ocean–atmosphere feedback amplifies small initial perturbations into large observable amplitudes.

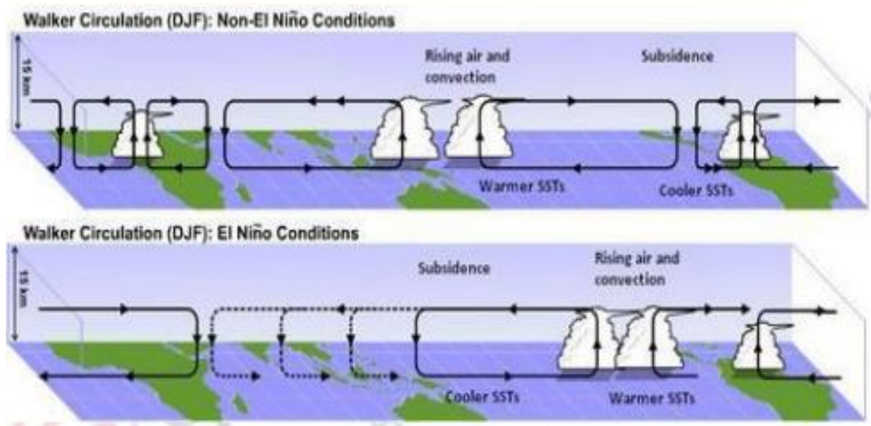

Figure 12: Sea surface temperature and sea level pressure during non-El Nino and El Nino conditions

Source: http://forum.arctic-sea-ice.net/index.php?topic=730.100

Considering the wide spread adverse impacts of El Nino, ten year (1985-94) international program known as Tropical Ocean and Global Atmosphere (TOGA) was launched to study the feasibility of modeling the coupled ocean-atmosphere system for predicting variations on time scales of months to years. The program has advanced the understanding, simulation, and prediction of coupled system. To improve further the prediction system, Equatorial Pacific Ocean 18 Climate Studies (EPOCS),Tropical Atmosphere Ocean(TAO), and TRITON were launched for the assessment of real- time thermal structure, currents and surface meteorology of the tropical Pacific.

The satellite based observations have played an important role in understanding air-sea interaction and climate research particularly in outgoing long wave radiation and SST. Space-borne microwave sensors have enabled all-weather observations of SST, rainfall, surface wind and sea surface height over the global ocean. With such a data base, there has been rapid progress in understanding and simulating the climate and its variations. Bjerknes, Manabe and Bryan were the first to work on ocean-atmosphere general circulation model. Since then, coupled oceanatmosphere models are being used to work out interaction for ocean atmosphere circulation

6.6.3 El Nino and Monsoon

The term El Niño refers to the extendedepisodes of anomalous warming of the ocean off the coast of Peru. On specific years when the sea surface temperatures (SSTs) in the equatorial eastern Pacific are anomalously warm, the east–west gradient in SST will be reduced. It results in the weakening of monsoon.

The effect of El Nino on summer monsoon is significant. El Nino is a warm Ocean current appearing along the coast of Peru. The appearance of El Nino reverts the condition of Peru current by developing warm water and moist air conditions over Eastern Pacific (Peru coast) and cold conditions in western Pacific (Eastern Australia and Indonesia). As a result, eastern

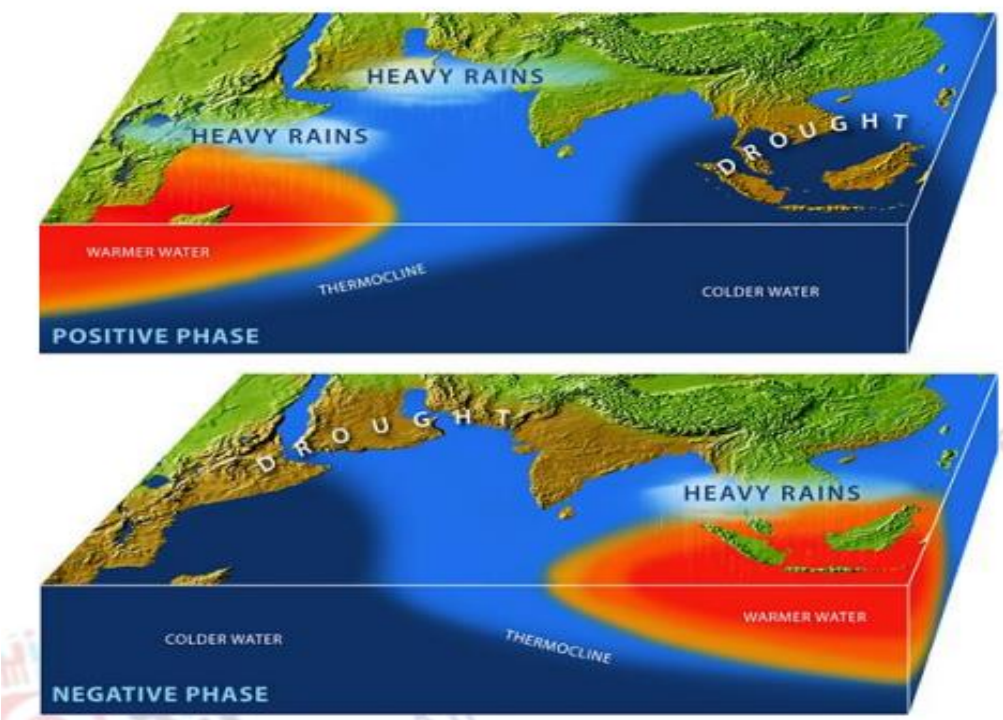

Figure 13: Impact of Positive and Negative Phases of El Nino on Summer Monsoon

Source: http://images.indianexpress.com/2015/03/iod.jpg

Pacific along Peruvian coast in South America records high rainfall while western Pacific along Australian and Indonesian coast record drought conditions. El Nino results in weakening of the monsoon causing drought conditions and crop failures in Monsoon regions of South and South East Asia. When western Indian Ocean records low air pressure during winter and high air pressure during summer, it is said to be the positive phase of summer monsoon and sea surface conditions are normal. Heavy rains are caused in Indian subcontinent and neighboring regions during normal phase (Figure 13).

6.6.4 La Nina and Monsoon

La Nina the word originates from Spanish meaning little girl. It is characterized by unusually cold ocean temperatures in equatorial Pacific. During the period of La Nina, sea surface temperature across equatorial eastern-central Pacific Ocean becomes lower than normal by 30 to 50 C. It has extensive effect on the weather in North America, even affecting Atlantic hurricane. La Nina causes heavy rains over Malaysia and Philippines and Indonesia. Western side of the equatorial Pacific is characterized by warm,

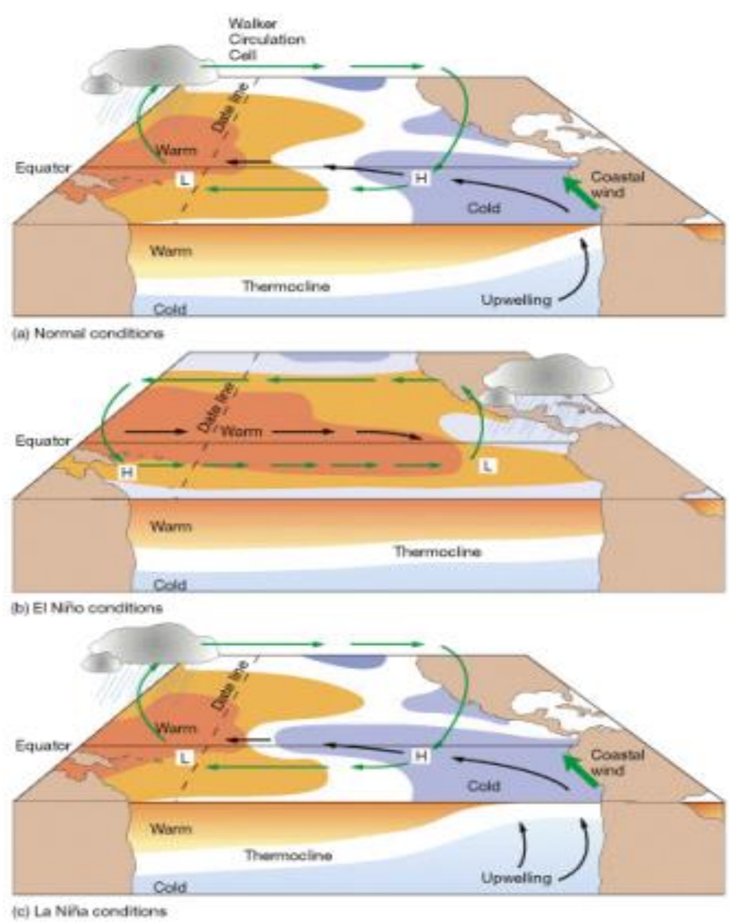

Figure 14: The Phases of Normal, El Nino and La Nina Conditions

Source: http://wps.prenhall.com/wps/media/objects/374/382993/Fg07_18.gif wet low pressure weather as the collected moisture is dumped in the form of typhoons and thunderstorms. As a result of this motion, the surface water of western Pacific Coast is some 60 centimeters higher as compared to eastern Pacific Coast. The water and air returns to the east. Both of them are now much cooler and the air in the surface much drier.

6.7 Southern Oscillations Phases

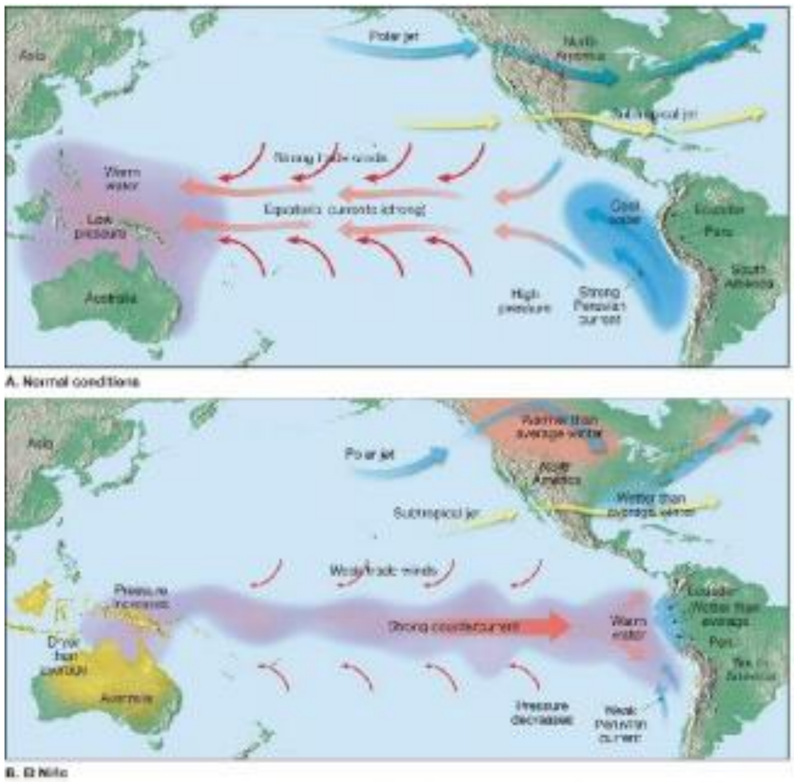

Figure 15: Southern Oscillation - Normal and El Nino conditions
Source: http://www.fccj.us/vocabulary/Tarbuck/Chapter18/ElNino40.jpg

Southern oscillation is linked to low frequency temporal fluctuations in sea surface temperature in the equatorial Pacific Ocean. It is one of a number of manifestations of atmospheric fluctuations associated with alternating episodes of warm and cool sea surface temperature in the equatorial 21 Pacific Ocean. Its impacts are also experienced in Indian Ocean where it influences the mechanism of monsoon. If air pressure along equatorial Pacific Ocean is higher than the air pressure in Indian Ocean during winter it is said to be a ‘Positive Southern Oscillation’ indicating a favorable summer monsoon. Whenair pressure during winter is higher in Indian Ocean and lower in Pacific Ocean, it is known as ‘Negative Southern Oscillation’. Such a situation results in the weakening of summer monsoon. The intensity of southern oscillations is worked out by the difference in sea level air pressures at Tahiti (180 South and 1490 west), a station in mid Pacific and port Darwin (120 South 1300 East), a representative station of Indian ocean. A negative value of 'Southern Oscillation Index' (SOI) implies low pressure over Peru coast and high pressure over Indian Ocean during winter season explaining a poor monsoon phase. There seems to be a close correlation between the appearance of El Nino and the negative SOI. The two adverse parameters (negative SOI and El Nino) are the cause of a weak monsoon phase. Together these parameters are known as ENSO event. Southern Oscillations has a period ranging between 2 to 7 years.

6.7.1 Positive Southern Oscillation:

It has been established that when sea level surface pressure (SLP) is high over the Pacific, air pressure over Indian Ocean tends to be low. Since surface air pressure over oceans during dry winter season is inversely related to summer rainfall; prevalence of low air pressure over Indian Ocean during winter season is considered to be a sign of 'positive southern oscillations'. The chances of favorable monsoon are generally linked with 'positive southern oscillations'.

6.7.2 Negative Southern Oscillation

The prevalence of high sea level air pressure (SLP) over Indian Ocean and low air pressure over Pacific Ocean during winter denotes the 'negative southern oscillations'. It has been established that negative southern oscillation index (SOI) is linked with a weak monsoon phase (Figure 15).

6.8 Seasonal Cycle

Solar radiation is dominated by an annual cycle with a spatial structure that is roughly antisymmetric near the equator. In response, the seasons in the northern hemisphere are opposite to those in the southern hemisphere. Over the oceans in the northern hemisphere, the seasonal maximum in SST generally takes place in September and March. Such a situation occurs after three months from summer and winter solstice.It is mainly due to a lag in large thermal inertia of the upper ocean. This local waxing and waning of solar radiation is a reliable predictor of seasons over most of the world except on the equator. The annual harmonic of solar radiation reaches a minimum near the equator. Thesame time, a pronounced annual cycle in SST is also observed in the eastern Pacific and Atlantic Ocean. The climatological – mean thermocline is shallow on both the locations. For example, the annual range of SST near the Galapagos Islands is about 6o C, greater than most of the tropical oceans. It is to be noted that there is a westward co-propagation of seasonal SST and zonal wind anomalies along the equator in the eastern Pacific. Significant increase from normal temperature in winters explains the occurrence of El Nino.

Conclusions

Solar heating is the basis for ocean - atmosphere interaction. The motions of the earth with reference to sun are responsible for the generation of energy and its distribution in different parts of the earth. Earth's rotation results in causing day and night. The cycle of interaction is augmented by processes such as radiation, conduction and convection. The energy so transferred is subjected to modification by the processes such as reflection, refraction and re-radiation. The variation in the length of day results in differential receipt of solar energy, its absorption and transmission. Earth's revolution results in causing the seasons and developing situations for the promotion of life forms.

The insolation is greatest near equator and keeps on declining towards poles. Ocean - atmospheric circulation transports energy towards poles. The resultant is the declining temperature gradient from equator to poles. Ocean and atmosphere are in constant exchange of heat, water and momentum. The interaction of the ocean and atmosphere adds rhythms in the structure of the world climates.

The discussion ocean–atmosphere interaction has enabled us to unlock the mysteries of ENSO and other climate phenomena, leading to skillful predictions of ENSO, its global impacts and certain aspects of tropical atmospheric variability. The success of TOGA has proved a premise that a better understanding of ocean–atmosphere interaction helps to improve model simulation, along with an adequate observing system that leads eventually to useful climate prediction.

Reference

Adapted from E PG Pathshala, Climatology, Geography- M 15 Ocean-Atmosphere Interaction

Unit 7: Atmospheric Pressure and Winds

Unit Structure

7.0 Learning Objectives

After completion of this unit you will be able to:

- define the air pressure and pressure gradient;
- enumerate the factors affecting atmospheric pressure;
- establish the relationship between air pressure and winds;

- explain the horizontal atmospheric motions;
- discuss the development of different pressure belts;
- describe the development of different atmospheric cells; and
- explain the seasonal variations in pressure belts and winds.

7.1 Introduction

The atmosphere is made up of several gases comprising several layers. The surface of the earth is not alike everywhere. The effectiveness of the solar energy distributed over the surface of the earth is different in different areas. They are caused by several factors. Depending on them, the atmospheric pressure develops in a definite pattern over the globe. The different pressure belts created is the root cause for the development of winds. Planetary pressure belts generate horizontal movement of air known as winds. Winds develop a certain pattern which itself is affected by several factors. Apart from all these, there is wide variations in the seasons all over the globe. Somewhere, it is very distinct while at some places, there is no change in season particularly in the equatorial regions. Therefore, an attempt has been made in this module to study wind belts and their controlling factors. The changes in pressure belts and winds with seasons are also concern of study here.

7.2 Air Pressure and Gravitational Pull

As air has weight, hence atmosphere exerts pressure on Earth. Atmospheric Pressure is the force per unit area exerted by a weight of air above it. The change in pressure measured across a given distance at certain level/ surface is called a "pressure gradient". Atmospheric pressure gradient is marked both horizontally as well as vertically. A very steep vertical pressure gradient is in the troposphere. As we go above, the change in air pressure is very drastic. It is caused by reducing air mass as long as we keep on going up and up (Figure 1). The force of pressure gradient pushes upward while the gravitational pull of the earth brings it down. Both of them are balanced and 4 the atmosphere is retained with the earth. Both of these forces are greater at or near the surface or sea level but at higher altitude, both are very weak.

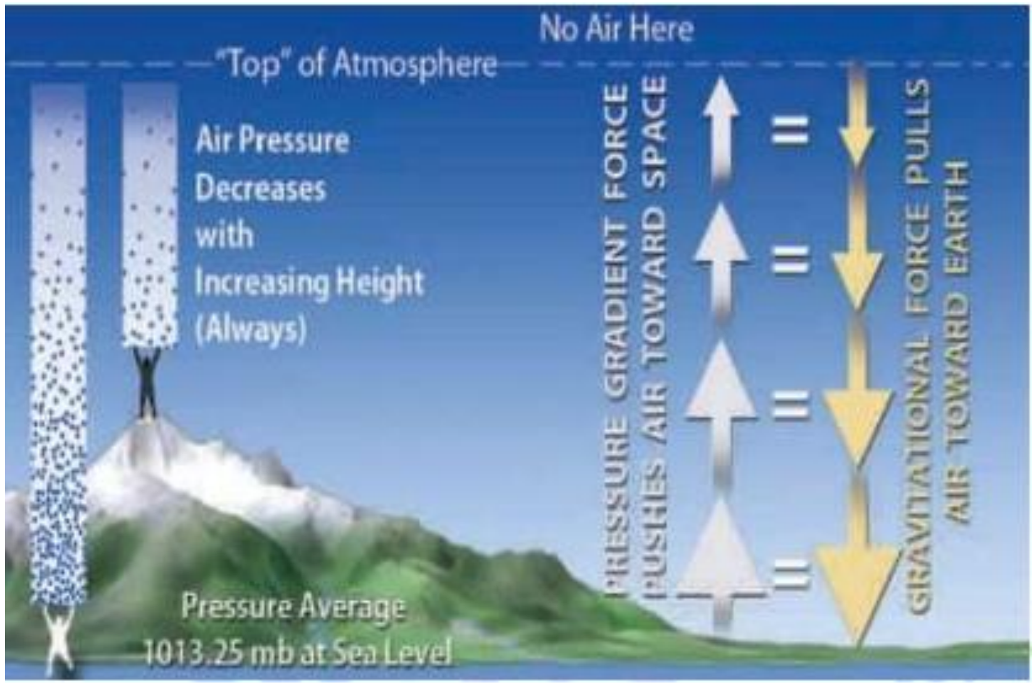

Figure 1: Vertical Air Pressure Gradient

Source: http://highered.mheducation.com/sites/dl/free/0078095166/1030553/Chapter3.pdf

7.3 Factors Affecting Atmospheric Pressure

Atmospheric pressure of any region is affected by following factors:

7.3.1 Temperature

There is a very close relation between temperature of the air and existing pressure. Higher temperature expands the air and hence low pressure is created whereas the lowertemperature contracts the air which occupies less volume and therefore becomes denser and heavier. Due to this high pressure results. So there is an inverse relationship between temperature of the air and its pressure.

7.3.2 Altitude

The lower level of the atmospheric gases are more compressed in comparison to the upper level. Upper layers are resting on the lower and hence exerting more pressure but at the upper level, the air mass laying above them is very less and hence less compressed. Therefore, maximum air pressure is at the lowest level whichgenerally sea level. But with increasing height, it keeps on declining. Figure 2shows the relationship between altitude and air pressure.

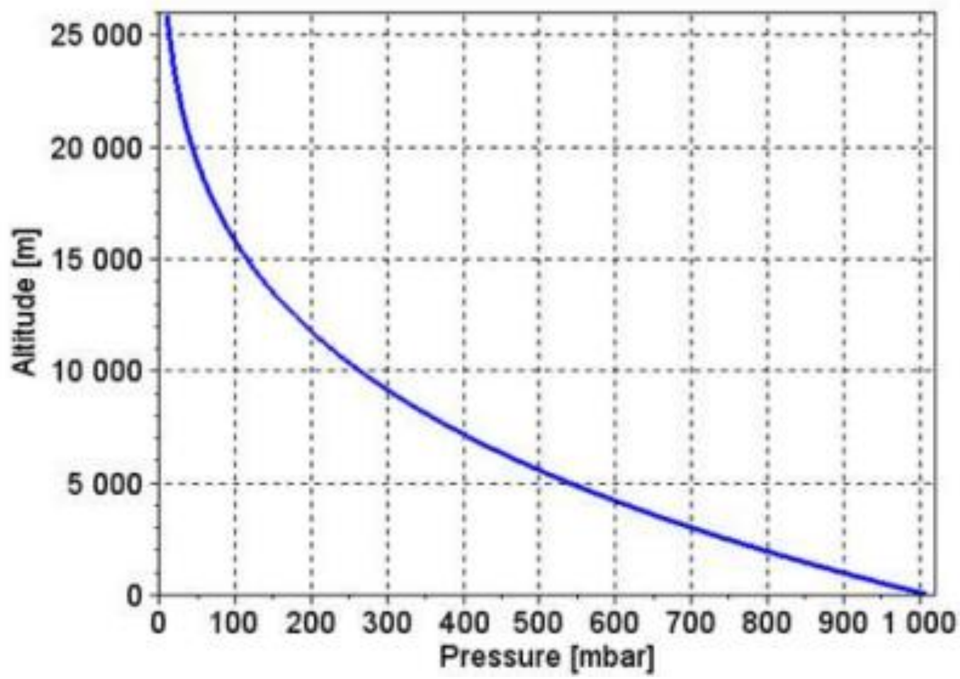

Figure 2: Declining Pressure with Increasing Altitude
Source: http://2.bp.blogspot.com/-cbLIXyVIuyk/VlNilmpTiCI/AAAAAAAABcQ/hJUT5jqVDHA/s1600/altitude-vs-mbar.gif

7.3.3 Water Vapour

The water vapour is lighter than the air. Therefore, addition of water vapour in the air causes the air pressure to decline. The dry air is heavier than the moist air (air with moisture). Increase in vapourleads to decline in the air pressure whereas its lowering lead to increase in pressure.

7.3.4 Gravitational Pull

Due to gravitational pull of the earth, the atmosphere of the earth is intact with it otherwise it would have escaped. Earth's gravity at any particular place is inversely proportional to the square of its distance from its centre. The air near the earth's surface or sea level exerts more pressure than the upper air. Equatorial radius is more than the polar radius, therefore, the atmospheric pressure is more at the pole than at equator at sea level.

7.3.5 Earth's Rotation

Due to the earth's rotation Coriolis Effect is produced which tends to deflect the winds from their original direction. Due to this, the air also develops a tendency of being thrown outwards and spreading outwards.

7.4 Relationship between Atmospheric Pressure and Wind

There is a direct and positive correlation between air pressure and winds. Difference in air pressure creates pressure gradient. The intensity of the pressure gradient is dependent upon the intensity of the pressure difference. If the difference between two places is the same but the distance is different, then the smaller horizontal distance will show a steeper pressure gradient whereas the distant one will be gentler. Hence, it is the pressure difference per unit of distance travelled in a straight direction across isobars. The wind blowing and its velocity is dependent upon the pressure gradient. It is very clearly shown in Figure 3. It is apparent that the atmospheric pressure is represented by isobars on the map. In Figure 3, the isobars are much closer in the north-west direction whereas in south-east direction, they are widely spaced. The boldness of the presented arrows shows the intensity of wind speed. Therefore, the wind blows very fast in the north-west direction from the high pressure but the wind is very gentle in southeast direction.

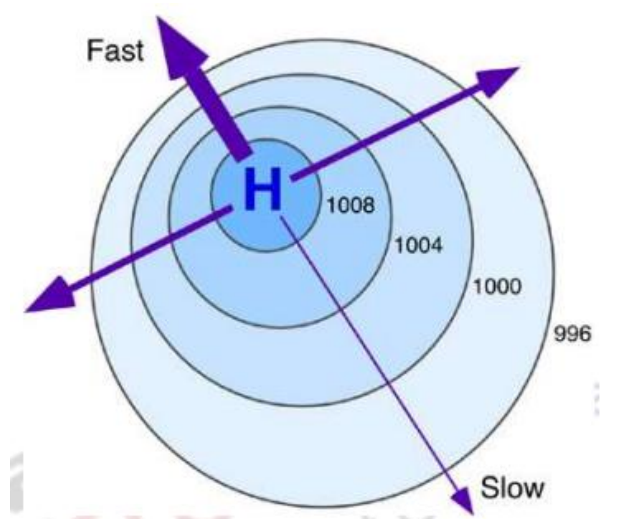

Figure 3: Pressure Gradient and Wind Speed
Source: http://www.physicalgeography.net/fundamentals/images/relativewindspeed.GIF

7.5 Development of Atmospheric Motion

Winds Atmospheric motion is movement of the air. This movement may be horizontal or vertical or both. Generally, the horizontal movement of air is termed as wind. As mentioned above, wind is blowing due to difference in the atmospheric pressure. The atmospheric pressure is also affected primarily by temperature. The temperature of the air is an outcome of the distribution of insolation over the earth's surface. Some of the portions have already been discussed in a preceding module. Let us however discuss a few of them in brief.

7.5.1 Temperature and Air Molecules

Increasing temperature makes the substance more flexible even if it is firm and very hard. You must have seen the blacksmith heating the iron items and changing the shape or altering the same by giving ordinary force. It happens because the atoms of iron get mobility and thus gets softened. In the same way, warm air also expands and different molecules of the air are on change and thus they move wide apart (Figure 4). It is due to this reason, the volume of the air is more when it is heated. Increase in volume with same mass lead to decrease in the density. 7 Decreased density causes the pressure to decrease. Compacted air (high pressure) moves towards the less compacted air (low pressure). Thus, wind starts blowing which is dependent upon the intensity of pressure gradient.

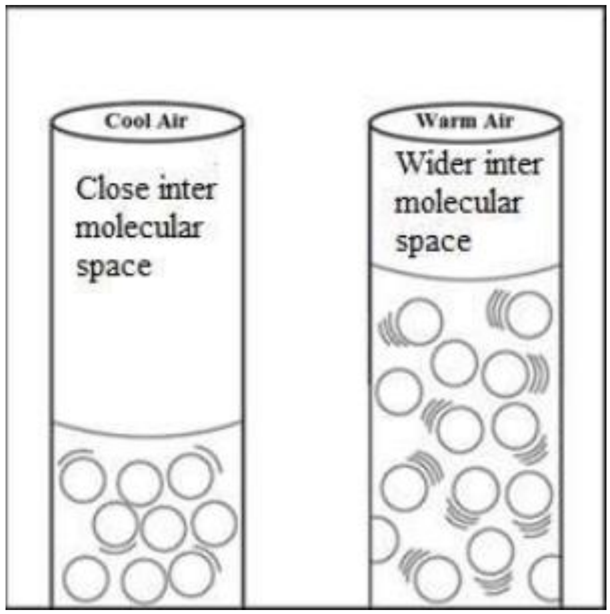

Figure 4: Difference in Air Pressure due to Change in Temperature

7.5.2 Temperature, Air Pressure and Winds

Thus, the change in temperature in the air column is reflected by change in air pressure as well as air movement.

7.5.3 Uniform Temperature in Two Air Columns

Similar temperature of two air columns with similar physical surface are generally comparable in terms of air pressure. In these two air columns, the similarity is not only seen horizontally, but also has vertical uniformity (Figure 5A). With increasing or decreasing altitude, the air pressure is alike in both the columns.

7.5.4 Differential Heating and Change in Pressure

Differential heating of the atmosphere is reflected by changing air pressure. For example, when one column is warmed up due to some reasons (insolation or change in physical characteristics of the surface or some other local reasons), the air in the warmed column will expand. Expansion causes the density to decrease. In the same way, when the other column is cooled, its column is reduced due to compacting effect (Figure 5B). It is causing the density of air to rise. Hence, the vertical distribution of air pressure is altered between these columns.

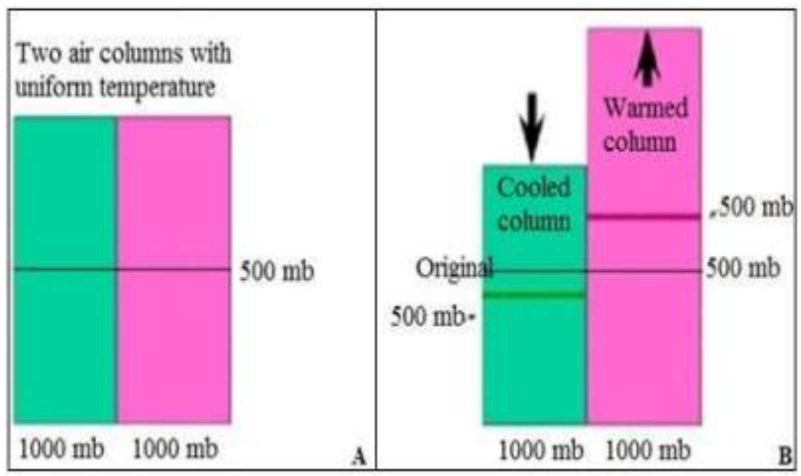

Figure 5: Pressure Change and Wind Blowing (I)

7.5.5 Changing Pressure and Start of Wind

Refer to the Figure 5B. In compressed column, the pressure level (say 500millibar) is lowered (in height) and in expanded column, the same air pressure level (say 500 millibar) is shifted up (Figure 5B and C) in terms of altitude. So in the upper part, pressure gradient develops between these two columns. From expanded column the air moves towards compressed column. Therefore, the pressure in the expanded column is reduced at the lower/ ground level because of shift of the air mass on the top. The shifting of the air over the compressed/ subsided column, the total mass on the cooled column becomes still greater in comparison to the initial one. Therefore, the high pressure develops there and at lower level air blows from the compressed column to expanded column (Figure 5B and 5C).

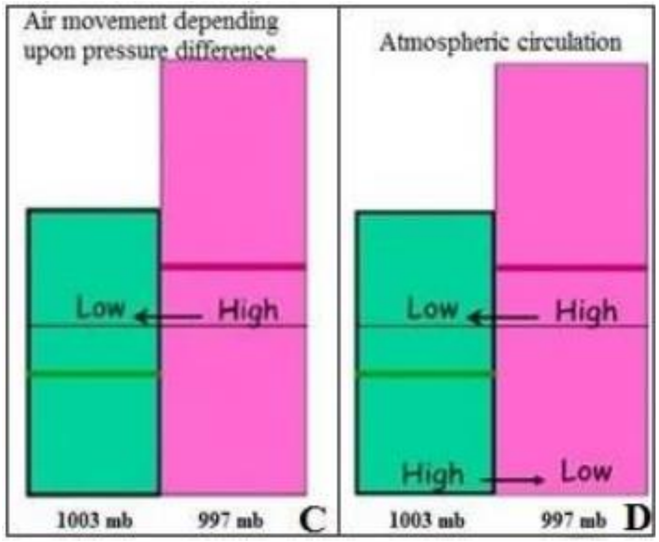

Figure 5: Pressure Change and Wind Blowing (II)

7.6 Vertical Air Mixing with Latitudes

Vertical mixing/ motion of air is the maximum at the equator and the lowest at the poles. It is again due to maximum vertical air rise caused by ITCZ. The troposphere is at the maximum height at equator and lowest at poles (Figure 6). In the tropical region, the tropopause is at a height of about 15 km and it come down to about 5 km near poles. It is all very clear as per the description already made through the illustrations in Figure 6.

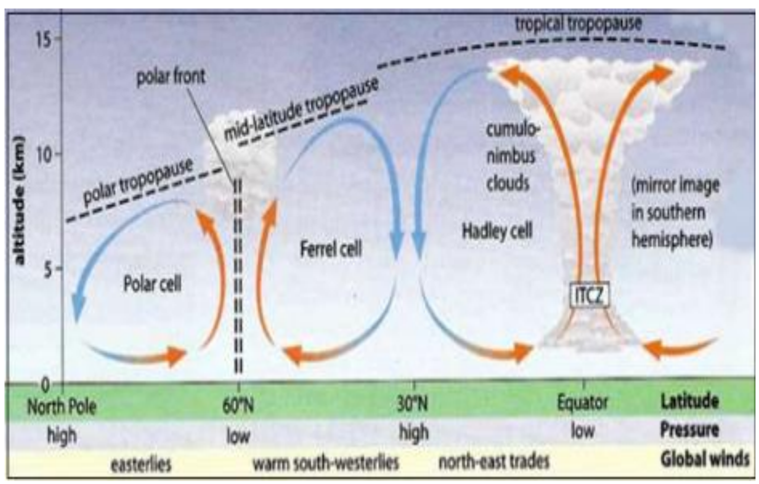

Figure 6: Vertical Air Circulation Cells and Troposphere
Source: http://weatherworkedout.weebly.com/uploads/2/2/3/5/22359606/622339660.gif?1376037245

7.7 Horizontal Atmospheric Motion

Winds As mentioned before as well, the horizontal air movement is affected by several factors and the important among them are:

- Atmospheric Pressure Gradient
- Coriolis Effect
- Frictional Force

7.7.1 Atmospheric Pressure Gradient

Atmospheric pressure is the determining factor for the wind direction and velocity. Direction is determined by the pressure difference (high/ low) and the velocity is guided by the pressure gradient. Basically pressure gradient is the change in the isobaric value per unit of distance travelled in a certain direction (already mentioned before and shown in Figure 3). The force applied by pressure gradient to drive winds is called pressure gradient force. The wind speed is dependent on the pressure gradient.

7.7.2 Coriolis Effect

The earth is spinning on its axis and the atmosphere is existing with the earth. Coriolis force is an invisible force due to which the wind is deflected. The deflection of the wind is perpendicular to the rotation of the earth. Since the earth is rotating on its axis from west to east, the Coriolis force is applicable in east-west direction. This force is zero at equator and 10 keeps on increasing towards poles. The diagrammatic presentation given in Figures 7 and 8 is very clear.

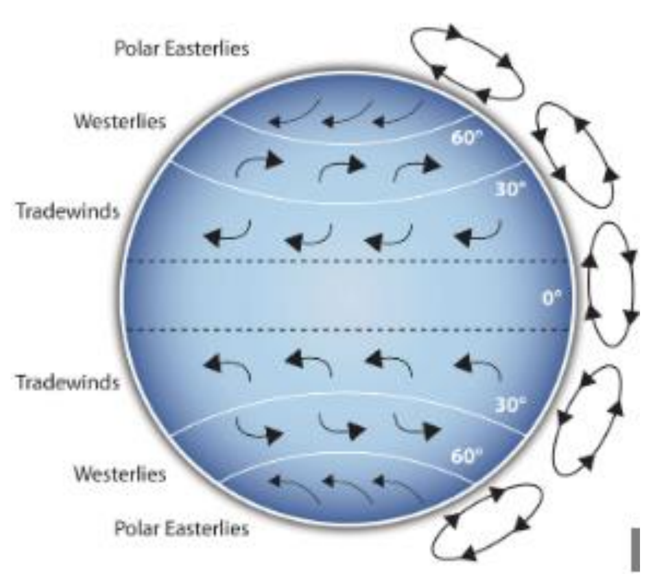

Figure 7: Coriolis Effect on Wind Direction

Any moving body or the wind coming from the north pole will reach to the equator along a meridian when the earth is static (Figure 8Aa). But the same is not the case when the earth is rotating. It is turned to right because the moving object or the wind will take some to reach equator from the pole. By the time it reaches to equator, the position of that longitude will move eastward and the object/ wind will be left behind to the right side to the designated direction (Figure 8Ab). The earth is rotating on its axis and it causes the wind to divert the path to the right in the northern hemisphere (Figure 8BA) and to the left in the southern hemisphere (Figure 8B).

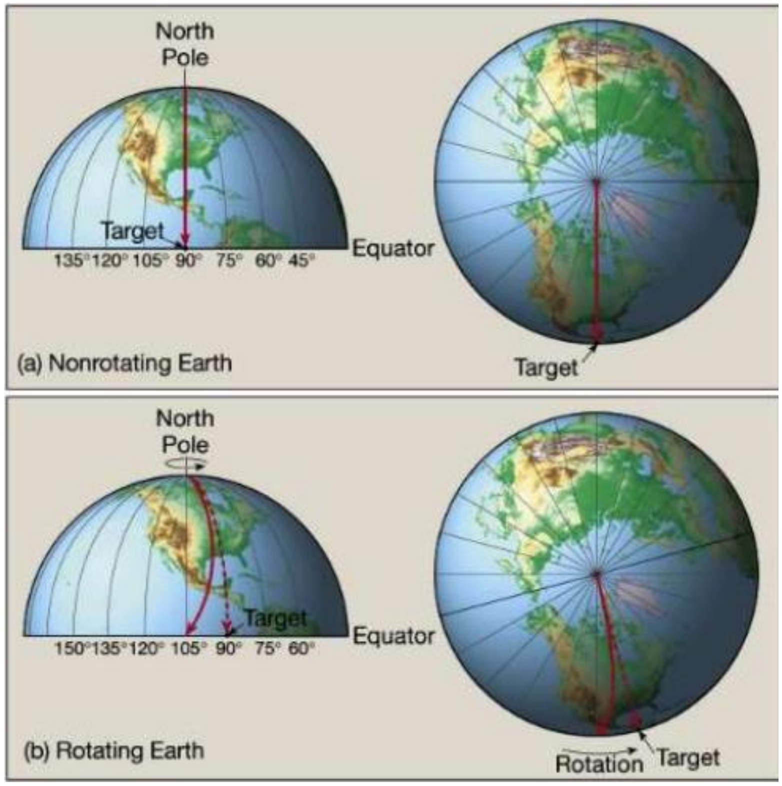

Figure 8A: Coriolis Effect on Wind Direction

Source: http://www.richhoffmanclass.com/images/chapter6/coriolisforce.jpg

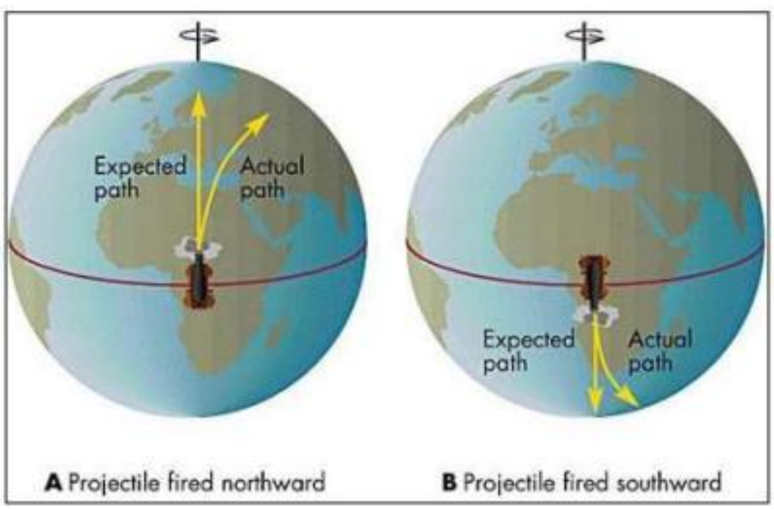

Figure 8B: Coriolis Effect on Wind Direction

Source: https://ibseedintorni.files.wordpress.com/2016/03/coriolis.jpg?w=676

7.7.3 Frictional Force

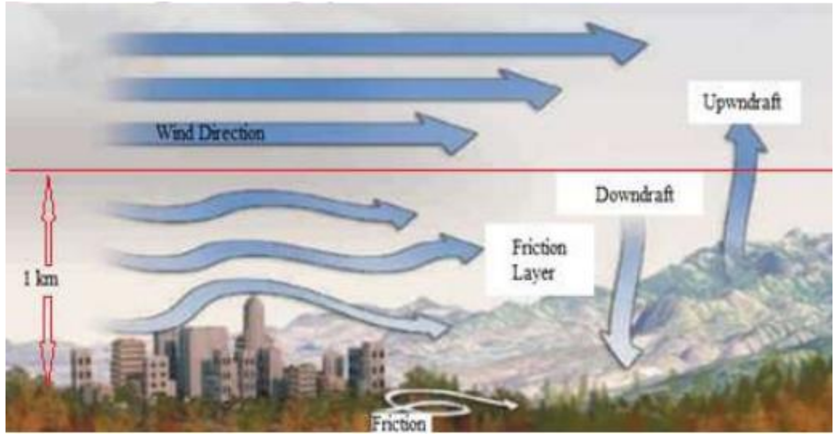

Figure 9. Friction and its Impact on Winds

Source:http://highered.mheducation.com/sites/dl/free/0078095166/1030553/Chapter3.pdf

Surface of the earth, particularly the land surface is rugged and have great friction. They are in the form of undulating surface, different types of land features, buildings, plants and trees. They all obstruct the free flow of air (wind). The friction is maximum at or near the surface. In another words, it is the earth-air interface where it is maximum. After that, the friction keeps on declining. It is found that the friction beyond one km from the earth/ land surface is almost negligible. After this limit, winds blow without any effect of obstruction / friction (Figure 9). That is why the stronger winds occur at higher altitudes. Friction near the earth surface is the cause for complicated wind patterns. Obstructions like undulated land, valleys, peaks, ridges, buildings, plants and trees etc. in the path of the winds results in curved or complex paths and creates turbulence near the earth.

7.8 Distribution of Idealized Pressure Belts

You must have read about the development of pressure belts and their distribution over the globe in the previous module. But let us discuss about them in very brief.

It is well known fact that the sun's rays are vertical in equatorial region throughout the year. Hence, higher temperature is observed in this region. The effect of high temperature is very clearly seen on the circulation of air. The incoming short wave solar radiation is primarily not trapped by atmosphere. Those rays reach to the earth surface almost directly. First of all, the surface is heated by the solar energy. The air in contact with the surface is warmed up when the earth radiates back through longwave radiations. The long wave earth's radiation is being absorbed by the air. Thus, the air gets the heat in this method. This process is applicable to entire earth including land and water surface but the effectiveness is different in different cases.

7.8.1 Inter Tropical Convergence Zone

Inter tropical convergence zone (ITCZ) is a low pressure belt found generally along the equator. It is a zone where the winds coming from sub-tropical high pressure belts of both the hemispheres converge near the equator. Since this zone experiences high temperature throughout the year, the air in this zone is heated up and get sparse in terms of density. Warm air is lighter and it moves upward. In this way, a temporary void space is created. Therefore, this area is termed as low pressure zone. This is also known as a zone of tropical low pressure or generally ITCZ (Figure 10). This low pressure is thermally induced because it happens due to high

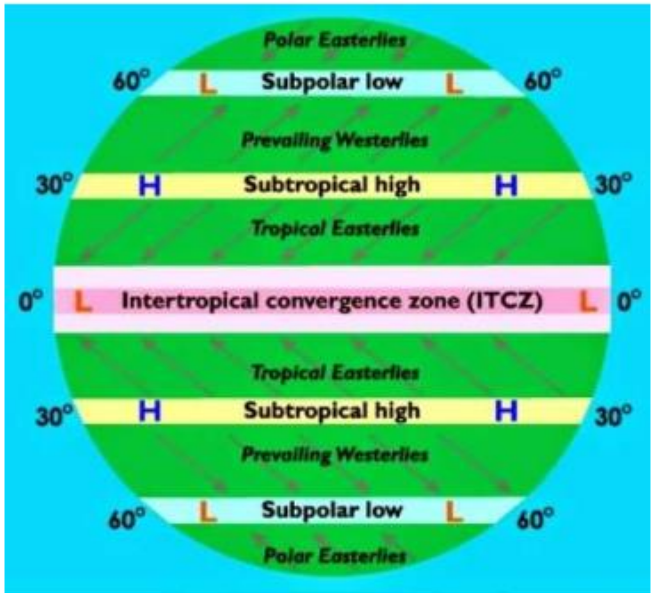

Figure 10. Pressure Belts Distribution
Source: http://uhfall2014dominicanrepublic.blogspot.in/

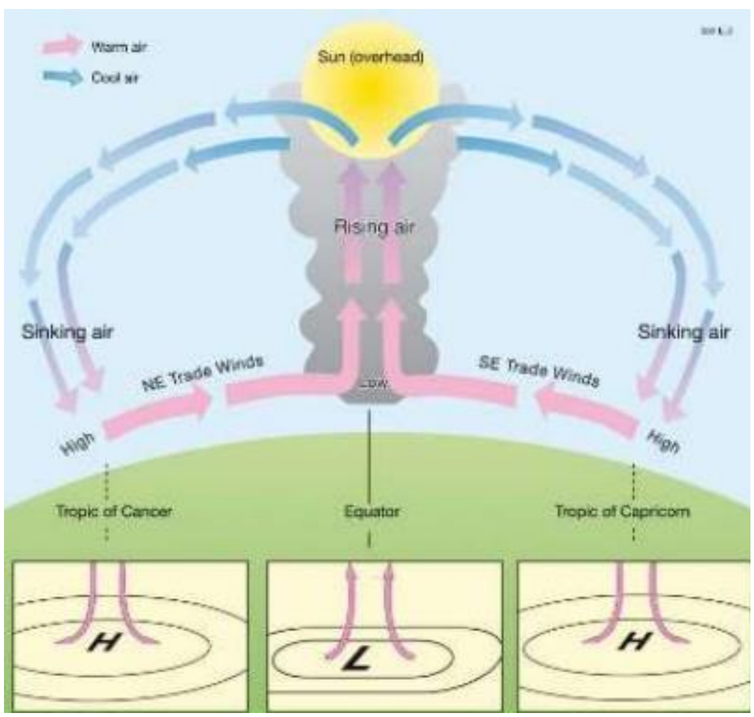

Figure 11. Low Pressure Creation over Equator
Source: http://media.diercke.net/omeda/800/13561E_3_Passat_ITC.jpg

temperature in this zone. The air laying in the surrounding areas starts rushing to fill this temporary void. Refer to Figure 11 to get a clear picture of it.

7.8.2 Subtropical High

The converged air at ITCZ rises up. We know that temperature decreases with increasing altitude. The rising air is diverged and displaced towards poles but it does not reach to that great distances. From the upper troposphere, it reaches to around 300 north and south latitudes and descends or sinks there. The descending or sinking air presses the underlying air. This increases the air pressure at the lower level. From this area of increased air pressure, winds start blowing towards the equator, where the low pressure zone is already generated (Figure 11). The completion of the air circulation from ITCZ/ equator to upper troposphere north/south divergence, sinking at subtropical high and again blowing towards

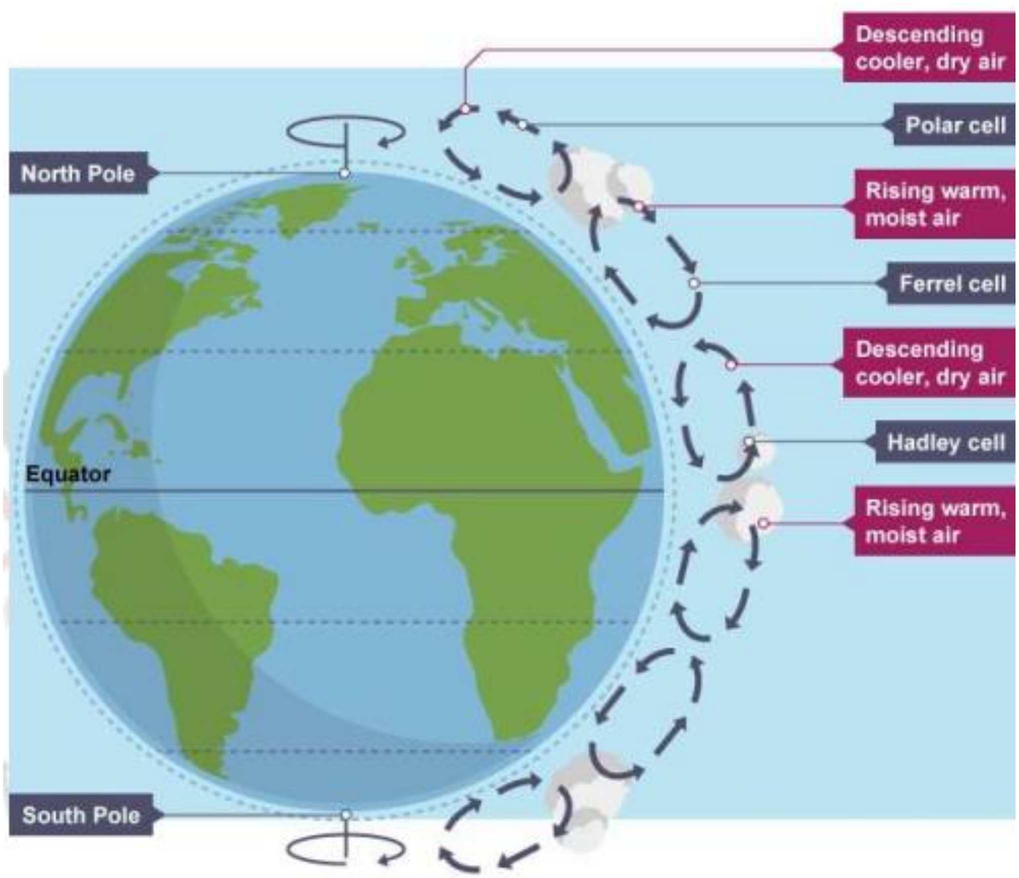

Figure 12. Vertical Air Circulation and Cells
Source: http://www.bbc.co.uk/education/guides/zym77ty/revision/2

equator is like a cell. This cell is popularly called Hadley Cell (Figure 6 and 12) as it was first explained by him.

7.8.3 Subpolar Low

The sinking air at subtropical high also blows towards the pole. The polar low pressure zone is created by dynamic behavior of the air movement. Poles are excessively very cold and due to this, poles have high pressure. It is also thermally induced high pressure because the poles are excessively cold. Between two high pressures, that is, the sub-tropical high pressure and polar high pressure, there is bound to be a low pressure. This low is developed around 600 north and south latitudes. The convergence of air at the polar low is causing to rise of the air 16 (Figure 12). The rising air from this zone is again diverted towards poles as well as towards subtropical high pressure where they descend. The rising from subpolar low, diverging towards subtropical, sinking there and blowing from subtropical high to subpolar low is a circular motion known as Ferrel's Cell (Figure 6 and 12).

7.8.4 Polar High

As mentioned before, the poles have excessively low temperatures. Excess cold causes the air to be very heavy and due to this the high pressure has developed over poles. Apart from this, the risen air at subpolar low, reaches to the polar region and sinks there. Due to both the reasons, polar areas are zones of high pressure. Hence, the winds are blowing towards subpolar low pressure area. The uplifted air at subpolar low, moving towards poles and descending there and finally reaching to the subpolar low is termed as Polar Cell (Figure 6 and 12).

Though the direction of air on Figure 10 is shown by straight lines from high pressure zone to low. This figure is placed only to show the air pressure belts. In reality, winds are not blowing on a straight path but are on a curvilinear path (Figure 13). The curvature of the path is due to rotation of the earth as well as Coriolis force about which you have already learnt in the previous section of this module.

7.9 Seasonal Variations in Pressure

Belts As discussed before, the earth's axis is inclined about 660 30' from horizontal or 230 30' from the vertical. It is also mentioned, the orbit of the earth is elliptical in shape on which it is revolving around the sun. Due to this, after third week of March to third week of September, for a period of six months, northern hemisphere gets more insolation. In the same way from third week of September to third week of March, for a period of six months, southern hemisphere receives more solar energy (Figure 14). As mentioned above that energy received from the sun is a determining factor for all sorts of weather and climatic phenomena.

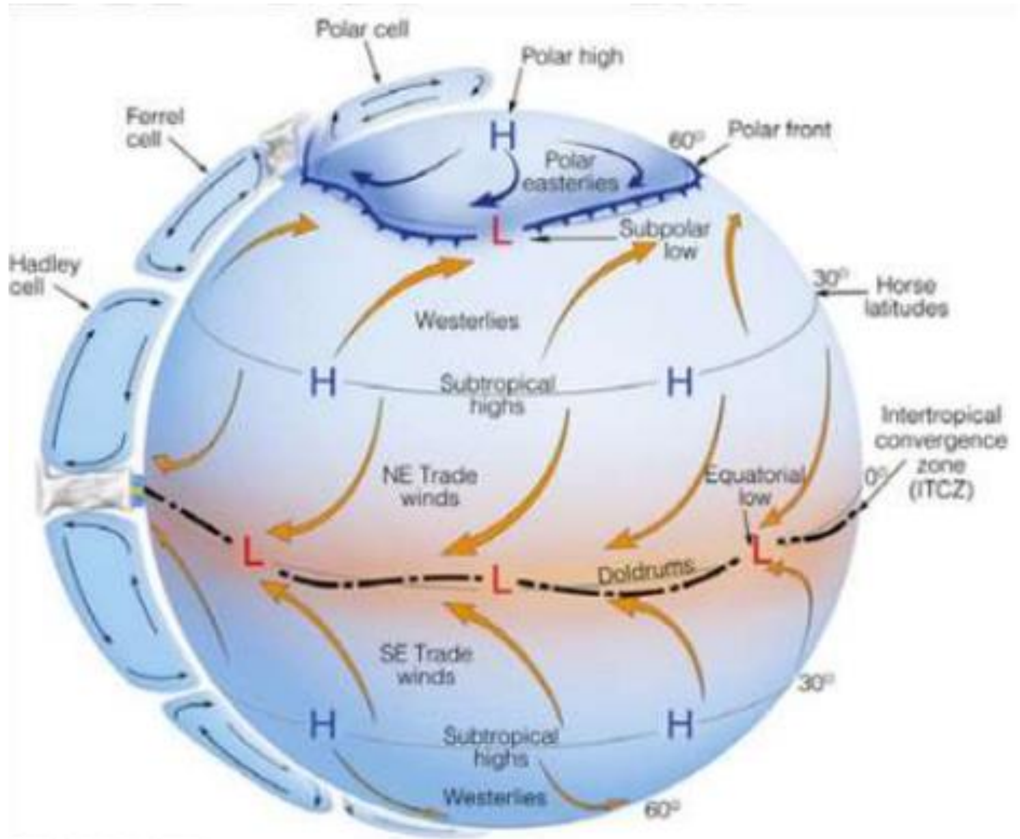

Figure 13. Curvilinear Path of Winds

Source: https://classconnection.s3.amazonaws.com/487/flashcards/1587487/png/three_cell_model1351023546708.png

In general, the global atmospheric pressure belts depart northwards as along as the sun shines vertically in northern hemisphere after third week of March. The departure of atmospheric pressure belts keeps on continuing till third week of June, when the sun is vertical over tropics of Cancer. Sun is vertical over tropic of cancer on 21st June while on 22nd December it is vertical over tropic of Capricorn (Figure 15).

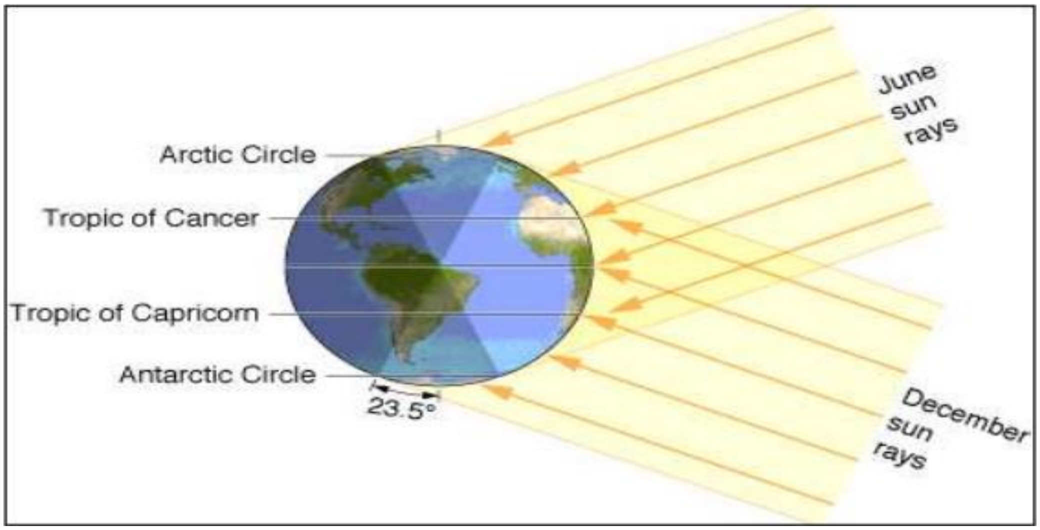

Figure 14: Seasonal Changes of Sun's Rays Incidence on Curved Surface of the Earth

Source: http://physics.weber.edu/schroeder/ua/EarthCirclesAndSunRays.pngng

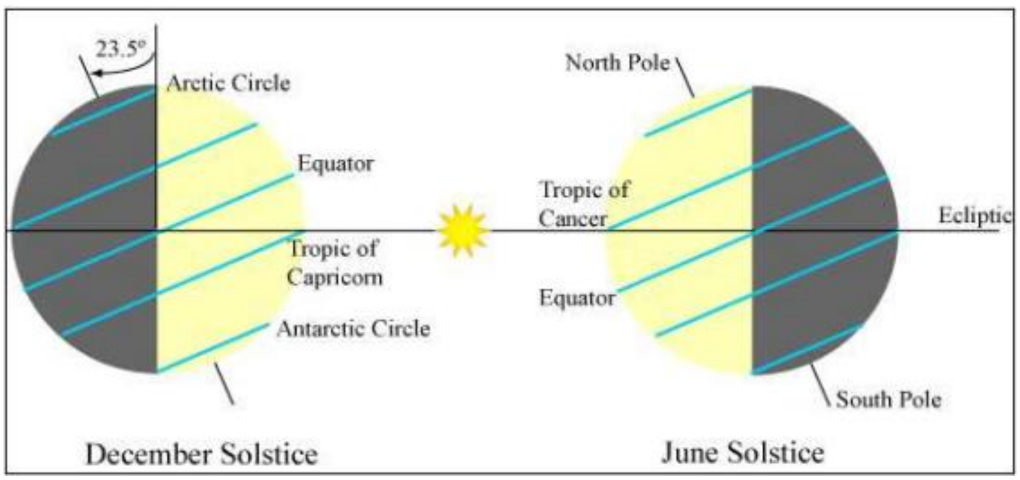

Figure 15: Sun Shining on Tropics of Capricorn and Cancer

Source: https://dept.astro.lsa.umich.edu/resources/ugactivities/Labs/seasons/SeasonsIntrotroppics.html

7.9.1 Seasonal Variations during July

By the end of third week of June, the sun shines directly over the tropic of Cancer. After that sun's rays starts turning towards south. July is the hottest month recorded in the northern hemisphere. Northward departures of the inclination of sun's rays from last week of March increases the temperature in northern hemisphere. Along with this, the ITCZ keeps on moving northwards (Figure 16 and 17). Its maximum departure is seen upto 250 north latitude in the large chunk of land of Asia. Though the ITCZ shifting is northwards, itsshift is minimum on the large water bodies of Pacific and Atlantic (Figure 17).

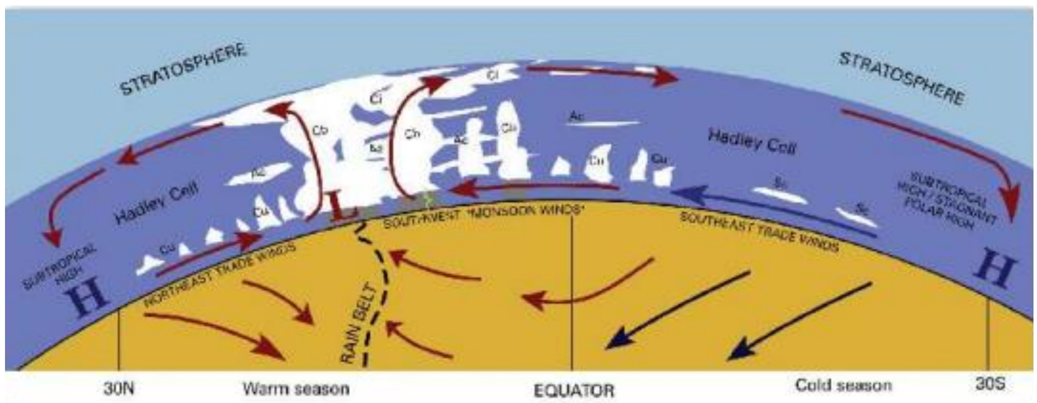

Figure 16: Changed ITCZ during Jun/July
Source: http://www.weatherwise.org/sebin/s/i/Convergence-Photo-4.gif

The effectiveness of the sun's departure is observed till July as it is the hottest month for northern hemisphere, while the southern hemisphere witness the coldest conditions in July. In this process, inter tropical convergence zone (ITCZ) is shifted according to shift in sun's rays (Figure 16). Shift in the ITCZ is associated with the shift in all the atmospheric pressure belts in the direction of the ITCZ shifting. Therefore shift in the all vertically developed cells like, Hadley, Ferrel's and Polar are also shifted simultaneously. The shift in the all the belts are evident from Figure 18.

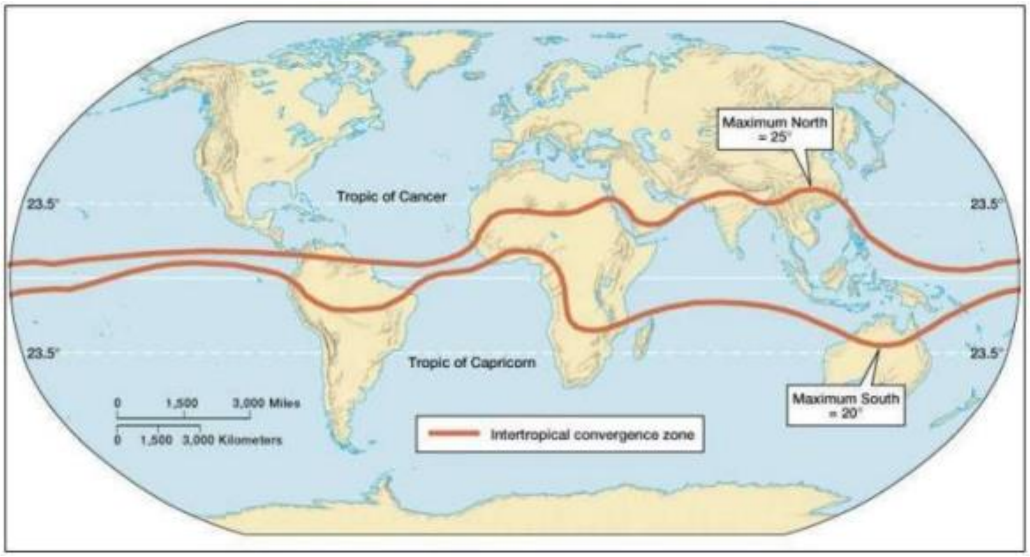

Figure 17: Changed ITCZ during June and July
Source: https://image.slidesharecdn.com/winds-111208234718-phpapp02/95/winds-16-728.jpg?cb=1323392487

Figure 18: Migration in all Atmospheric Pressure Belts during Certain Months
Source: adapted from: https://www.slideshare.net/iqbalmuhammed4/geo02-wind

The northward departure of ITCZ is further northward over the continental landmass (Figure 17). It happens so because the land is getting heated up very quickly and intensely. The low pressure is developed over such regions. The ocean surface is relatively cool because specific heat of water is high compared to land. So, it does not get heated or cooled so quickly like land. Though the temperature of the ocean water also rises, but due to differential low temperature, oceans possess high pressure.

Over Pacific and Atlantic, the average sea-level atmospheric pressure is more than 1024 mb whereas the low pressure over widespread continental area of Africa and Asia records less than 1000 mb (Figure 19). In the same month (July), a very widespread and extensive

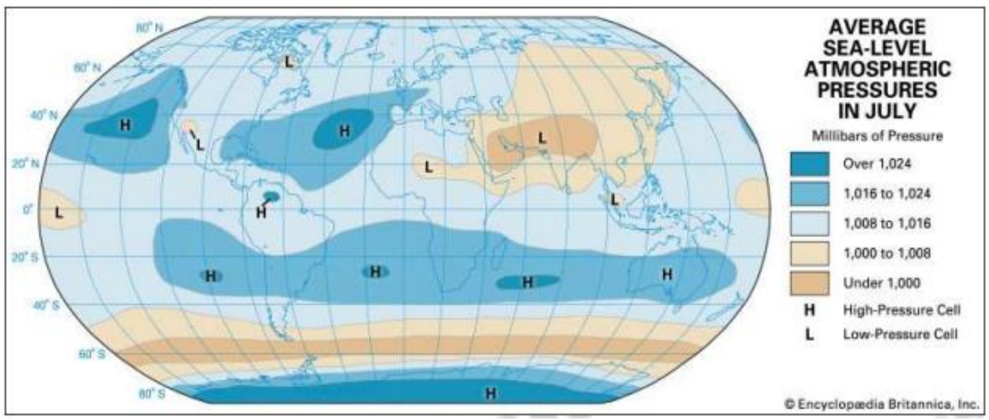

Figure 19: Average Atmospheric Pressure in July
Source: https://media1.britannica.com/eb-media/42/104242-004-338AFD20.jpg

area of high pressure is developed almost encircling the entire southern hemisphere between 5^0 to 40^0 south latitudes. It encompasses both land and water bodies. The subpolar low pressure belt has also shifted northward and occupies its position between 45^0 to 60^0 south latitudes.

7.9.2 Seasonal Variations during January

By the end of third week of September the sun's rays become vertical towards southern hemisphere. The effectiveness of solar radiation increases in southern hemisphere with the passage of time, but simultaneously it keeps on decreasing in the northern hemisphere. It all happens due to inclined rays of the sun in the northern hemisphere. With more and more vertical rays in the southern hemisphere, the increase in temperature is very significant and prominent in southern hemisphere. Increasing temperature causes the high atmospheric pressure region turns into a low air pressure zone. The continuous widespread high pressure belt is confined only to the southern parts of Pacific, Atlantic and Indian oceans. The subpolar low pressure belt is also reduces to a narrower belt in comparison to July. The same is the case with polar high confining to a contracted region (Figure 20).

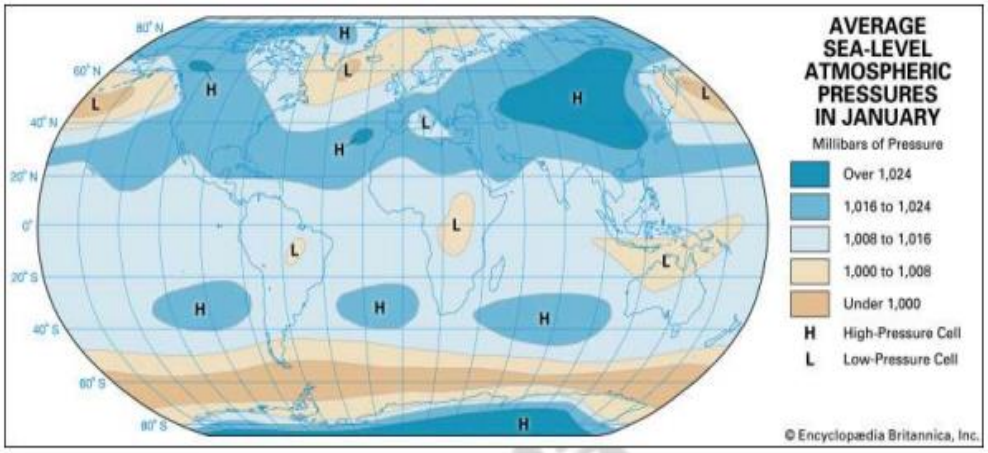

Figure 20: Average Atmospheric Pressure in January
Source: https://media1.britannica.com/eb-media/41/104241-004-1DC78D2A.jpg

So the case of northern hemisphere is reversed in January in comparison to July. Everything is due to seasonal changes due to earth's revolution round the sun. A huge area is under the influence of high atmospheric pressure. It extends over enormous landmass of Europe, Africa, Asia and North America. This belt is relatively narrower over the water bodies of Pacific and Atlantic. These are having the reason of the nature of the surface and their differential response to the heat received.

Summary and Conclusions

The planetary wind pattern is affected by the sequential development of high and low atmospheric pressure. The intensity and velocity of wind is affected by the pressure gradient which is the function of the inter spacing of the isobars and the distance. In other words, the atmospheric pressure is controlled primarily by important factors like temperature, altitude, water vapour, gravitational pull and earth's rotation.

Lowering the temperature of the air of an area causes the pressure to rise whereas the increase of the same lead to decrease in pressure. With increase in altitude, the pressure is decreased and vice-versa. Increase in water vapour in the air causes the air pressure to decrease as it makes the air lighter. So decreasing vapour increases the air pressure. Gravitational pull is greater near the surface but with increase in height, it is reduced. Earth's rotation causes the air to throw away due to centrifugal force of earth's spinning.

The heating of air creates convectional currents particularly in inter tropical convergence zone. The risen air from ITCZ is diverted towards poles but it descends near subtropical high. It creates Hadley cell. Another Ferrel cell is created between subtropical high to subpolar low. The third cell, that is, Polar cell gets developed between subpolar low to polar high. As demarcated by these cells, sequential development of the pressure belts are created. The horizontal movement of wind is primarily affected by the pressure gradient, Coriolis effect and frictional force.

With change in season, complete reversal in weather and climatic elements are seen over the globe. In a cycle of one year, sun is bright for six months in northern hemisphere from last week of March to the third week of September. Thus, in this period, all pressure belts and ITCZ shifts northwards. The reverse is the case from third week of September to the third week of March when sun is bright in the southern hemisphere. During those days, all air pressure belts as well as ITCZ are shifted southwards. The effect of the land water distribution in the two hemispheres also play a very crucial role in determining the atmospheric pressure belts and the wind pattern over the globe.

Reference

Adapted from E-PG Pathshala- Geography, Climatology, Planetary Wind Patterns: Wind Belts and Seasonal Variations

Unit 8: Weather and Climate

Unit Structure

8.0 Learning Objectives

On completion of this unit you should be able to understand:

- Define climate
- know about the types of climatic classification
- know about climatic classification of Köppen and Thornthwaite
- Know about various factors that determine the weather and climate of a place or region

8.1 Introduction

Earth's environment comprises of five important components, viz., atmosphere, ocean, land surface, ice and snow surfaces (both land and ocean areas), and biosphere (both terrestrial and marine). Continuous interactions among these components determine the state and dynamics of our climate system and produces weather at any given place and time. Our forefathers since ages before have been fully aware of roles that weather or climate plays in our lives. One can find numerous direct or indirect references of weather and climate in the historical texts and scriptures; the need and desire to control weather, for the best advantage of the society, led to worshipping and rituals involving natural elements like sun, moon or wind in almost all religions.

Weather and climate determine the way people live at a place; type of clothes they wear, kind of food they eat or type of houses they build in to live. In fact, it is the climate that determines natural vegetation, ecosystem functioning, water supply, agricultural practices, comfort level etc. factors which leads to development of general human or animal habits and habitats in that area; however, instantaneous choices have more to do with the current weather situation.

Although the evolution of weather and climate is largely a natural process, recent scientific evidences suggest that anthropogenic influences on the nature earth have had something too in shaping this evolution around the world and would continue to do so in coming days. It would be interesting and imperative as well, to know how things unfold in future. So, it is necessary to understand various aspects of weather and climate..

8.2 Weather and climate: definition and differences

Weather is the day-to-day physical condition or state of the atmosphere (i.e., hot/cold, wet/dry, calm/windy, sunny/cloudy) at a given time and place and its short-term variation in minutes to weeks. Fig. 1 shows one aspect of weather, the surface air temperature measured at 0830 Indian Standard Time (IST) on 10th October, 2016 over Indian region and indicates that warmest temperatures of 30oC and above were experienced by few stations from Tamil Nadu and West Bengal. On the other hand, lower temperatures were experienced by stations from northwestern and northern most parts of the country.

Climate is the average weather pattern of a place over a long time period, often 30 years or more. In a more scientifically accurate way, climate is the statistical description of weather pattern over a place in terms of the mean and its variability over a long time period. Fig. 2 shows the annual climatology of rainfall over India, computed using data for the period 1951-2000. As seen in it, northeast India, and west coast & adjoining Ghats experience highest rainfall. On the other hand, western parts of Rajasthan and southeast Tamil Nadu experience lowest rainfall.

The comparison is further elaborated in the following bullets:

- Weather and Climate are two different meteorological terms that are related but not interchangeable. For example, it would be wrong to say that the `climate has become so hot` or `Siberia has a cold weather`. In a day to day conversations, it is even common to see, when the sudden changes occur in the weather conditions like rain, temperature etc., some of us wrongly mention that climate has changed
- Climate is what you expect, weather is what you get. In our day to day life, we often discuss a cold morning, a cloudy sky, a sultry afternoon or a warm evening. All these refer to the weather conditions of a given place at a given time. In most places weather may change from minute-tominute, hour-to-hour, day-to-day, and season-to-season

Figure 1: Dry bulb temperature recorded at 0830 Indian standard time on 10th October, 2016.
(**Source:** India Meteorological Department)

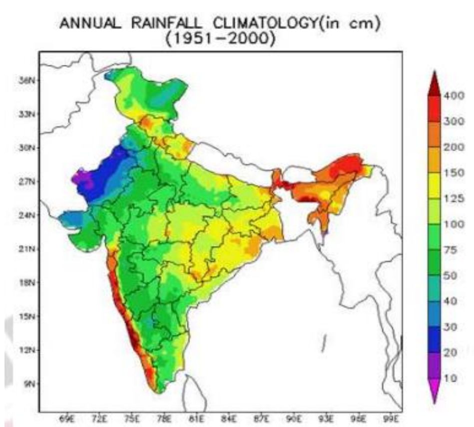

Figure 2: Map showing annual rainfall climatology over Indian region computed using data for the period 1951- 2000 (Source: India Meteorological Department).

- • Climate is the average of weather over time and space. For example, In India we can expect snow in the northern most parts and Himalayan ranges during December to February, dry and hot during April to June over northwest and central parts of India, rains in most parts of the country during the southwest monsoon season (June to September). This is climate. Generally, the climate information of a place includes extreme values such as record high/low temperatures or record amounts of rainfall. When you hear from your local weather agency saying today's maximum temperature hit a record high, the agency is mentioning it based on the historical climate records of that place.

8.3 Elements of weather and climate

Atmospheric variables that can be used in combination to describe Weather and Climate are called elements. These variables are temperature, humidity, precipitation, visibility, atmospheric pressure and wind. These atmospheric variables vary from once place to another, with the height and with time. Table 1 shows list of various weather elements along with instruments used for its measurements.

8.3.1 Temperature

The temperature refers to measure of degree of warmth or coldness of the atmospheric air at a given place and level with respect to some standard value. At the surface the air temperature is measured by a thermometer (in Celsius, oC; Fahrenheit oF; Kelvin, oK). It is governed by many factors, including incoming solar radiation, humidity and altitude. The temperature of the air has an effect on the rate of evaporation in the atmosphere, the amount of humidity and form of precipitation.

8.3.2 Humidity

The amount of water vapor in the atmosphere is called humidity. The main sources of water vapor in the lower atmosphere are evaporation from the Earth's surface and transpiration by plants. In the stratosphere, the breakdown of methane by sunlight is another source. The main sink is precipitation. Meteorologists have defined several different measures of humidity. These can be divided into two categories: those that describe the actual amount, or concentration, of water vapor in the air and those that relate the actual amount to the potential amount that the air could hold if it were saturated with respect to water vapor. Air is saturated when it holds the maximum possible amount of water vapor. At that point, the rate at which water molecules enter the air by evaporation exactly balances the rate at which they leave by condensation. A device to measure relative humidity is called a hygrometer. The simplest hygrometer - a sling psychrometer - consists of two thermometers mounted together with a handle attached on a chain. One thermometer is ordinary. The other has a cloth wick over its bulb and is called a wet-bulb thermometer.

8.3.3 Precipitation

Precipitation is the condensed water vapor in the form of liquid or solid falling from the air onto the ground. Different forms of precipitation include rain, sleet, snow, hail, and drizzle plus a few 8 Environmental Sciences Atmospheric Processes Weather and Climate less common occurrences such as ice pellets, diamond dust, fog precipitation and freezing rain. The total amount of precipitation that reaches the ground in a stated period is expressed in terms of the vertical depth of water (or water equivalent in the case of solid forms) to which it would cover a horizontal projection of the Earth's surface. Snowfall is also expressed by the depth of fresh, newly fallen snow covering an even horizontal surface.

Precipitation gauges (or rain gauges if only liquid precipitation can be measured) are the most common instruments used to measure precipitation. Generally, an open receptacle with vertical sides is used, usually in the form of a right cylinder, with a funnel if its main purpose is to measure rain. The volume or weight of the catch is measured, the latter in particular for solid precipitation. The measurement of precipitation is very sensitive to exposure, and in particular to wind.

8.3.4 Visibility

Visibility is a measure of the horizontal opacity of the atmosphere at the point of observation and is expressed in terms of the horizontal distance at which a person should be able to see and identify: in the daytime, a prominent dark object against the sky at the horizon; at night, a known, preferably unfocused, moderately intense light source. Visibility affects all forms of traffic: roads, sailing and aviation. Visibility can be reduced by fog, pollution, snow or even sand blown up by the wind. Visibility degradation is caused by the absorption and scattering of light by particles and gases in the atmosphere. For last many years, meteorological visibility was used to be estimated by the human observer judging the appearance of distant objects against a contrasting background, usually the sky. Recently, many synoptic observing stations have sensors which provide a measurement of visibility. Visibility sensors measure the meteorological optical range which is defined as the length of atmosphere over which a beam of light travels before its luminous flux is reduced to 5% of its original value. In most instances this is approximately equivalent to, but not the same as, visibility measured by e contrast of a distant object against its background.

8.3.5 Atmospheric pressure

The force per unit area exerted against a surface by the weight of the air above that surface is called atmospheric pressure. Atmospheric pressure is measured using a metric unit called a millibar 9 Environmental Sciences Atmospheric Processes Weather and Climate (mb) or hecta Pascal (hPa) and the average pressure at sea level is 1013.25 millibars. Pressure decreases exponentially with altitude. If P(0) is the pressure at the surface and P(z) is the pressure at altitude 'Z', the fraction of total atmospheric weight located above altitude z is P(z)/P(0). The atmospheric pressure at about 80 km altitude is about 0.01 hPa, i.e., 99.99% of the atmosphere is below this altitude. The instrument used for measuring the atmospheric pressure is barometer. The most commonly used barometer is mercury barometer. A mercury barometer consists of a thick-walled glass tube, filled with mercury after removing air bubbles is closed at one end and its open end is inverted into a container of mercury. The column of mercury in the tube is supported by the atmospheric pressure and its height depends on the magnitude of the atmospheric pressure. The mean sea level pressure or atmospheric pressure at sea level is the atmospheric pressure normally given in weather reports. The altimeter setting in aviation is an atmospheric pressure adjustment. Average sealevel pressure is 1013.25 hPa or mbar or 76 centimetres of mercury (cm Hg).

8.3.5 Wind

Movement of air caused by differences in air pressure within the atmosphere is called wind. Air moves from high pressure areas to low pressure areas and the speed of the winds is directly proportional to the difference in pressure. Wind is described with speed and direction. Wind direction is reported by the direction from which it originates. For example, a westerly wind blows from the west to the east. Wind direction is usually reported in cardinal directions or in azimuth degrees. For example, a wind coming from the south is given as 180 degrees; one from the east is 90 degrees. Meters per second (m s1) is the standard SI unit commonly used for the reporting and forecasting of wind speed. Another commonly used unit of wind speed in meteorology is ‘knot’, which is a non-SI unit. 1 knot is equal to 0.514444 m s^{-1}.

Anemometer is used to measure wind speed and wind vane is used to measure wind direction. A typical wind vane has a pointer in front and fins in back. When the wind is blowing, the wind vane points into the wind. For example, in a north wind, the wind vane points northward. A cup anemometer is a common tool to measure wind speed. The cups catch the wind and produce pressure difference inside and outside the cup. The pressure difference, along with the force of the wind, causes 10 Environmental Sciences Atmospheric Processes Weather and Climate the cups to rotate. Electric switches measure the speed of the rotation, which is proportional to the wind speed.

Table 1: List of some weather elements and instruments used for their measurements

Weather element	Instrument used for measuring the element	Unit of measurement
Temperature	Thermometer 	in Celsius (^oC) or Fahrenheit (^oF), or Kelvin (^oK)
Humidity	Hygrometer 	Absolute humidity using grams per Kilo grams
Rainfall	Rain Gauge 	Measured in either millimeters or inches
Visibility	Visibility Sensor 	Metres or Kilometres
Atmospheric Pressure	Barometer 	Millibar (mb) or Hecta Pascal (hPa)

Wind (Direction)	Wind Vane 	Cardinal directions or in azimuth degrees (from north). Northerly is taken as zero, easterly as 90 degrees, southerly as 180 degrees etc.
Wind (speed)	Anemometer 	Meters per second (m s-1) or Knots

8.4 Classification and variability

Climate classifications, the formalization of systems that recognize, clarify, and simplify climatic similarities and differences between geographic areas in order to enhance the scientific understanding of climates. Such classification schemes rely on efforts that sort and group vast amounts of environmental data to uncover patterns between interacting climatic processes.

The earliest known climatic classifications were those of Classical Greek times. Such schemes generally divided Earth into latitudinal zones based on the latitudes, i.e. the Equator, the Tropics of Cancer and Capricorn, and the Arctic and Antarctic circles, respectively and on the length of day. Modern climate classification has its origins in the mid-19th century, with the first published maps of temperature and precipitation over Earth's surface, which permitted the development of methods of climate grouping that used both variables simultaneously.

8.4.1 Types of climatic classification

Different schemes of climatic classification are broadly differentiated as either empiric or genetic methods. **Empirical methods** make use of observed environmental data, such as temperature, humidity, and precipitation, or simple quantities derived from them (such as evaporation). In contrast, **genetic methods** classify climate on the basis of its causal elements, the activity and characteristics of all factors (circulation systems, fronts, jet streams, solar radiation, topography etc.) that give rise to the spatial and temporal patterns of climatic data. Hence, while empirical classifications are largely descriptive of climate, genetic methods are explanatory. However, for all practical applications empirical classifications are widely adopted. In this section two classic and most widely accepted climatic classification schemes of Koppen and Thornthwaite have been discussed.

8.4.2 Köppen's classification

The most popular empirical classification is given by Wladimir Köppen, in 1900 and several revised versions thereafter. Koeppen's scheme used certain critical values of temperatures of the warmest and the coldest months and of rainfall of the wettest and the driest months. His climatic divisions generally coincide with vegetational divisions. Koppen (1936) divided the world climate into the following 5 principal groups.

A: Tropical rainy climate

Temperature of the coolest month does not exceed 18 ^{0}C

Af - Tropical rainforest (equatorial climate): Warm Temperature throughout with. mean value exceeding 27°C, abundant rainfall (annual average 250 cm), suitable for luxuriant vegetation. Prevails over Amazon basin, Zaire basin and south-east Asia.

Aw - Tropical savanna: Mean annual temperature 23°C, wet summers (due to convectional rainfall) and dry winter with annual rainfall 160 cm. Floods and droughts are common. Vegetation is tropical grassland or savanna with scattered deciduous trees. Prevails over Sudan, Veld plateau and the tropical grasslands of Australia.

Am - Monsoon type: Seasonal reversal of winds, associated with alternate periods of rainfall and drought with a short dry season.. This climate is experienced over the Pacific coast of Colombia, Guinea coast of west Africa, south-east Africa, south and south-east Asia and northern Australia.

As - Dry summer: A rare climatic type prevailing over some rainshadow areas along eastern coast of southern India in Tamil Nadu and Orissa that remain dry during summer monsoon and receive winter rainfall from retreating monsoons.

B: Dry climates

Potential evaporation exceeds precipitation and constant water deficiency is experienced.

Bwh - Desert (Low Latitude) Climate: Sub-tropical high pressure region with mean annual temperature is 38°C and scanty and erratic rainfall. Vegetation varies with the soil type. This climate is experienced over southwest USA, north Africa (Sahara), west Asia, Thar desert, and central Australia.

Bwk - Mid-Latitude Deserts: These climatic conditions prevail over Takla Makan (China) and Gobi desert (Mongolia) and are similar to the low- latitude desert conditions.

Bsh and Bsk - Semiarid and Steppe: Mean annual temperature is around 21°C and rainfall a meager 30 cm. These regions are dry due to an interior location and absence of mountain barriers across the path of prevailing winds. These climatic conditions prevail over in the deep interiors of landmasses, such as Eurasia and North America.

C: Humid mesothermal/Warm temperate rainy

Mild winters; mean temperature of coldest month is below 18°C but above -3°C and that of the warmest month is above 10°C.

Cfa - Humid subtropical or China type climate: Hot and humid summer and mild winter with average annual temperature is 20°C and well distributed rainfall (100 cm). Hurricanes and typhoons are common. Prevails within 25° to 45° latitude on east coast in both hemispheres e.g., south-east USA, southern Brazil, Uruguay, Argentina, and south-eastern Africa, eastern coastal belt of Australia, eastern China and Japan.

Cfb - Marine west European climate: Characterised by on shore oceanic influences, short cool summers, mild winters with average annual temperature around 10°C and. and rainfall is 140 cm. Weather is variable and unpredictable. Prevails between 45° latitude and 65° latitude on west coast in both hemispheres e.g., Western Europe, narrow coastal belt in North and South America, -south-eastern Australia and New Zealand.

Cs - Mediterranean climate: Warm and dry summer (mean temperature 20°C- 27°C) due to sub-tropical high pressure conditions, mild winter (temperature 4°C to 10°C). with rainfall from low pressure cyclones (annual rainfall 40 cm- 60 cm). Prevails within 25° and 45° latitudes on west coasts in both hemispheres—over central California, central Chile, Mediterranean region, southern South Africa, southeastern and southwestern Australia.

D: Humid microthermal or Cold forest climates

Severe winters, temperature of the coldest month is below -3°C and warmest month, above 10°C.

Df - Cool east coast climate: Hot and humid summer (mean temperature 25°C), influenced by tropical maritime air masses, cold winter (mean temperature -4°C to 0°C), . variable precipitation - convectional rainfall during summer and snowfall in winter. Prevails between 45° and 65° latitude on east coasts, over north-eastern USA, lower Danube plains, Korea, Japan, northern China.

Ds - Taiga climate: Short summer (temperature between- 10°C and 15°C), long and cold winters and low precipitation as influenced by continental polar air masses. Prevails over the belts from Alaska to Newfoundland and from Norway to Kamchetka peninsula sub-Arctic region. 'Taiga' actually refers to the softwood coniferous forest cover.

Dw - Continental type climate: Short and cool summer (temperatures 10° to 21°C), long and cold winters (temperatures below 0°C) and variable rainfall mostly during summers and snowfall during winter. Prevails in deep interiors of the continents between Taiga and the mid-latitude deserts over Poland and the Baltic states, Russian plains, northern states of USA and the southern states of Canada.

E: Polar climates

Temperature of the warmest month is below 10°C. There is no warm season.

ET - Tundra Climate: Experienced over coastal fringes of the Arctic Ocean. Short, cool summer, long, cold winter and meager precipitation that limitTaiga vegetation.

Ef - Ice Cap: Areas permanently covered with snow. Average temperature of the warmest month is below 0°C. These conditions occur over the poles and the interiors of Greenland.

H: Highlands climate

Prevails over the mountainous regions of Rockies, Andes, Alps and the Himalayas. Vegetational zoning from foothills upwards is similar to latitudinal change. High insolation, low temperature, low pressure, high precipitation and larger diurnal ranges at higher altitudes.

The significant aspect of Koeppen's classification scheme is that it uses measurable and visible physical, elements like temperature and precipitation and their combined interaction with vegetation as the basis of classification. Koeppen's scheme uses letter symbols to denote various characteristics, which is practical and convenient. However it ignores other factors, such as cloudiness, wind, rainfall intensity, currents and, above all, the air masses which form the basis of modern climatology. It is also difficult to explain the existence of different vegetation types within the same climatic division and similar vegetation types in different climatic divisions.

8.4.3 Thornthwaite's rational classification

The main limitation of Koppen's classification is the lack of rational basis for selecting temperature and precipitation values for different climatic zones. Thornthwaite's (1948) improved the same by introducing water balance concept in his classification scheme. He compared the potential evapotranspiration, PET (defined as the amount of water that could evaporate and transpire from a vegetated landscape without restrictions other than the atmospheric demand) with precipitation and computed 'moisture index' which considers the water surplus (s) and water deficit (d) which occur in different seasons in most places. Water surplus means seasonal addition to sub soil moisture that is being used by the crop at a reduced rate of transpiration during deficit period.

Thus, the climate of a place is defined on the basis of (i) Potential evapotranspiration i.e. the combines loss of moisture from vegetation surface as evaporation and transpiration and , (ii) Seasonal variation of effective moisture and (iii) Average annual thermal efficiency.

According to Thornthwaite's classification scheme,

Humidity Index = $I_h = \frac{100 \times s}{n}$, and Aridity Index= $I_a = \frac{100 \times d}{n}$

Where,

s = Monthly water surplus calculated as the sum of the monthly differences between precipitation and potential evapotranspiration when precipitation is greater than evapotranspiration

d = Monthly water deficit calculated as sum of monthly values of potential evapotranspiration for those months when precipitation is less than evapotranspiration

n = Water need

Thornthwaite assumed that a surplus of 6 inch of water will counteract a deficit of 10 inch and thus gave higher weightage to humidity index. Thus Moisture Index is given by

$$I_m = I_h - 0.6 \times I_a = \frac{100\,s - 60\,d}{n}$$

Table 1. Climate types and moisture index in Thornthwaite's classification

Symbol	Climate type	Moisture Index	Broad group
A	**Per Humid**	**100 and above**	**Moist Climate**
B4	**Humid**	**80 to 100**	
B3	**Humid**	**60 to 80**	
B2	**Humid**	**40 to 60**	
B1	**Humid**	**20 to 40**	
C2	**Moist Sub- Humid**	**0 to 20**	
C1	**Dry Sub humid**	**-20 to 0**	**Dry Climate**
D	**Semi arid**	**-40 to -20**	
E	**Arid**	**-60 to -40**	

Thornthwaite has considered moisture index above zero as moist climate (A, B4, B3, B2, B1 and C2) and moisture index below zero as dry climate (C1, D and E). He has given subdivisions to express the extent of dry period under moist climate and extent of moist period under dry climate.

Table 2. Subdivisions of moist and dry climates in Thornthwaite's classification

Moist	Climate - description	Aridity Index	Dry -	Climate description	Humidity Index
R	Little or no water deficiency	0-10	D	Little or no water surplus	0 – 16.7
S1	Moderate summer water deficiency	10- 20	S1	Moderate summer water surplus	16.7 – 33.3
W1	Moderate winter water deficiency	10- 20	W1	Moderate winter water surplus	16.7 – 33.3
S2	Large summer water deficiency	≥ 20	S2	Large summer water surplus	≥ 33.3
W2	Large winter water deficiency	≥ 20	W2	Large winter water surplus	≥ 33.3

Thornthwaite considered potential evaporation as Thermal Efficiency (T-E index) and used it as a thermal limit in his climatic classification scheme.

Table 3. Thermal limits in climatic in Thornthwaite's classification

T-E Index	Thermal regime – climate Type*
0-14 cm	Frost (E)
14-28 cm	Tundra (D)
28- 56cm	Microthermal (D,C1, C2)

56-98cm	Mesothermal (C2, B1, B2, B3, B4)
Above 98 cm	Megathermal (B4, A1)

*Boundaries were taken in an arithmetic progression of T-E index with a common difference of 14 cm

8.4.4 Comparison of Koeppen's and Thornthwaite's Schemes

There are certain similarities as well as some distinct differences between the schemes of Koeppen and Thornthwaite. Both the schemes are based on empirical investigation. While Koeppen had considered vegetation to be a direct indicator of the totality of climate, Thornthwaite has given indirect recognition to the vegetational aspects through the concept of evapotranspiration which includes transfer of water from plants to atmosphere.

Both have used temperature and rainfall as basic atmospheric elements controlling climate. Koeppen considered the absolute values of critical climatic determinants, temperature and rainfall as recorded at different places. Thornthwaite. on the other hand, considered them through Thermal Efficiency and 'Precipitation Effectiveness', calculated by using evapotranspiration and moisture indices.

SSThornthwaite gave his scheme in 1931 and modified it thrice—in 1933, 1948 and 1955—each one being an improvement over the previous one. Thornthwaite's scheme is more widely used in applied climatology.

8.5 Climate Control

There are several natural factors that determine the climate of a place. These are called climatic controls. The varying influence of these factors leads to different parts of the earth experiencing differing climates. It is now well accepted that human activities also influences the climate of a place, but its impact is not the same everywhere. For example, changes appear to be happening faster near the poles than in many other places. Some of the most important natural factors are listed and discussed below. The influence of the human activities on the climate is also discussed.

8.5.1 Latitudinal variation in the solar radiation

Solar illumination at the earth varies in space and time. The annual amount of incoming solar energy varies considerably from tropical to polar latitudes. There is also considerable seasonal variation at the middle and high latitudes. Polar region receive solar radiation at lower angles and after passing through a thicker layer of atmosphere than at the equator. As a result the climate is cooler in the poles than equator. The poles also experience the greatest difference between summer and winter day lengths: in the summer there is a period when the sun does not set at all at the poles; conversely the poles also experience a period of total darkness during winter. In contrast, day length varies little at the equator.

8.5.2 Elevation or altitude

In the troposphere, the atmospheric air temperature normally decreases with altitude. As a result, high altitude regions experience cooler climate than adjacent low lands. In regions, where high mountain chains lie in the path of prevailing winds, the transfer of warm or cold air masses get blocked. In addition, the upward movement of air in the wind ward side and down ward movement of air in the leeward side may cause increased (decreased) precipitation in the windward (leeward) side. For example, Western Ghats that runs parallel to the western coast of the Indian peninsula block southwest monsoon winds from reaching the Deccan Plateau resulting large amount of rainfall (wet climate) in the windward side and relatively drier climate in the deccan plateau situated in the leeward side of the mountain ranges.

8.5.3 Distance from the sea

As oceans store heat, it can moderate climates of coastal areas. Coastal areas may enjoy refreshing breezes in summer, when cooler ocean air moves ashore. Coastal areas are cooler and wetter than inland areas. Clouds form when warm air from inland areas meets cool air from the sea. The interior parts of the continents experience large range of temperatures. For example, in the summer, the northwest India and central India experience very hot and dry climate as moisture from the sea evaporates before it reaches the interior parts.

8.5.4 Pressure and wind systems

The differential heating between high and low latitudes, land and ocean, snow-covered and bare land leads to difference in the atmospheric pressure. The pressure patterns drive wind patterns which in turn drive the oceanic circulation patterns. The pressure and circulation patterns have significant impact on the precipitation and atmospheric temperature patterns. For example, the southwest monsoon circulation over India is caused by the differential heating between large Asiatic land mass and Indian ocean south of it. Flow of moist air mass from the ocean to the warm land region results in rising of moist air, formation of clouds and precipitation. During the southwest monsoon season, Indian subcontinent experiences a wet climate.

8.5.5 Ocean currents

Ocean currents are caused by earth’s rotation, surface winds and the Coriolis force. Trade winds force warm water near the equator flow from east to west. The Coriolis effect causes water to be deflected northward away from the equator and sets up a rotational cycle in the oceans, making currents flow clockwise in the Northern Hemisphere and counter-clockwise in the Southern Hemisphere. When the currents reach the poles, the water cools and sinks. The temperatures (warm or cold) of these currents affect the climate of surrounding areas. Ocean currents induced by the global scale wind systems can also increase or reduce temperatures of a place.

8.5.6 Local features

Various local features such as the slope of the land, exposure conditions and the characteristics of vegetation and soil impact the climate of the place. In the northern Hemisphere, south facing slopes receive more direct sunlight and have warmer climate than those with a northern exposure, which not only face away from the sun, but are also more open to cold northerly winds. Areas with sandy, loosely packed soil, because of their low heat conductivity are inclined to experience more frosts than do areas with hard packed soils; Valleys normally have more frequent and severe frosts than the adjacent slopes. Cities are usually warmer than the adjacent country sides. The amount of sunlight that is absorbed or reflected by the surface determines how much atmospheric heating occurs. Darker areas, such as heavily vegetated regions, tend to be good absorbers; lighter areas, such as snow and ice-covered regions, tend to be good reflectors. The ocean absorbs and loses heat more slowly than land as the specific heat capacity of the ocean is higher than that of the land. Ocean water gradually release heat into the atmosphere, which then distributes heat around the globe.

8.5.7 Human activities

The factors described above affect the climate naturally. Earlier, impact of human activities on the climate was negligible. However, recently, this impact has become significant due to the increased populations and industrial activities. In the recent several decades, temperatures have been rising steadily throughout the world. However, it is not yet clear how much of this global warming is due to natural causes and how much is due to human activities, such as the burning of fossil fuels and the clearing of forests. Due to global warming, increase in the extreme weather and climate events like heat and cold waves, heavy rainfall, droughts and floods, cyclonic systems etc. have been reported from many parts of the globe.

8.6 Weather and climate predictions

Answers to the questions like will it rain today evening and how much will be the rainfall?, what will be the minimum/ maximum temperature tomorrow, will it be cooler tomorrow than today are provided by weather prediction. At present, weather predictions are prepared using complex mathematical models. Fig. 3 shows a 24 hr rainfall forecast

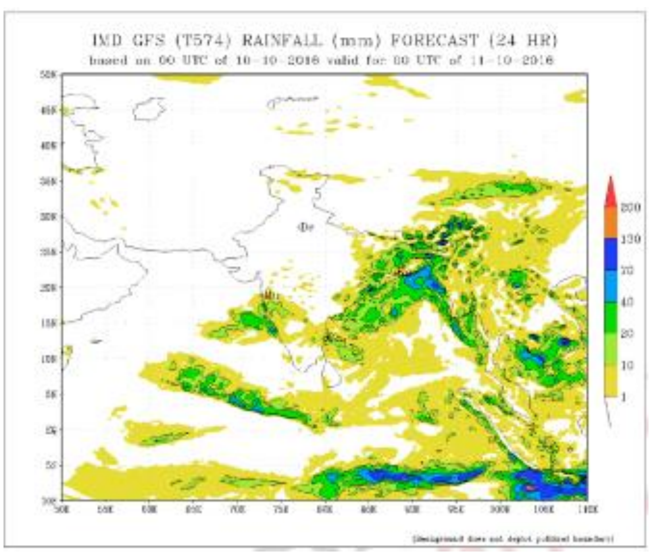

Fig. 3: The map shows the weather (rainfall in mm) forecast for 24 hr rainfall prepared on 10th October, 2016. **(Source: IMD)**

over Indian region using India Meteorological Department's (IMD) global forecast system model prepared on 10th October, 2016. These models use initial atmospheric conditions such as air pressure, temperature, humidity, winds, precipitation rates etc. to produce the best estimate of the future condition in the atmosphere. The initial atmospheric conditions are obtained from real time observations taken and transmitted using the global observational network set up by the countries around the world through an international arrangement. A schematic diagram of typical global observational network is shown in Fig. 4. This observation network includes surface meteorological stations, balloon measurements, shipboard measurements, and satellite and radar measurements. Once the model outputs are generated, weather forecasting involves interpreting the model outputs to figure out the most likely scenario. The accuracy of weather forecasts depends on the accuracy of the observed data that are used for running the models, capability of the model to simulate the weather phenomena accurately, and skill and experience of the forecaster.

Fig. 4. A schematic diagram of global observational network

(Source: World Meteorological Organisation, WMO)

The accuracy in the estimate of the initial conditions specified to the computer models decides the accuracy of the weather prediction. In spite of the large size of the current observational network, the observed data have several gaps as observations are made only from limited locations. Further these measurements are not always perfectly accurate. This causes imperfection in the initial conditions, which contributes some amount of uncertainty in the weather predictions even if understanding of the physics of the weather is perfect. Due to imperfect initial conditions, the errors in the model simulations of weather tend to grow. Thus longer the weather model is run into the future, the less accurate will be the prediction. Predictions of the weather just a week or two in advance, let alone decades, become highly problematic. As per the present capability, short-term weather forecasts are accurate only for around 5-10 days.

Climate predictions provide a much longer-term view and less concerned with exact time and place. It focuses on spatially and temporally averaged conditions. It provide answers to questions like how much warmer will the earth be 50 to 100 years from now?, which part of the globe (ocean or land, southern or northern hemisphere, low or high latitudes) will warm faster?, how much more precipitation will be there?, how much will sea level rise? what will be impact on the extreme weather events like cyclones, heavy rainfall, heat and cold waves etc. Climate predictions are made using global climate models. The climate prediction of annual mean surface temperature change & average percent change in annual mean precipitation during 2081-2100 with respect to 1986-2005 provided by InterGovernmental Panel on Climate Change (IPCC) in the 5th assessment report published in 2013 is given as Fig. 5. As can be seen, the warming is expected to be greatest over land; most increase could be at high northern latitudes and the least over the Southern Ocean and parts of the North Atlantic Ocean. Increase in precipitation is very likely in high latitudes and decrease is likely in most subtropical land regions.

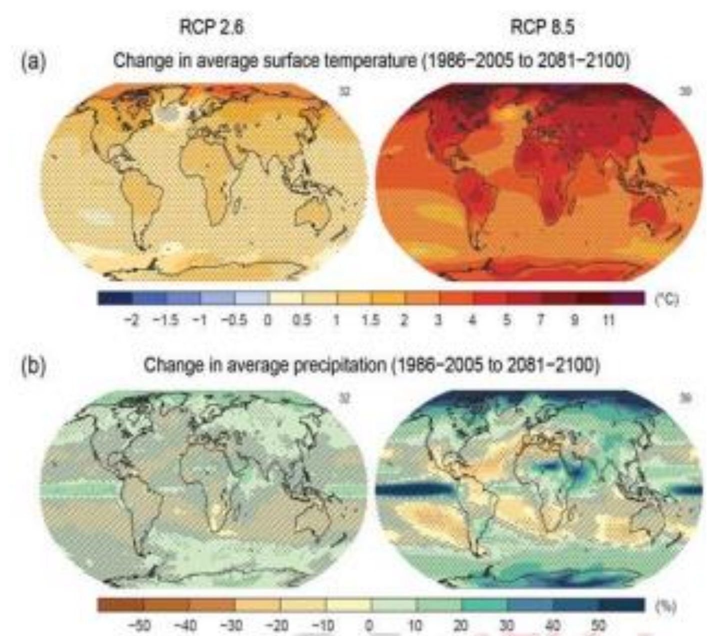

Fig. 5. Projected annual mean surface temperature change & average percent change in annual mean precipitation in 2081-2010 with respect to 1986- 2005 (Source: Inter Governmental Panel on Climate Change, IPCC).

Unlike in weather prediction where the accuracy of the prediction depends on the initial conditions of the atmosphere, the accuracy of the climate prediction depends on a host of boundary 16 Environmental Sciences Atmospheric Processes Weather and Climate conditions, many of which are linked to the atmosphere's energy. Boundary conditions are both natural and that influenced by human activities. Solar radiation and volcanic aerosols are natural boundary conditions. During the last about 1150 years, total solar insolation, observed at the top of the atmosphere, has varied by about 2 Wm-2 around an average of about 1361 Wm-2 . Similarly, large changes in the concentration and distribution of aerosols in the atmosphere associated with large volcanic eruptions produce changes in the reflectivity of the incoming solar radiation.

Human influenced boundary conditions include changes at the surface and changes in the atmosphere. At the surface, changes in the land use like cutting of forest for pasture and crops modifies the surface reflectivity and moisture, heat, and momentum exchanges between land and atmosphere. In the atmosphere, the most important human influenced changes are those that affect greenhouse gases. Greenhouse gases principally water vapor and carbon dioxide keep earth habitable by absorbing enough long-wave radiation to keep surface temperatures tens of degrees Celsius warmer than they would be otherwise. The warming of earth's surface due to the presence of greenhouses gases in the atmosphere is known as greenhouse effect. However, due to the rapid increase in the emission of different greenhouse gases into the atmosphere over the past two centuries, primarily due to burning of fossil fuels has caused significant warming of the global surface temperatures in recent decades. This is known as global warming.

Warming of air inside a car parked in the sunlight can be used an analogues example to understand the trapping of heat in the atmosphere by greenhouse gases. Sun's energy entering into the car through the windshield warms the air inside and gets trapped as the warm air cannot pass outside the car through the windshield, causing inside of the car to warm up.

Earth's energy balance is also altered by the human emissions of atmospheric aerosols. The composition of the aerosols and their distribution decide how they contribute to both warming and cooling of the climate. However, aerosols are thought to contribute an overall cooling effect equal to about half of the warming caused by greenhouse gases when averaged over the globe.

Summary

- Weather is the instantaneous physical condition or state of the atmosphere at a given time and place and its short-term variation in minutes to weeks.
- Climate is the statistical description of weather pattern over a region in terms of its mean and variability over a period of 30 yrs or more.
- Climate is what you expect, like a very hot summer, and weather is what you get, like a hot day with pop-up thunderstorms or a cool evening due to sudden summer rains.
- Atmospheric state variables or elements generally used to describe weather and climate over a place are temperature, humidity, precipitation, visibility, atmospheric pressure and wind. These atmospheric variables vary from once place to another, with the height and with time.
- The climate of a place is determined by influence of several natural factors called climate controls.

References

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Unit 9: Climate Change: Evidence and causes

Unit Structure

9.0 Learning Objectives

After reading this module, you will be able to:

- define climate change;
- explain natural and human induced factors responsible for climate change;
- Describe various evidences of climate change and their sources;
- describe the adverse impact of human activities on climate change; and
- analyse the probable consequences and impact of climate change at global as well as national level.

9.1 Introduction

We experience or hear about intense storms, frequent floods, severe drought, melting and receding glaciers etc. and the list goes on. You might have also read or heard that climate change is being cited as the major reason for such extreme events. For several years, global warming or climate change was considered as 'sceptics' argument. But, today it has been accepted as a reality. This was possible due to the significant contribution made by various scientists engaged in climate science research. Since the formation of Inter-Governmental Panel on Climate Change (IPCC) a concerted effort has been made to compile researches conducted across the globe on human induced climate change. Till now, IPCC has produced five Assessment Reports that provides latest scientific advancement in this area. This has also provided guidelines for policy makers for future.

In this module, we shall study climate change and describe various natural as well as human induced factors responsible for climate change. This would be followed by corroborating scientific evidences about human induced climate change. We will also discuss about the probable consequences and impacts of climate change both at global as well as at national level.

9.2 Definition Climate Change

In simpler terms, climate change may be expressed as any substantial change in the Earth's climate that lasts for an extended period of time. Normally, minimum thirtyyears' time period are being considered for analysing or predicting any climatic condition of a place. Two major elements of climate are temperature and precipitation.According to the Inter-Governmental Panel on Climate Change (IPCC), climate change refers to "***any change in climate over time, whether due to natural variability or as a result of human activity***" (IPCC, 2001a). The United Nations Framework Convention on Climate Change (UNFCC) in Article 1defined it as: "***climate change refers to a change in climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time period***" (IPCC, 2001a).

9.3 Global Change and Climate Change

Today, there are lots of discussions on global change issues rather than merely discussing about climate change. While talking about climate change, there is a need for a discussion on global change for two reasons:

1) Climate change is one among many global changes that has been affecting the earth.

2) Climate change has been affecting and has been affected by many of the global change phenomena.

Global change is a transformation that occurs on a worldwide scale e.g., an increase in carbon dioxide in the atmosphere or exhibits sufficient cumulative effects to have worldwide impact e.g. local species extinction resulting in global loss of biodiversity. In the past, the main drivers of global change have been solar output, plate tectonics, volcanism, proliferation and abatement of life, resource depletion, changes in Earth's orbit around the sun and changes in the tilt of Earth on its axis. There is increasing evidence that, now the main driver of global change, is the growing human population's demand for energy, food, goods and services, and disposal of its waste products. In the last 250 years, global change has caused climate change, widespread species extinctions, fish-stock collapse, desertification, ocean acidification, ozone depletion, pollution, and other large-scale shifts.

9.4 Sources of Climate Change

Do you know climate change had happened many a times on the Earth's history since itsorigin? Then, you must be thinking that why we are making so much hue and cry about this. This is because climate change in today's context is anthropogenic or in simpler term created by human activities. Evidences suggest that earlier climate change occurred due to natural processes. Therefore, in the beginning of the module we will discuss briefly about various natural sources responsible for climate change during different geological periods of earth's history. We will also discuss in details climate change due to anthropogenic activities that have been taking place in recent times.

The sources or the causes for climate change could be grouped into two:

- natural and

- anthropogenic

9.5 Natural Sources of Climate Change

Some of the factors mentioned below are responsible for long term climate change whereas others are responsible for short term climate change. Major natural sources of climate change aresolar variability, changes in Earth's orbit and tilt, plate tectonics and biological evolution.

Let us discuss briefly above mentioned factors one by one.

9.5.1 Solar Variability

This happens due to variation in solar energy output. You might have read that the energy output of the sun varies slightly over time. This has been measured by the data obtained through satellite. The variation in the total output has been observed both throughout the day as well as during the solar cycle. These variations can directly affect Earth's climate. But the exact role that solar variability plays is still a controversial and not unanimously accepted by the scientific community.

9.5.2 Changes in Earth's Orbit and Tilt

This was another major natural source responsible for climate change. You might have read that earth generally changes its orbit over a 100,000- year cycle. It normally shifts from almost a circular to elliptical orbit. This has led to changes in the tilt of Earth's axis between

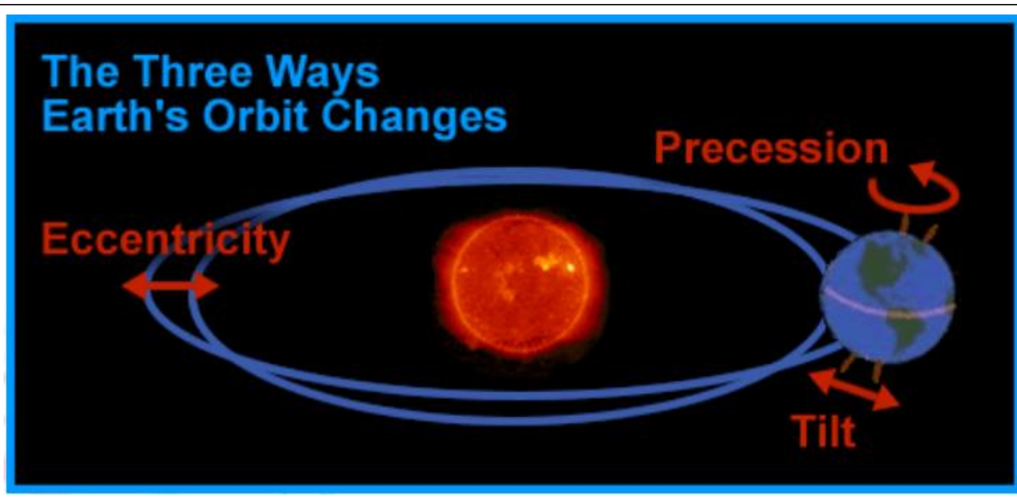

Figure 1: Climate Change due to Changes in Earth's Orbit and Tilt
Source:https://www.windows2universe.org/earth/climate/images/milankovich_lg.gif

21.8 and 24.4 degrees. As a result of which there has been change in the planet's solar energy budget. In other words, there used to be a change in the amount of solar radiation that different areas of the Earth receive. The northern hemisphere is now closer to the sun in winter and farther away in summer. As a result of which it receives five percent less sunlight in summer than 12,000 years ago. More tilt leads to greater seasonal variations. This is known as Milankovitch cycle (Refer to Figure 1). Milankovitch was a Serbian geophysicist and astronomer who theorized this above mentioned phenomena.

9.5.3 Plate Tectonics

As a geography student, you might have read about continental drift and plate tectonic theory in your course on Physical Geography or specifically in geomorphology. As described by both the theories, millions of years ago most of the Earth's land mass was a single continent known as Pangea and surrounded by one huge water bodies known as panthalas. Over time, portions of it drifted apart, gradually forming the continents and ocean basins existing today. The redistribution of land mass and ocean area has had a major effect on global climate.

9.5.4 Biological Evolution

This natural process took place mainly during the evolution of photosynthetic organism. Do you know that several billion years ago Earth's pre-life atmosphere was mainly covered by carbon dioxide and methane? The gradual shift in the atmospheric concentrations fromcarbon dioxide and methane to nitrogen and oxygen took place because photosynthetic organisms consumed carbon dioxide and generated oxygen.

9.6 Climate Change due to Anthropogenic Activities

As mentioned in the beginning of the module, today's climate change is primarily due to anthropogenic activities. But, do you know how we have arrived on such conclusion? There was lots of scientific research that took place over the last two hundred years that helped in concluding about the present climate change is due to anthropogenic activities. Let us discuss these scientific developments in brief.

9.6.1 Scientific Study to Establish Human Induced Climate Change

As we know, today's climate change is due to presence of excessive greenhouse gases in the atmosphere due to human activities. This led to increase in temperature on the earth surface due to greenhouse effect. Do you know the scientist who identified the problem created by greenhouse effect? The French mathematician, Joseph Fourier highlighted the greenhouse effect. Fourier realized that the earth's temperature is determined not only by the radiation absorbed by, and emitted from the earth, but also by the existence of the atmosphere. The atmosphere absorbs some of the radiated heat and acts as a blanket over the Earth that maintains the temperature higher than it would otherwise be.

The next major breakthrough was made in 1860 by the British scientist John Tyndall in terms of measuring the absorption of radiation by different gases. This led to the remarkable discovery that the most prevalent gases in the atmosphere i.e. oxygen and nitrogen weren't absorbing any of the energy at all. Only the minor gases in the atmosphere, i.e., carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O) and water vapour, were doing so. These gases are called greenhouse gases (GHG).

The Swedish scientist, Svante Arrhenius was the first person to estimate the extent to which increases in atmospheric carbon dioxide increase Earth's surface temperature. This is also known as Arrhenius effect. Presently, studying climate system is much more advanced due to the advancement in information and communication technology aided by space technology.

9.6.2 Global Warming and Anthropogenic Activities

Till now, you might have realized that global warming is most commonly associated with human interference, specifically the release of excessive amounts of greenhouse gases. These gases, act like a greenhouse around the earth. This means that these gases allow the heat from the Sun to enter into the atmosphere, but do not allow the heat to escape back into space. In other words, more increase in the greenhouse gases, the larger is the percentage of heat trapped inside the earth's atmosphere. You might be knowing that the earth would have not been inhabitable without the presence of some naturally occurring greenhouse gases (GHG). This is because without these gases, no heat would be trapped in the atmosphere, so the earth would be extremely cold. It is estimated that the average temperature of the earth would be about -170C without greenhouse effect which is not at all the condition for the growth of biota. Naturally occurring greenhouse gases (not fluorinated gases) are good in naturally occurring amounts; it's when people start contributing excessive amounts of these that greenhouse gases become a problem. With excessive greenhouse gas build-up, the earth's atmosphere warms to unnatural temperatures.

Let us understand how various human activities contribute in increasing these GHGs.

9.6.3 How do Human Activities Contribute to Climate Change?

Different anthropogenic activities lead to emissions of four principal greenhouse gases: carbon dioxide, methane, nitrous oxide and the halocarbons (a group of gases containing fluorine, chlorine and bromine). These gases accumulate in the atmosphere and have been increasing with the passage of time. The most significant aspect about the increases in all of these gases is that they have occurred in the industrial era which is not more than 300 years old. This is because of influence of human activities particularly in recent centuries. Itis so significant that it has been affecting all the living organisms on the earth.

Carbon dioxide has been increasing from the utilization of fossil fuels in transportation, building heating/ cooling and in the manufacture of cement and other goods. Deforestation releases CO2 and reduces its uptake by plants. Carbon dioxide is also released in natural processes such as the decay of plant matter.

Methane has increased as a result of human activities related to agriculture, natural gas distribution and landfills. Methane is also released from natural processes that occur, for example, in wetlands.

Nitrous oxide is emitted by human activities such as fertilizer use and fossil fuel burning. Natural processes in soils and the oceans also release N2O.

Halocarbon gas concentrations have increased primarily due to human activities. Principal halocarbons include the chlorofluorocarbons (e.g., CFC-11 and CFC-12), which were used extensively as refrigeration agents and in other industrial processes before their presence in the atmosphere was found to cause stratospheric ozone depletion.

We will discuss in detail about these gases and their major sources in the next module which exclusively discuss about role human being on climate change.

9.7 Sources of Evidences about Climate Change

When we discuss about the science of climate change we generally look for evidences and causes responsible for climate change. As a result of which the scientific community including geographers look for three key elements. These three key elements are “the study of past climates, the measurement of current climate change and the modelling and projections of future climate scenario.” (Christopherson and Birkeland, p. 316) Scientists all over the world have been systematically compiling and analyzing different climate related parameters to ascertain about the changing climate. They have also made an attempt to ascertain that the present climate change is human induced. The IPCC, since its inception in 1988 has been working as the international scientific organization coordinating global climate change research, climate forecasts, and policy formulation by engaging in collaboration of scientists and policy experts from many disciplines across the globe. Therefore, this assertion is based on certain facts rather than any speculation or politically motivated. Some of the sources of evidences are as follows:

9.8 Evidences of Climate Change

Climate scientists have been constantly engaged in gathering information on key parameters of climate that indicates that some of these parameters have been unequivocally reflect warming of climate. These evidences are gathered from various sources for last hundred years as well as in extensive details for the last two to three decades. Various sources used for gathering such information are innumerable weather stations across the globe, satellites, ships, aircrafts, weather balloons and buoys. These evidences are collated and trend analysis has been undertaken by numerous scientists engaged at national and international level.

At the international level, these researches are compiled and global trends have been reported by the Intergovernmental Panel on Climate Change (IPCC) in the form of Assessment Reports. IPCC since its origin in 1988, has already been published these assessment reports. So far, five reports have been published in chronological order. The latest Fifth Assessment Reports have been published between September 2013 and April 2014. For details about IPCC and its reports, you can refer its website http://www.ipcc.ch.

As mentioned above, there are certain parameters that provide indication of warming of climate. Some of these indicators are as follows:

a. Increasing temperatures over land and ocean surfaces;

b. Melting glacial ice and sea ice;

c. Rising sea level; and

d. Increasing humidity. (Christopherson and Birkeland, p. 316)

Let us have a detailed discussion on these indicators of climate change in the following section.

9.8.1 Increasing Temperatures over Land and Ocean Surfaces

If we analyse temperature data in terms of hemisphere since 1880, it has been observed

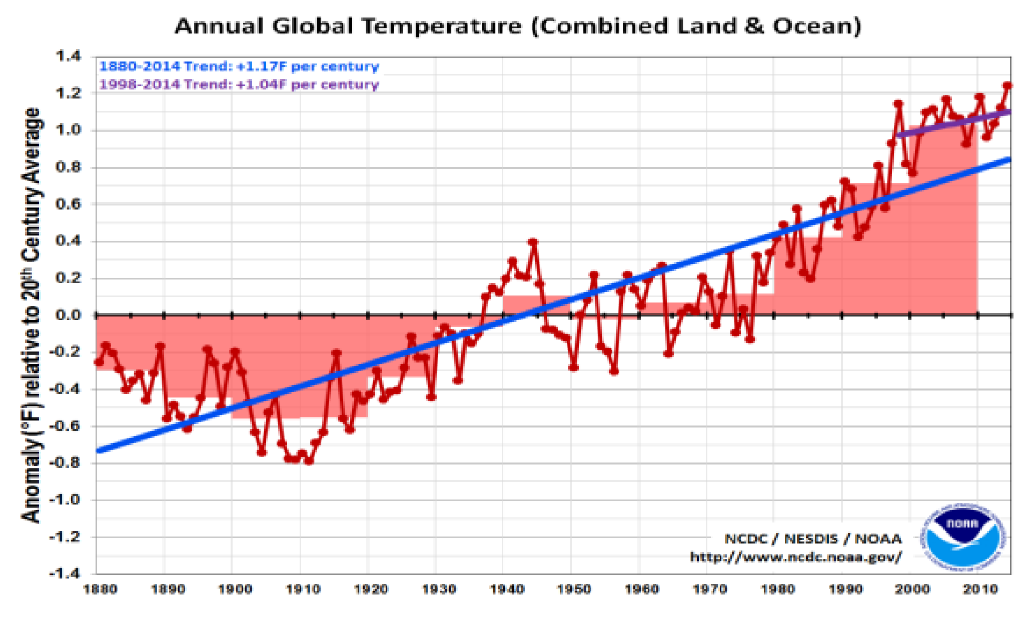

Figure2: Global Temperature Change 1880-2004

Source:https://www.ncdc.noaa.gov/monitoring-content/sotc/global/2014/ann/timeseries/trend-since-1998.png

that the years with the warmest land-surface temperatures were 2005 and 2010 in the Northern Hemisphere. In the Southern Hemisphere, 2009 was the warmest. It has also been observed that the period from 2000 to 2010 was the warmest decade since 1880 Refer to Figure 2). The data from long-term climate reconstructions of temperature point to the present time as the warmest in the last 120,000 years. These reconstructions also suggest that the increase in temperature during the twentieth century is extremely likely (within a confidence interval of greater than 95%–100 %) the largest to occur in any century over the past 1000 years. Recordsetting summer daytime temperatures are being recorded in many countries. According to National Oceanic Administration of America (NOAA) oceantemperatures have also been rising. According to NOAAsea surface temperatures increased at an average rate of 0.07 C° (0.13 F°) per year from 1901 to 2012 as oceans absorbed atmospheric heat. This rise is reflected in measurements of upper-ocean heat content, which includes the upper 700 m (2296 ft.) of ocean.

9.8.2 Melting of Glacial and Sea Ice

You might have read in the newspapers, magazines or heard from TV, Radio etc. that glacier in Greenland and Antarctica have been receding due to fast rate of melting. Is this a fact? If yes, what are the reasons responsible for such situation? As discussed in the previous paragraph that there has been increase in surface temperature both at land and sea. This rise in temperature has a direct relationship with the melting of glacial and sea ice.

As temperatures rise in Earth's atmosphere, glaciers are losing ice mass, shrinking in size. This process is known as glacial retreat. Earth's two largest ice sheets, in Greenland and Antarctica, are also losing icemass. This is evident from the satellite records. Analysis of satellite data of July 2012 revealed that 97% of the ice sheet's surface was melting. This was the greatest extent in the 30-year record of satellite measurements. Another analysis related to summer melt of the Greenland ice sheet has also revealed that it has increased 30% from 1979 to 2006. On the basis of these evidences, scientists now estimate that between oneand two-thirds of Arctic permafrost will thaw over the next 200 years. As you know, these permafrost reserves took thousands of years to form.

Similar kind of observation has also been noticed in relation to sea ice. Maximum sea ice cover in the world is found in the Arctic Sea. The extent of Arctic Sea ice varies over the course of a year. Every summer, some amount of sea ice thaws whereas in winter, the ice refreezes. It has been observed with the help of satellite data that the minimum extent of summer sea-ice occurs in September whereas maximum extent of winter sea-ice occurs in the months of February or early March. However, analysis of satellite data revealed that this has declined since 1979 (Refer to Figure 3). September sea ice is declining at a rate of 11% per decade in comparison to the 1979– 2000 average and reached its lowest extent in the

Figure 3: Shrinking of Glacial and Sea Ice 1984-2012
Source: https://scitechdaily.com/images/arctic-sea-ice-comparison.jpg

modern record in 2012. The accelerating decline of summer sea ice, in association with record losses of sea ice in 2007 and 2012, suggests that summer sea ice may disappear sooner than predicted by most models. Some scientists have also estimated an ice-free summer Arctic Ocean within the next few decades.

9.8.3 Rising Sea-Level

This is another important indicator of climate change. It has been observed that sea level is rising more quickly than the prediction simulated by most of the climate models. During the last century, sea level rose 17–21 cm (6.7–8.3 in.). However, this rise is not uniform across the globe. A greater rise has been observed in some areas like Atlantic coast of U.S. than at any time during the past 2000 years. How did the scientists arrive at such conclusion? Do you have any idea about the tools used for assessing the rise in sea level? Generally we use tidal gauges and satellites to generate such kind of data. Tidal gauge records from 1901 to 2010 show that sea level rose at a rate of 1.7 mm (0.07 in.) per year. Satellite data for the period 1993 - 2013 show that sea level rose 3.16 mm (0.12 in.) per year. This rise is primary due to two major factors that are presently contributing to sea-level rise. About two-thirds of the rise comes from the melting of glaciers and ice sheets whereas the rest one third comes from the thermal expansion of seawater due to absorption of atmospheric heat and expand in volume.

9.8.4 Increasing Humidity and Extreme Events

It has been observed that global average specific humidity has increased by about 0.1 g of water vapour per kilogram of air per decade since 1973. This change is consistent with rising air temperatures, since warm air has a greater capacity to absorb water vapour. A greater amount of water vapour in the atmosphere affects weather in a number of ways and can lead to “extreme” events involving temperature, precipitation, and storm intensity. According to the World Meteorological Organization, the decade from 2001 to 2010 showed evidence of a worldwide increase in extreme events, notably heat waves, increased precipitation, and floods. However, to establish a strong linkage between trends related to extreme weather and climate change requires data for a longer timeframe than what is now available.

These above mentioned change have differential impacts in terms of geographical locations, sectors of economy and socio-economic groups. Therefore, some of the major impacts/ consequences of climate change are mentioned for two levels. One is at macro scale i.e. at global level and the other at micro-level i.e. at national level.

9.9 Observations of Changes in Climate at Global Level

Some of the major observations of Fifth Assessment Report (2013) by IPCCare given below:

- Each of the last three decades has been successively warmer at the earth’s surface than any preceding decade since 1850.
- Ocean warming dominates the increase in energy stored in the climate system, accounting for more than 90% of the energy accumulated between 1971 and 2010. Further uptake of carbon by the ocean will increase ocean acidification.
- Over the last two decades, the Greenland and Antarctic ice sheets have been losing mass, glaciers have continued to shrink almost worldwide, and arctic sea ice and northern Hemisphere spring snow cover have continued to decrease in extent.
- The rate of sea-level rise since the mid-nineteenth century has been larger than the mean rate during the previous two millennia. Over the period 1901–2010, global mean sea level rose by 0.19 m (0.6 ft).
- The atmospheric concentrations of carbon dioxide (CO2), methane, and nitrous oxide have increased to levels unprecedented in at least the last 800,000 years, primarily from

fossil-fuel emissions and secondarily from net land-use-change emissions. The ocean has absorbed about 30% of the emitted anthropogenic carbon dioxide, causing ocean acidification.

- Total radiative forcing is positive and has led to an uptake of energy by the climate system. The largest contribution to total radiative forcing is caused by the increase in the atmospheric concentration of CO2 since 1750.
- Warming of the climate system is unequivocal. Many of the temperature changes observed since the 1950s are unprecedented over decades to millennia. It is extremely likely (95%–99%) that human influence has been the dominant cause of the observed warming since the mid-twentieth century.
- Climate models have improved since the Fourth Assessment Report. Models reproduce observed continental-scale surface temperature patterns and trends over many decades, including the more rapid warming since the mid-twentieth century and the cooling immediately following large volcanic eruptions.
- Continued emissions of greenhouse gases will cause further warming and changes in all components of the climate system. Limiting climate change will require substantial and sustained reductions of greenhouse gas emissions.
- Changes in the global water cycle will not be uniform. The contrast in precipitation between wet and dry regions and between wet and dry seasons will increase.
- Global mean sea level will continue to rise. The rate of sea-level rise will very likely exceed that observed during 1971–2010, due to increased ocean warming and increased loss of ice mass from glaciers and ice sheets.

Source: Climate Change 2013, The Physical Science Basis, Summary for Policy Makers, Working Group I, Contribution to the Fifth Assessment Report of the IPCC.

9.10 Observations of Changes in Climate at National Level

In India, Ministry of Environment, Forest and Climate Change is the nodal agency which has been sending reports to UNFCC. Till now, it has already sent two reports titled as India's First and Second National Communications to the United Nations Framework Convention on Climate Change in 2004 and 2012 respectively. Let us discuss briefly about these reports.

The future impacts of climate change, identified by the Government of India's National Communications (NATCOM) in 2004 include:

- Decreased snow cover, affecting snow-fed and glacial systems such as the Ganges and Brahmaputra. About70% of the summer flow of the Ganges comes from melt water
- Erratic monsoon with serious effects on rain-fed agriculture, peninsular rivers, water and power supply
- Drop in wheat production by 4-5 million tonnes, with even a 1ºC rise in temperature
- Rising sea levels causing displacement along one of the most densely populated coastlines in the world, threatened freshwater sources and mangrove ecosystems
- Increased frequency and intensity of floods. Increased vulnerability of people in coastal, arid and semi-arid zones of the country
- Studies indicate that over 50% of India's forests are likely to experience shift in forest types, adversely impacting associated biodiversity, regional climate dynamics as well as livelihoods based on forest products.

Indian Network for Climate Change Analysis (INCCA) in the recently released report titled "Climate Change and India: A 4x4 Assessment - A Sectoral and Regional Analysis for 2030s" assess differential impacts on the basis of observed climate change and climate change projections for the year 2030s on selected sectors such as water resources, agriculture, forests and human health of selected four distinct geo-ecological regions of India that are sensitive to climate change. These regions are the Himalayan region, North-Eastern region, Western Ghats and Coastal regions.

According to the report "The choice of the sectors and regions is in conformity with the significance and importance of the climate sensitive sectors of the economy that cover the wellbeing and livelihoods of the large population residing in these regions" (INCCA 2010, p.12). But the complete extent and level of climate change impacts on India are still to be studied because it is very diverse and complex in nature. This is because vulnerability to climate change increases due to "low adaptive capacity to withstand the adverse impacts of climate change due to high dependence of the majority of the population on climate-sensitive sectors like agriculture and forestry, poor infrastructure facilities, weak institutional mechanisms and lack of financial resources" (Shukla et al. 2003, p.13).

Summary and Conclusions

Climate change refers to a change in climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time period. Major natural sources of climate change are solar variability, changes in Earth's orbit and tilt, plate tectonics, and biological evolution.Various anthropogenic activities lead to emissions of four principal greenhouse gases: carbon dioxide, methane, nitrous oxide and the halocarbons. These gases accumulate in the atmosphere and have increased with the passage of time.

The increase in greenhouse gases within a small period of human history is a problem since it has adverse and differential impacts on different sectors and region. Some of the adverse impacts would be: melting of ice cap, rise in sea level, submergence of many island countries and densely populated coastal areas, increasing frequency of extreme weather events etc.

There are certain global parameters that provide indication of warming of climate. Some of these indicators are increasing temperatures over land and ocean surfaces; increasing sea surface temperature and ocean heat content; melting glacial ice and sea ice; rising sea level; increasing humidity and increase in extreme events.

In India, Ministry of Environment, Forest and Climate Change is the nodal agency which has been sending reports to UNFCC. Till now it has already sent two reports titled as India's First and Second National Communications to the United Nations Framework Convention on Climate Change in 2004 and 2012 respectively.

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Unit 10: Climate Change and Food Security

Unit Structure

10.0 Learning Objectives

After completion of this unit you will be able to:

- define climate change and food security,
- explain the impacts of climate change on agriculture,
- discuss various dimensions of food security,
- explain the impacts of climate change on food security, and

- Explain the importance of climate smart agriculture.

10.1 Introduction

We know that food systems, a product of human ingenuity, is a complex ecosystem whose outcome and sustainability is driven by its inherent potential and biophysical and social environment. Food security is the outcome of functioning food system and innate properties of the food systems. Food system and food security are influenced by a web of factors like climate change, technological interventions and structural changes in the food system, demographic changes, energy security, population pressure and income driven consumption pattern. The detailed study of climate change and food security help in better conceptualization of the effect of climate change on agriculture and consequently on food security. It is pertinent to know that, the food security is dependent on food production, socio-economic condition, land-use, trade policy, demographics, and food - and water- borne disease.

It is hard fact to state that about 800 million people across the globe are food insecure and about 2 billion thrive with food diet with insufficient nutrients. This grim scenario has led the global community to place utmost importance on food security, climate change and kindred issues through Sustainable Development Goals. As regards the relationship persisting among climate change, agriculture and food security, there is an urgent need to develop climate smart agricultural practices as today's humanity is facing greatest environmental challenge in the form of climate change and global warming. You would be well aware about the negative repercussions of climate change and variabilityon agro-biodiversity, soil resources, water resources which eventually increases the vulnerability of agriculture.In this module, it is attempted to discuss the climate change and its impacts on food security in the present day society.

10.2 Climate System

10.2.1 Weather and climate

Though words weather and climate sounds similar, the differences exist between the terms from the perspective of space and time. You have studied that weather reflects the state of atmosphere at a particular time and place. Weather is the daily or short term variations of different conditions of lower air in terms of temperature, pressure, wind, rainfall, etc.On the other hand, climate is a statistical measure of state of atmosphere in terms of meteorological variables like temperature, rainfall, humidity, etc. for a particular region for a period of more than 35 years. The climate can fluctuate on short time scales, producing for instance the hydrological drought and over much longer time-scale giving rise to glacial epochs.

10.2.2 Components of climate system

The United Nation Framework convention on climate change defined the climate system as the totality of the atmosphere, hydrosphere, biosphere and geosphere and their interactions (McGuffie and Henderson-Sellers, 2005). The schematic view of the components of the climate system, their processes and interactions are presented in Figure 1.

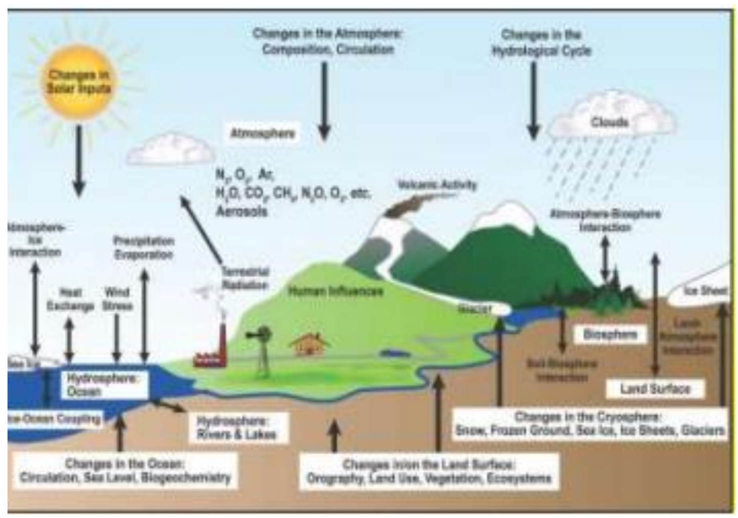


Figure 1: Components of Climate System, their Processes and Interactions

Source IPCC, 2007

You can see from the schematic presentation, that the climate system is powered by solar radiation. Since the Earth's surface temperature has been relatively constant over many centuries, the incoming solar shortwave radiation (SWR) must be nearly in balance with outgoing longwave radiation (LWR). About half of SWR is absorbed by the Earth's surface. About 30% of SWR is reflected back to space and 20% of SWR is absorbed in the atmosphere. The LWR emitted from the Earth's surface is largely absorbed by radiatively active gases like water vapour, carbon dioxide, methane, nitrous oxide and other greenhouse gases. The downward directed component of this LWR heats the lower atmosphere and this process is popularly called greenhouse effect (IPCC, 2013).

10.2.3 Climate Forcing

The climate system is a dynamic system in temporary balance. Changes in the climate system either due to the natural and anthropogenic reasons can perturb the Earth's radiation budget, resulting in a radiative forcing (RF) that affects climate. The forcings can be construed broadly as external and internal forcings (McGuffie and Henderson-Sellers, 2005; IPCC, 2013). The factors influencing the climate of our Earth is diagrammatically presented in Figure 2. External forcing refers to a forcing agent outside the climate system causing a change in the climate system. The galactic variations, orbital forcing and solar forcing are external forcings (IPCC, 2013). On the other hand, the processes intrinsic to Earth and its atmosphere alter climate. These internal forcing factors include mountain building (orogeny), distribution of landmasses, volcanic activity, atmospheric composition, chemistry and surface reflectivity as presented in the Figure 2.

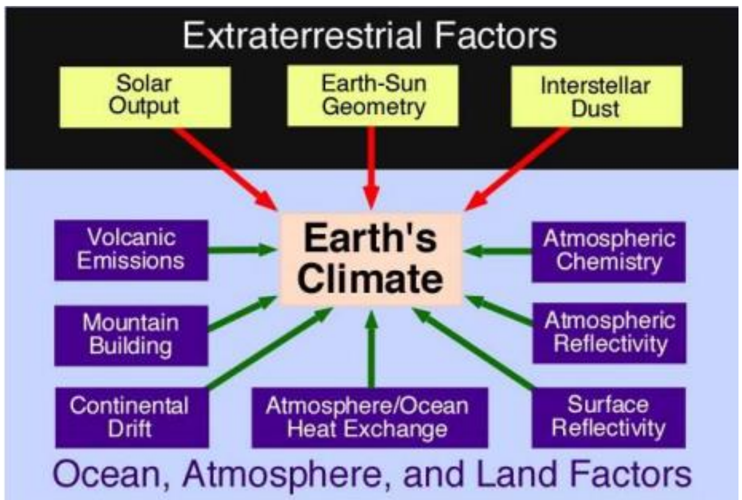


Figure 2: Factors Affecting the Climate of the Earth
Source: Source:http://www.physicalgeography.net/fundamentals/images/climatefactors.jpg

10.3 Climate Change

Climatic conditions are varying in nature all through the earth's history. The weather records for most part of the world exist only for few hundred years in developed countries but in less developed countries, the weather data exists for few decades only. However, the proxy indicators of past data from pollen analysis, tree rings, ice cores, beetles, sea sediments have provided ample evidence for non-static nature of climate. The IPCC in its fifth assessment report stated that warming of the climate system is unequivocal, and since the 1950s, many of the observed changes are unprecedented over decades to millennia. The atmosphere and ocean are getting warmer with every passing year. The amounts of snow and ice are on decline, sea level is on rise and the concentration of greenhouse gases is increasing. Climate change influences all the components of biosphere. The Figure 3a depicts the trend of globally averaged combined land and ocean surface temperature anomaly, globally averaged sea level change (3b), and globally averaged greenhouse gas concentrations (3c). The climate change that we witness is reported to be induced by anthropogenic activities and the Figure 3d exemplifies the contributions and increasing trend of anthropogenic CO2 and the atmospheric build-up of GHG are one of the prime drivers of climate change. There is very high correlation among the variables shown in the Figure 3 as all are increasing with the

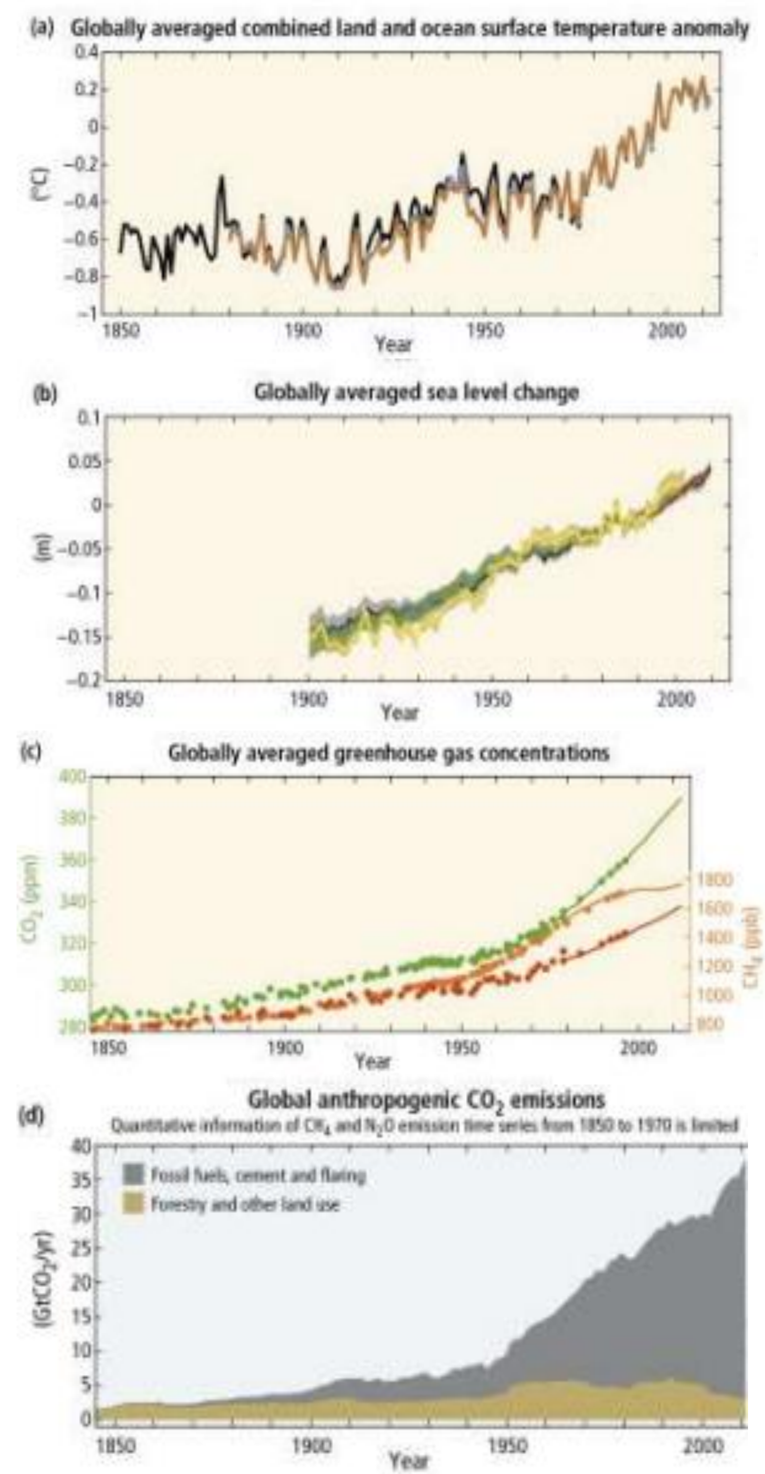


Figure 3: Increasing Trends of Temperature, Sea Level, GHG and CO2
Source: IPCC, 2014

record time since 1850.

10.3.1 Defining Climate Change and Variability

Climate change is the variation in either mean state of the climate or in its variables persisting for an extended period, typically decades or longer. It includes temperature increase (global warming), changes in precipitation pattern, sea level rise and increased frequencies of extreme weather events. Further, climate change follows a specific pattern of change in climate or its variables over the time. On the other hand, Climatic variability refers to sudden and discontinuous seasonal or monthly or periodic changes in climate or its components without showing any specific trend of temporal change (IPCC, 2013).

10.3.2 Global Temperature Rise

Global temperature is considered as a popular metric indicating the state of global climate. Global warming is defined as the increase in the average temperature of earth's near surface air and oceans due to the transmission of incoming short wave solar radiation and the absorption of outgoing long wave terrestrial radiation. The globally averaged combined land and ocean surface temperature data as calculated by a linear trend, show a warming of 0.85°C, over the period 1880 - 2012 (Figure 3a). Between 1906 and 2005, the global climate system was observed by 0.74°C. The graph showing the influence of natural and human factors on global temperature change is represented in Figure 4. Changes in many extreme weather and climate events have been observed since about 1950. Particularly, the number of cold days and nights has decreased and the number of warm days and nights has increased on the global scale (IPCC, 2013).

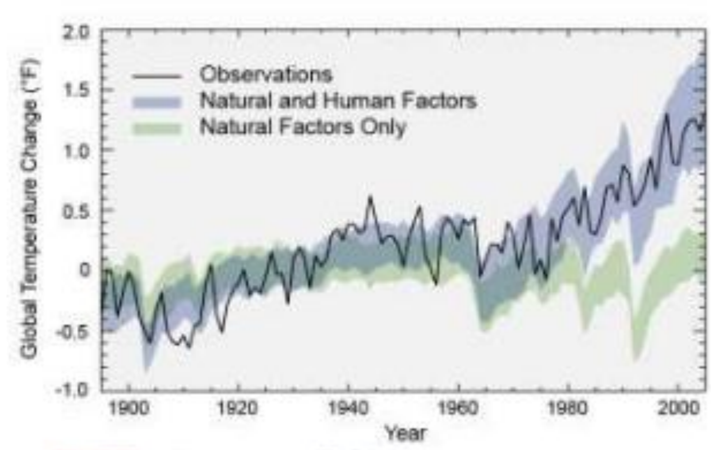


Figure 4: Influence of Natural and Human Factors on Global Temperature Change

Source:https://19january2017snapshot.epa.gov/sites/production/files/2016-07/models-observed-human-natural.png

10.4 Climate Change and Agriculture

Modern agriculture with the aid of advanced technologies and practices like chemical fertilization, pest and disease control using diverse group of pesticides, irrigation, crop varieties and hybrids, etc. had increased global crop production substantially. However, converging trends in population growth, natural resource use, food prices, climate variability and climate change jeopardize agricultural production system, food and nutritional security and agricultural sustainability. Systematic understanding of the linkages between agriculture and climate change reveals the net negative impacts of climate change on crop distribution and crop production, emission of greenhouse gases from agriculture and the potential of agricultural sector to augment the global efforts to address both adaptation and mitigation to climate change.

10.4.1 World Agriculture

Globally, croplands cover 1.53 billion hectares (about 12% of Earth's ice-free land), while pastures cover another 3.38 billion hectares. Altogether, agriculture occupies about 38% of Earth's terrestrial surface and it is essentially the largest use of land on the planet (Ramankuttyet al., 2008). Climate change will influence crop distribution and production and increase risks associated with agricultural farming (Scherret al., 2012). IPCC through its various reports categorically states that climate change affects crop production in several regions of the world, and developing countries and island countries are highly vulnerable to negative impacts (IPCC, 2014a). Climate change induced extreme events such as drought, floods, marine transgression, abnormally high maximum temperatures have become common occurrence in the last decade.

10.4.2 Greenhouse Gases Emission from Agriculture

The changing concentrations of greenhouse gases are key indicator of global climate change. Total anthropogenic GHG emissions from different economic sectors in 2010 as depicted in the Figure 5 amounts to 49 gigatonne of CO2-equivalent per year (GtCO2-eq/yr). Greenhouse gases emissions are converted into CO2-equivalents based on 100-year Global Warming Potential (GWP100). Equivalent carbon dioxide emission is defined as "the amount of carbon dioxide emission that would cause the same integrated radiative forcing, over a given time horizon, as an emitted amount of a greenhouse gas or a mixture of greenhouse gases" (IPCC, 2013). The emission data on agriculture, forestry and other land use (AFOLU) includes landbased CO2 emissions from forest fires, peat fires and peat decay that approximate to net CO2 flux from the sub-sectors of forestry and other land use (FOLU). The AFOLU sector accounts for about 10–12 gigatonne of CO2-equivalent per year.

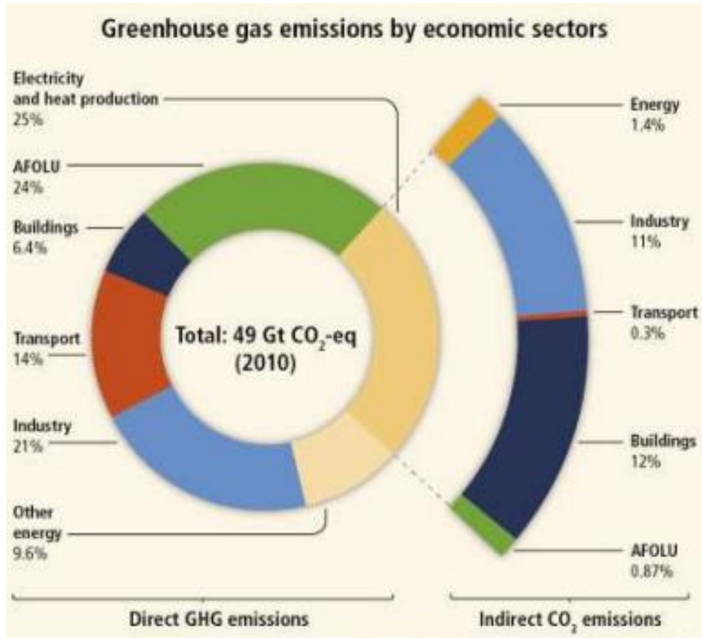


Figure 5: Greenhouse Gases Emissions from Different Economic Sectors
Source: IPCC, (2014). Climate Change 2014: Synthesis Report

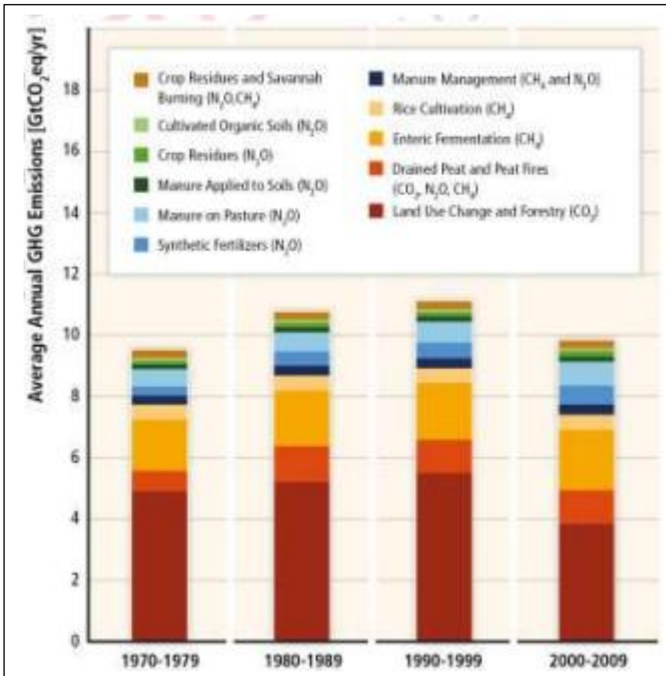


Figure 6: Average Annual Greenhouse Gases Emissions from Agriculture
Source: IPCC, (2014). Climate Change 2014: Synthesis Report

The greenhouse gases emissions in agriculture as shown in the Figure 6 are mainly due to land use change and forestry, enteric fermentation, drained peat and peat fires, lowland rice cultivation and use of synthetic fertilizers, and biomass burning (Lipper et al., 2014). As regards the GHG emissions from agriculture, the most cost-effective mitigation options are cropland management, grazing land management, and restoration of organic soils. It is observed that policies governing agricultural practices are more effective when involving both mitigation and adaptation (IPCC, 2014b).

10.4.3 Impact of Climate Change on Agriculture

Some of the direct impacts of climate change over the coming decades will be on agricultural food system. Climate change can affect agriculture through their direct and indirect effects on the crops, livestock, soils and pests. The potential impacts of climate change on different sectors of agriculture are presented in the Table 1. Climate change through its negative impact on crop yields increases theproduction and market risk and results in food insecurity among the vulnerable sections of the farming community. Climate change is reported to reduce the crop yields (Lobell et al., 2011). Globally, climate change is expected to reduce cereal production by 1% to 7% by 2060. Climate change could potentially interrupt progress toward a world without hunger. Climate variability and change will exacerbate food insecurity in areas currently vulnerable to hunger and under-nutrition. Food access and utilization will be affected indirectly via collateral effects on household and individual incomes, and food utilization could be impaired by loss of access to drinking water and damage to health (Wheeler, T. and Braun, J., 2013).

Table 1. Potential Impacts of Climate Change on Different Sectors of Agriculture

Sector	Impact
Crop	• Carbon dioxide fertilization effect: Increase in ambient CO2 concentration is beneficial since it leads to increased photosynthesis in several crops, especially those with C3 photosynthetic pathway such as wheat and rice, and decreased evaporative losses. • Yields of major cereals crops, especially wheat are likely to be reduced due to decrease in grain filling duration, increased respiration, and / or reduction in rainfall/irrigation supplies. • Yield Reduction in rainfed crops is ascribed to erratic monsoonal rainfall and increased crop water demand. • Increase in extreme weather events such as floods, droughts, cyclones and heat waves will adversely affect agricultural productivity. • Increase in Pest and disease outbreak on account of rapid pathogen transmission and increased host susceptibility. • Threat to Agricultural biodiversity due to the global changes in the climaterelated parameters like temperature, rainfall and sea level.
Water	• Irrigation water demand would increase with rise in temperature and evapotranspiration rate.

	• The water balance in different parts of India will be affected and the quality of groundwater in the coastal region will be affected more due to intrusion of sea waters.
Soil	• Organic matter content, which is already quite low in Indian soils, would become still lower. • Rise in soil temperature will increase N mineralization, but its availability may decrease due to increased gaseous losses through processes such as volatilization and denitrification. • Change in rainfall volume and frequency, and wind may alter the severity, frequency and extent of soil erosion. • Sea level rise may lead to sea water ingression in the coastal areas, turning them less suitable for conventional agriculture.
Livestock	• Climate change and associated phenomena will affect fodder production and nutritional security of livestock. • Changes in rainfall pattern may also influence vector population during wetter years, leading to large outbreaks of diseases. Climate change is likely to aggravate the heat stress in dairy animals, adversely affecting their reproductive performance.
Fishery	• Increasing temperature of sea and river water is likely to affect breeding, migration and harvests of fishes. • Impacts of increased temperature and tropical cyclonic activity would affect the capture, production and marketing costs of the marine fish. Source: Aggarwal et al. (2009) and Pathak et al., 2012

Particularly in the agriculture sector, climate change adaptation can go hand-in-hand with mitigation. Climate change adaptation and mitigation measures need to be integrated into the overall development approaches and agenda.

10.4.4 Mitigation Strategies to Climate Change

Mitigation of climate change is considered as a human intervention to reduce the sources or enhance the sinks of greenhouse gases (GHGs).Mitigation strategies essentially differ with crop, and soil environment. For instance, the methane emission from lowland rice cultivation can be mitigated to a large extent through water and nutrient management including mid-season aeration by short term drainage, use of fermented manures, improved organic matter management. The nitrous oxide emission in crop land is reduced by adopting site-specific, efficient nutrient management and also using nitrification inhibitors like neem oil, neem cake, nitrapyrin, dicyandiamide, etc. As regards the methane emissions from ruminants like cow, sheep, etc., the emissions can be reduced by altering suitably the feed composition. The carbon dioxide emission from agriculture can be reduced by the adoption of conservation tillage practices, increasing carbon sequestration, improving soil environment, manure management and soil biodiversity conservation.

10.4.5 Adaptation Strategies to Climate Change

Adaptation is said to be the process of adjustment to actual or expected climate and its effects. The adaptation strategies encompasses developing crop cultivars tolerant to abiotic stresses like heat stress and salinity stress, crop diversification, modifying and improving the crop management practices, harnessing the traditional/indigenous knowledge of farming community, adoption of conservation agriculture practices, resource conserving technologies weather forecasting and agricultural insurance.

10.5 Sustainable Development Goals, Climate Change and Food Security

Sustainable development of humanity and our planet is challenged by a number of environmental challenges. The challenges are Food Security, Water Security, Energy Security, Climate Change Abatement, Biodiversity Protection and Ecosystem Service Delivery. At the granular level, these challenges have commonality in terms of striking characteristics, occurrence, inter-relationships, and these challenges demand concerted effort from United Nations and other organizations. The foremost challenge is food security as it is related with other key challenges. The need to feed 10 billion people by 2050 with quality food and to provide clean environment demands productive soil, rich agro-biodiversity, augmentation of ecosystem services, continued energy supply and productive water use.

10.6 Sustainable Development Goals

The United Nations Rio+20 Summit in Brazil in 2012 committed governments to create a set of sustainable development goals (SDGs) that would be integrated into the follow-up to the Millennium Development Goals (MDGs) after their 2015 deadline (Griggs et al., 2013). There are 17 SDG's comprising 169 targets and this global development agenda spans from 2015-2030 (Lu et al., 2015). The Sustainable Development Goals (SDGs) build on the successes of the Millennium Development Goals are a universal call to action to end poverty, protect the planet and ensure that all people enjoy peace and prosperity. The goals are interconnected – often the key to success on one will involve tackling issues more commonly associated with another. Unlike the MDGs, which are targeted at poor and emerging nations, the SDGs will have a global reach. They will apply to developed and developing countries alike, and will concern the earth system as well as people (Glaser, 2012). The SDG framework addresses key systemic barriers to sustainable development such as inequality, unsustainable consumption patterns, weak institutional capacity, and environmental degradation that the MDGs neglected (ICSU, ISSC, 2015).

10.7 SDG 2 and SDG 13

The SDG 2 is to end hunger, achieve food security and improved nutrition, and promote sustainable agriculture. The SDG 13 is to take urgent action to combat climate change and its impacts. SDG 2 and its targets are intrinsically connected to almost all other goals. The interconnectedness of food security with soil security (SDG 15), water security (SDG 6), energy security (SDG 7), climate security (SDG 13), economic security (SDG 8 and SDG 9) consumption patterns (SDG 12), gender equality (SDG 5) and political stability (SDG 16) are illustrated in the Figure 7.

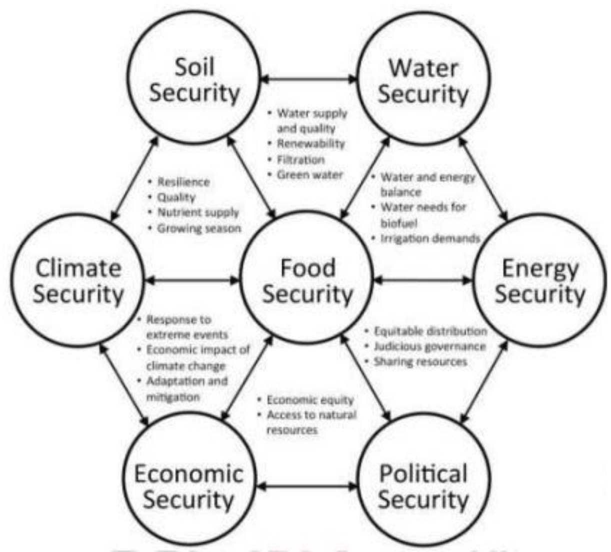


Figure 7: Linkages of Food Security
Source: https://flores.unu.edu/en/news/news/taking-hunger-out-of-the-poverty-equation-food-security-and-the-sdgs.html

10.8 Food Security

The term "food security" initially was used to describe whether a country had access to enough food to meet dietary energy requirements (Pinstrup-Andersen, 2009). The concept of food security evolved and the definition agreed upon at the World Food Summit in 1996 is that food security exists when all people, at all times, have physical and economic access to sufficient safe and nutritious food to meet their dietary needs and food preferences for a healthy and active life (Barrett, 2010).

10.9 Dimensions of Food Security

Primarily, there are four key dimensions of food security. The dimensions of food security are clearly illustrated in Figure 8. The dimensions are

- Availability,
- Stability,
- Access, and
- Utilization.

10.9.1 Availability

The first and foremost dimension relates to the availability of sufficient food, i.e., to the overall ability of the agricultural system to meet food demand. It is concerned with the production of the food items for the population.

10.9.2 Stability

The second dimension, stability, relates to individuals who could afford to have the food. The work availability, getting wage/ salary/ or self-production of food from the owned land. It means the food has to be available to the people for the whole of the year.Access: The third dimension, access cover access by individuals to adequate resources to acquire appropriate foods for a nutritious diet. A key element in this dimension is the purchasing power of consumers and the changes in the real income and food prices. It also refer to the movement of the people or the goods for proper distribution among the masses. Hence, transport is equally important to the food from deficient zone to the zone of deficiency, apart from purchasing power.

10.9.3 Utilization

The fourth dimension utilization includes all food safety and quality aspects of nutrition. The available food has to be in a consumable state and therefore, the hygiene and cooking facilities are also of great concern (FAO, 2008).

Figure 8: Key Dimensions of Food Security

Source: **Source:http://www.foodsource.org.uk/sites/default/files/fig-722.png**

An important component of food security is nutritional security. In order to provide safe and nutritious food, the pulse crops, which are source of protein, should be included in the cropping system. The pulse crops in addition to enriching soil fertility enhance the livelihood security of marginal and small farmers. Nutri-cereals such as bajra, ragi, sorghum, maize, etc. are usually cultivated in rainfed areas and are more climate-resilient. Additionally, the demand for coarse cereals from nutritional point of view will act as an incentive for resource poor rain fed farmers to grow the climate resilient coarse cereals. Hence, in an era of climate change, climate resilient agriculture will play an important role in human nutrition security and livelihood security. Due to changes in consumption patterns, demand for fruits, vegetables, dairy, meat, poultry, and fisheries has been increasing. There is need to increase crop diversification and improve allied activities.

10.10 Effect of Climate Change on Food Security

We know that the agricultural crop production is a product of interaction between genetic potential and the crop environment. By adopting traditional and modern breeding methods, the plant breeders are in constant urge to increase the potential crop yield. Nevertheless, the farmers are not in a position to achieve the potential yield of crop plants. There exists a yield gap between actual yield and potential yield. The yield gap is a function of biotic and abiotic stress in agro-ecosystem. The agricultural crop production will increase, if the yield gap is narrowed down. Unfortunately, the yield gap is widening due to change in climate and consequent impact on the components of agro-ecosystems.

Climate change will affect all four dimensions of food security; food availability, food accessibility, food utilization and food systems stability. It will have an impact on human health, livelihood assets, food production and distribution channels, as well as changing purchasing power and market flows. Its impacts will be both short term, resulting from more frequent and more intense extreme weather events, and long term, caused by changing temperatures and precipitation patterns. People who are already vulnerable and food insecure are likely to be the first affected very greatly.

Agriculture-based livelihood systems that are already vulnerable to food insecurity face risk of increased crop failure, new patterns of pests and diseases, lack of appropriate seeds and planting material, and loss of livestock. The need of the hour is climate resilient agriculture. At the same time, it is necessary to strengthen the resilience of rural people and to help them cope with this additional threat to food security. In this context, agricultural research should be tailored to meet the requirements of climate resilient farming systems.

10.11 Climate Smart Agriculture

The way forward is extremely challenging for global agriculture demanding a paradigm shift in agricultural crop production, agricultural development planning, investments in agriculture and integrated farming approach empowering small and marginal farmers. It is important to transform and reorient agricultural production system by including resilient pathways to achieve increased agricultural productivity and at the same time capitalize the synergy existing between the mitigation and adaptation to climate change. It was timely that an approach christened as Climate Smart Agriculture took shape in this century with the proactive role of Food and Agriculture Organization (FAO) and World Bank. Climate Smart Agriculture (CSA) aims at maximizing the global agricultural productivity, reducing the vulnerability of agriculture to climate change, increasing the resilience of agricultural system in the era of climate change, and reducing the greenhouse gases emissions from agriculture.

CSA is a comprehensive policy, technology and financing approach to enable countries to achieve sustainable agricultural development in the face of climate change. CSA includes sustainable agriculture and the need for adaptation and the potential for mitigation with associated technical, policy and financing implications (FAO, 2013). Climate Smart Agriculture includes farm-based sustainable agricultural land management practices like conservation agriculture, crop residue management, agroforestry, manure management, etc. CSA is site specific and adopts ecosystem approach, integrated landscape management and ensure inter-sectoral co-ordination and co-operation. CSA approach strives to provide safe operating space for global food systems.To live sustainably within planetary constraints, we must grow more on the same amount of land using less water, energy, and chemicals and adopt sustainable agricultural practices (Fedoroff, 2015).

Climate Smart Agriculture can be defined as an agricultural approach that sustainably increases productivity, resilience (adaptation), reduces/removes greenhouse gases (mitigation) and enhances achievement of national food security and development goals.

10.12 Goals of Climate Smart Agriculture

The goals of climate smart agriculture are:

• Sustainably increase agricultural productivity and incomes in order to meet national food security and development goals

• Build resilience and the capacity of agriculture and food system to adapt to climate change

• Seek opportunities to mitigate emission of greenhouse gases and increase carbon sequestration

Climate smart agricultural practices are adopted at all scales including food supply chains, and landscape. CSA addresses the challenge of meeting the growing demand for food, fibre and fuel, despite the changing climate and fewer opportunities for agricultural expansion on additional lands. Further, CSA emphasis on poverty reduction and food security; maintaining and enhancing the productivity and resilience of natural and agricultural ecosystem functions (Steenwerthet al., 2014).

Summary and Conclusions

Agriculture has contributed immensely for the existence of humanity. Modern agriculture had exhibited its potential to feed seven billion people. The issues and challenges related to agriculture gains urgency on account of growing human population, competing uses for natural resources, increased dependency on few food crops, lack of biological diversity in agro-ecosystem, inadequate knowledge of ecological processes and negative impacts of climate variability and climate change. Agriculture too contributes to climate change through the emissions of greenhouse Gases to the tune of 10-12% of global total greenhouse gases emissions.

Scientific understanding of the linkages between agriculture and climate change reveals the disruptive impacts of climate change on crop distribution and crop production and the potential of agricultural sector to augment the global efforts to address both adaptation and mitigation to climate change. In order to maximize the global agricultural productivity, to reduce the vulnerability of agriculture to climate change, to increase the resilience of agricultural system in the era of climate change, to reduce the greenhouse gases emissions from agriculture, to achieve food and livelihood security, to reduce poverty and improve nutritional wellbeing of people.

International Organizations like Food and Agriculture Organization (FAO), World Bank and Consultative Group on Integrated Agricultural Research (CGIAR) conceptualized the reformative and transformative approach in agriculture called Climate Smart Agriculture (CSA). CSA includes sustainable agriculture and the need for adaptation and the potential for mitigation with associated technical, policy and financing implications. All said, sustainable agricultural practices, policies and finance can effortlessly move agriculture sector onto the resilient pathways paving way for food security, poverty eradication and mitigation of climate change.

References

Adapted from E-PG Pathshala, Geography, climatology, climate change and food security

Unit 11: Ozone and Climate

Unit Structure

11.0 Learning Objectives

On completion of this unit you should be able to:

- describe the distribution of ozone,
- explain the process of ozone depletion and cycle of ozone formation,
- identify the ozone depleting substances and their Role Name Affiliation Principal Investigator
- explain the mechanism of ozone hole formation over the Antarctica,
- highlight the impact of ozone depletion.
- describe the steps taken as remedial measures to overcome the problem of ozone depletion.

11.1 Introduction

Ozone layer is a vital component of our atmosphere. In stratosphere, it acts as a protective layer as it absorbs the harmful ultraviolet radiation and does not allow it to reach the earth's surface. Therefore, the presence of the ozone layer is essential factor in the life environment. Ozone is a very reactive molecule and with the help of a catalyst it is easily reduced to the more stable oxygen. The ozone destroying catalysts are natural as well as manmade. The primary cause of ozone depletion is the trace gases mainly chlorine and bromine, from anthropogenic sources. The depletion of ozone layer was discovered for the first time by Farman in 1985. It was established that, ozone 'hole' has occurred in the ozone layer over Antarctica. In 1987, the Montreal protocol set legally binding controls on the production and consumption of gases associated with ozone depletion. The outcome of this response is decline in the total abundance of CFCs in the atmosphere and trend of gradual healing of ozone layer.

The ozone layer exists at altitudes between about 10–50 km from Earth surface that is between 100 to 0.1 mb pressure altitude just above the tropopause. The natural seasonal and latitudinal variation in stratospheric ozone is now well established. The ozone distribution in stratosphere is strongly dependent upon stratospheric circulation patterns, which vary according to seasons, short term meteorological changes and photochemical processes of formation and destruction. Since last several decades, stratospheric ozone as a tracer for atmospheric circulation has been the subject of the study by physicists. In 1984, John Farman and his team belonging to British Antarctic Survey and engaged in measuring routinely the stratospheric ozone over Antarctic stations at Halley Bay (76° S 27°W) and at Argentine Islands (65°S 64°W) since 1956 made a startling statement that value of total ozone had decreased dramatically for about six weeks in September-October (1980-84). The press coined the catchy phrase ozone hole to describe this unusual phenomenon.

In this unit-, we will discuss on the causes and impacts of ozone depletion.

11.2 Ozone

Ozone is a rare gas made up of three atoms of oxygen. You have already studied the composition and structure of earth's atmosphere. You are well aware that the contribution of ozone in the constitution of the atmosphere is very little. Overall its share is just three per every 10 million molecules. Moreover, the distribution of ozone in atmosphere is highly uneven. In troposphere, ozone represents less than one part per 100 million molecules. Still, ozone is a very significant component of atmosphere. It is found concentrated mainly in stratosphere at the height range of 10 to 50 km (Figure 1).Its concentration is much higher in the low latitudes but much lower in the high latitudes. The maximum is just a few km above the tropopause.

Ozone gas is predominantly found in stratosphere and has also a limited presence in the troposphere. Near surface, ozone is undesirable because it is a pollutant. It results into photochemical smog and greenhouse effect resulting into global warming. Here ozone exists as a by-product of photochemical processes between sunlight and pollutants, particularly nitrogen oxides from vehicular exhausts. It is regarded toxic when presence is above sixty parts per billion. It has harmful effects on plant growth as well as causes respiratory problems.

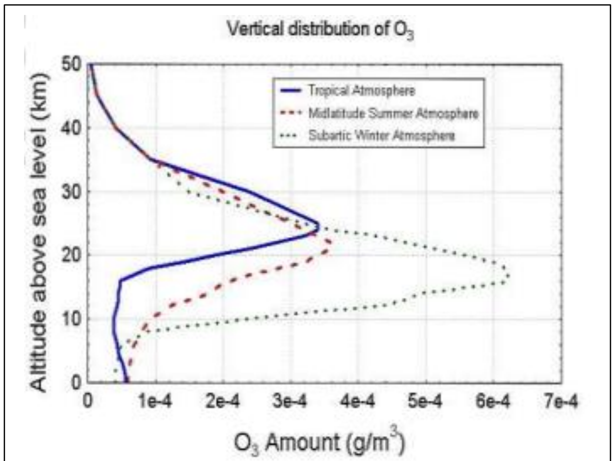


Figure 1. Vertical Distribution of Ozone
Source: http://cimss.ssec.wisc.edu/wxwise/ozone/O3vert.gif

The presence of ozone in stratosphere is essential because it absorbs the UV-B radiation (λ = 280–320 nm). UV-B radiation is absorbed only by O_3 and by no other gas. It may be pointed that the UV-A ($\lambda = 320$ –400 nm) radiation are not absorbed by O_3 . On the other hand UV-C ($\lambda = 200$–280 nm) radiation is absorbed by other gases as well as by O_3 . Ozone also controls temperature profile of stratosphere. Any loss or depletion of ozone in stratosphere would lead to greater amounts of UV-B radiation reaching the Earth. This would create, among other problems, an increase in melanoma (skin cancer) in humans as these damage surface cells of animals and plants. Under such circumstances, the normal life cycles of animals and plants would be disturbed. The UV radiation may interrupt lower level of food chains also. These possibilities led to a keen public interest in the matter and the stratospheric chemistry and physics became a focal point.

11.2.1 Formation of Ozone in Stratosphere

In the stratosphere it is formed through the interaction of the shorter, ultra-violet part of the solar radiation and oxygen molecules, which consist of two atoms of oxygen. Ozone is dominantly concentrated at the height range of 15 and 35 km from surface. The solar ultraviolet radiation breaks-up the oxygen molecules at altitudes above 30 km (i.e. O2→O + O). These separated atoms of oxygen (O + O) when join individually with other oxygen molecules ozone is formed as following:

O2+ O + M →O3 + M

Here, M represents the energy and momentum balance provided by collision with a third atom or molecule. Ozone is formed due to the collision of a single atom of oxygen (O) and a molecule of oxygen (O2). This collision requires the presence of a third, neutral molecule to act as a catalyst. The catalyst allows the interactions without being consumed in this process.

This type of three-body collisions is exceptional at 80 to 100 km above surface, due to very low density of the atmosphere. At height, below 35 km majority incoming ultraviolet radiation gets already absorbed at higher levels. Therefore, ozone is dominantly formed in the height range of 30 to 60 km, where such collisions are more likely.

Sydeny Chapman (1930) discovered the basic physical and chemical processes resulting into the formation of ozone in stratosphere. The ultraviolet radiation breaks an oxygen molecule (O2) into two oxygen (O) atoms. These atoms then join with other oxygen molecules to create ozone. Ozone is dissolved when an oxygen atom and an ozone molecule rejoin to give two oxygen moleculesi.e. $O + O_3 \rightarrow 2O_2$ (Figure 2). In the 1950s, David Bates and Marcel Nicolet proved that various free radicals, especially

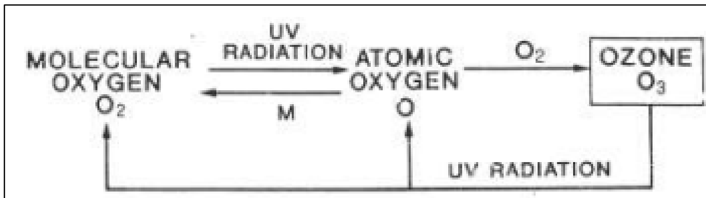


Figure 2. Ozone Formation (Chapman Cycle, Oxygen ↔ Ozone)

Source: Barry, R.G. and Chorley, R.J. (1998), P-5.

hydroxyl (OH) and nitric oxide (NO), could catalyze this recombination reaction, depleting the overall amount of ozone. These free radicals are present in the stratosphere. They maintain the natural balance by reducing the overall amount of ozone. It is estimated that in the absence of these free radicals the ozone layer would have thickness twice of the present layer.

The Chapman cycle (oxygen ↔ ozone) results into filtering of the harmful ultraviolet solar radiation. Therefore, it works as a protective layer; it absorbs harmful radiation and restricts it to reach the surface. In addition, it helps to trap the weather conditions within the lower atmosphere i.e. troposphere by creating an inversion of temperature in the stratosphere.

11.2.2 Ozone Depletion: Process and Causes

Ozone is a very reactive molecule and with the help of a catalyst it is easily reduced to the more stable oxygen. The ozone destroying catalysts are natural as well as manmade. Ozone can be destroyed by a number of free radical catalysts such as (i) OH (hydroxyl) -the odd hydrogen atoms and OH come from the dissociation of water vapour, molecular hydrogen and methane (CH4); (ii) nitric oxide –ozone is destroyed in stratosphere due to the presence nitrogen oxides (NOx, i.e. NO2 and NO). The source gas of theNOx is nitrous oxide (N2O) - it is produced by combustion, supersonic jets and fertilizer use; (iii) Chlorine and (iv) Bromine (Figure 3).Anthropogenic activities have sharply increased the levels of chlorine and bromine.

A single chlorine atom has the capability to interact with thousands of ozone molecules in catalytic cycle before it is finally removed. On a per atom basis, the efficiency of bromine is far more than chlorine to destroy ozone, but its abundance is much less in the atmosphere. Therefore, both chlorine and bromine are the major contributors in overall ozone destruction. The increase in abundance of chlorine and bromine during the decades of 1970-90 is reflected in the observed decrease of stratospheric ozone over the Antarctica and other parts. A simplified illustration is given to show ozone destruction in figure 3.

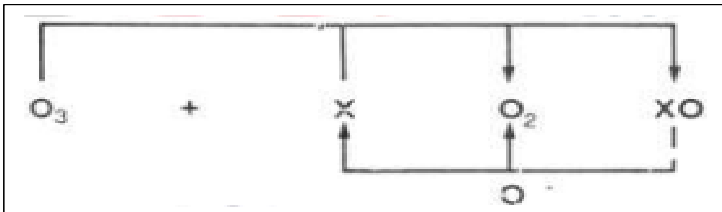


Figure 3: Ozone Destruction Process (where X is any ozone-destroying species, e.g. OH, NO, CR, Br)

Source: Barry, R.G. and Chorley, R.J. (1998), P-5.

The depletion of ozone in the stratosphere due to human activities is a serious global environmental problem. The major offending chemicals are Freons, synthetic compounds containing carbon, fluorine and chlorine atoms. Compounds of this class are also known as halocarbons. The popular alternate name for these ischlorofluorocarbons, or CFCs. They are versatile compounds that are chemically stable, odorless, nontoxic, noncorrosive, and inexpensive to produce. CFCs, carbon tetrachloride (used in fire extinguishers and solvents), alternates of CFCs - hydrochlorofluorocarbons (HCFCs) and methyl chloroform are the chief chlorine containing gases. These gases are used in many applications such as – refrigeration, air conditioning, foam blowing, aerosol propellants and cleaning of metals and electronic components (Table 1).Methyl chloroform is used in industries for cold cleaning, vapor degreasing, chemical processing, adhesives and aerosols.

The most important source halogen gases for bromine are the halons and methyl bromide. Halons are used to extinguish fires. Methyl bromide, used as an agricultural fumigant, is another significant source of bromine to the atmosphere. Methane and nitrogen oxide, which react in stratosphere to form water vapour and reactive hydrogen and nitrogen oxides, respectively have ozone depletion capabilities.The emission of oxides of nitrogen by supersonic jet planes is also destructive for ozone layer.

There are a few halogen source gases present in the stratosphere that have large natural sources. Methyl chloride contributes about 17 per cent of the chlorine currently into the stratosphere. Likewise, about 30 per cent of the bromine is contributed by natural source methyl bromide (Figure 4). These gases are emitted by oceanic and terrestrial ecosystems. Sunspot cycle shows that global total ozone levels vary by 1 to 2 per cent between the

Table 1: Common Chlorofluorocarbons and Halons

Compound (chemical formula)	Ozone Depletion Potential	Atmospheric Lifetime (Years)	Major Uses
CFC-11 (CFCl3)	1.0	64	Rigid and flexible foams, refrigration
CFC-12 (CF2Cl3)	1.0	108	Air conditioning, refrigeration, rigid foam
CFC-113 (C2F3Cl3)	0.8	88	Solvent
Halon-1211 (CF3BrCl)	3.0	25	Portable fire extinguishers
Halon-1301 (CF3Br)	10.0	110	Total flooding fire extinguisher systems
HCFC-22 (HCClF2)	0.05	22	Air conditioning

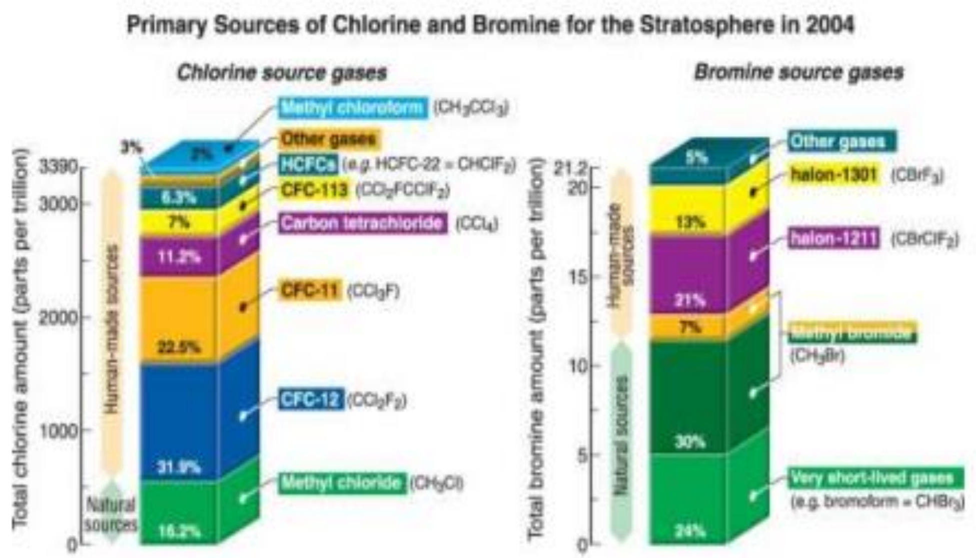
Source: Oliver, J.E and Hidore, J. (2003), P-366. (aOzone-depleting potentials represent the destructiveness of each compound in relation to CFC-11, which is given value of 1.0)

maximum and minimum. Volcanoes can emit some chlorine containing gases. In addition, volcanic sulphur and particulate matter emissions reduce solar transmission and ozone abundance. Sunspots and volcanic eruptions bring only short term changes in ozone abundance. Therefore, the main causes of ozone depletion are anthropogenic.

There was no concern about the negative consequences of nitrous oxide and CFCs until three scientists, Paul Crutzen, F.S. Rowland, and Mario Molina, studied the relationship. In 1970, Crutzen highlighted that emissions of nitrous oxide (N2O), from increased use of fertilizers and supersonic aircrafts could deplete ozone in the stratosphere, where due to photochemical process it is converted into nitric oxide (NO). In 1974, Rowland and Molina concluded that, like N2O, the CFCs under ultraviolet radiation in stratosphere would be dissociated and released chlorine atoms will destroy ozone layer. This way they alerted the world through their research work that CFCs were probably reducing the average concentration of ozone in the stratosphere.

Later on, when in 1995 ozone hole formation was reported, Dr Rowland expressed his frustration and stated, “What’s the use of having developed a science well enough to make predictions, if in the end all we are willing to do is stand around and wait for them come true. Unfortunately, this means that if a disaster is in the making in the stratosphere we are probably not going to avoid it." In 1995, scholarsCrutzen, Rowland and Molina, were awarded the Nobel Prize in chemistry for their pioneering research work on ozone depleting substances.

Figure 4. Natural and Anthropogenic Sources of Chlorine and Bromine in Stratosphere



Source:https://www.esrl.noaa.gov/csd/assessments/ozone/2006/images/Q7-1HighRes.jpg

They discovered that molecules of ozone depleting substances like CFCs drift upward and reach the ozone layer in stratosphere. In stratosphere, CFCs in photochemical process absorb ultraviolet radiation and get decomposed, releasing chlorine. These released chlorine atoms in a complex series of reactions attack molecules of ozone. In a series of chain reactions large numbers of ozone molecules are converted into ordinary oxygen molecules. The chlorine atoms basically interact with ozone molecules by acquiring one oxygen atom to constitute chlorine monoxide (ClO) and leaving behind an oxygen molecule (O2). As the molecule of chlorine monoxide encounters a single oxygen atom, the oxygen "breaks up" the chlorine monoxide, acquires its oxygen atom and chlorine is released back to indulge in further destruction of ozone in stratosphere. These reactions are chain reactions. In this manner, through chain reactions each chlorine atom that reaches the stratosphere is able to destroy thousands of molecules of ozone resulting into ozone depletion. The simplified reactions are following:

(i) $O_3 + Cl \rightarrow ClO + O_2$ (chlorine acting as the catalyst)

$O + ClO \rightarrow O_2 + Cl$

(ii) (ii) $O_3 + NO \rightarrow NO_2 + O_2$ (with nitrous oxide acting as the catalyst)

$O + NO_2 \rightarrow O_2 + NO$

11.3 The Antarctica Ozone Hole

The first significant data based on scientific observations about the depletion of ozone layer was presented by Farman and his British Antarctic Survey team in 1985. This team on

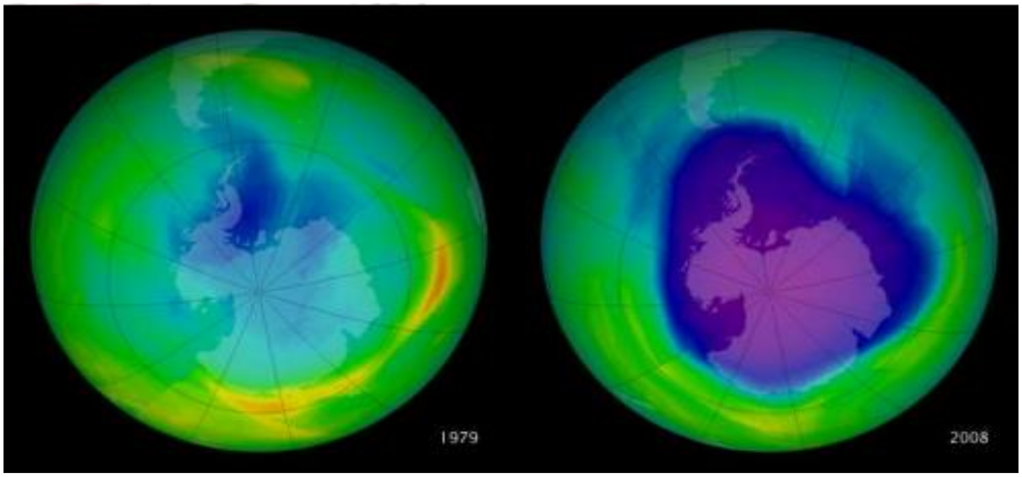


Figure 5: Ozone Hole over Antarctic

Source:http://noair-rors.weebly.com/uploads/5/1/4/5/51453091/288240858.png

factual basis established that ozone ‘hole’ has occurred in the stratospheric ozone layer each spring since 1977 over Antarctica. They observed that for the period 1977-84, the abundance of ozone depleted by 40 per cent during spring season of southern hemisphere. Basically ozone hole is not like a ‘hole in the windshield’. The ozone does not disappear in a particular part entirely nor is the depletion in the form of uniform thinning of layer. Therefore, the term holeis representative of more of a depression or decline in quantity. The ozone hole covers about 90 per cent of Antarctica and has also expanded over the adjoining oceans. It extends over an area of about 26 million square km. i.e. about the size of North America (Figure 5).

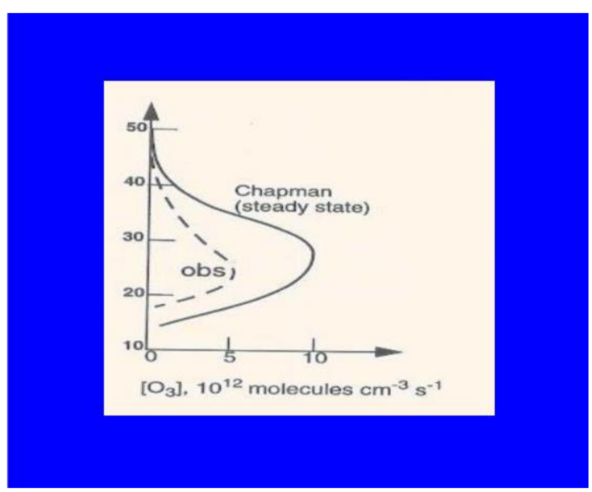
The ozone hole develops during the Antarctic spring from September to early December. It is most extensive in October. During this time strong westerly winds start to circulate around the continent and a polar vortex gets established. Due to lack of sunlight temperature decreases and polar vortex traps and chills air to around below -800C. These temperatures form polar stratospheric clouds (PSCs). These clouds provide surface for reactive chlorine compounds for chemical reactions leading to ozone depletion.

The role of sun light in ozone depletion is most significant. In winter, PSCs are most abundant but due to absence of sunlight chemical reactions don't take place. During the spring, as the sun comes out, photochemical reactions start along with melting of PSCs. The released ClO drives the ozone hole formation mechanism. At the end of spring season (Mid December) due to warming, polar vortex breaks down, the PSCs are destroyed and air flows from lower latitudes restrict the enhanced ozone depletion and ozone hole closes.The depletion of ozone is measured in terms of reduction in the total column ozone above a point on the earth's surface and it is observed with the help of the Total Ozone Mapping Spectrometer (TOMS) and measured in Dobson Units (DU).

11.4 The Arctic Hole

Kerr (1988) reported that ozone layer depletion is also going on in the Arctic atmosphere. In the Arctic stratosphere, the ozone abundance is more variable than in the Antarctic. The maximum depletion is up to 30 per cent and it is in winter and spring, when the lowest temperatures prevail in stratosphere. Later on it was reported that the background ozone levels have depleted in northern hemisphere to about 15 per cent and the trend was observed over the Mediterranean Sea and the southern United States also. This is of special significance because the northern hemisphere is more densely populated as compared to southern hemisphere and mid-latitude zone is dominated by developed countries. The seriousness and required responses are reflected in the follow up conferences and meetings of the Montreal Protocol.

In the lower stratosphere short wavelength radiation for O2 photolysis are highly diminished having been absorbed higher up, and in upper stratosphere, there is less O_2 because of decrease in O_2 as the altitude increases. Thus, there is layer type structure of O_3 in stratosphere, maximum ozone being around 30 km in the tropics and around 15-20 km over the polar region. Since the level of peak is considerably higher in



altitude over the tropics than poles, the ozone is distributed pole-ward through the stratospheric circulation. Ozone accumulates over poles particularly in winter; some of it enters the troposphere over the poles (Bridgman, 1990).

11.5 Impact of Ozone Depletion

Ozone layer by filtering the harmful ultraviolet radiation functions as a protective shield. In case the ultraviolet radiation reaches the surface with full intensity, it will severely damage the animal tissues and destroy the exposed bacteria. Hence, the presence of the protective ozone layer in stratosphere is essential factor in the life environment. As a consequence of ozone depletion earth surface is exposed to increased ultraviolet radiation. The scholars have estimated that 1 per cent decrease in ozone in stratosphere results into about 2 per cent increase in ultraviolet radiation on surface.

11.5.1 Health of Biotic Life

The increased ultra violet radiation due to ozone depletion can cause damage to human health, ecosystems and global climate (Table 2).Ozone depletion intensifies all of the effects of ultraviolet radiation on health of human beings and other organisms. In addition, increase in ultraviolet radiation at surface results into increase in tropospheric ozone. Ozone concentration in lower part of troposphere is a health risk for human beings and other organisms. Ozone because of its intense oxidant properties, it is toxic in nature. Juvenile and senile age groups and persons with asthmatic and other respiratory difficulties are more vulnerable.

11.5.2 Greenhouse Effect

Near surface, ozone is produced due to photochemical decomposition of NO2 by ultraviolet radiation into NO and O. Reaction of atomic oxygen with molecular oxygen results into formation of ozone. Ozone formation takes place here, mainly because of interaction of ultraviolet radiation with combustion gases from vehicular exhausts. Ozone in troposphere acts as a greenhouse gas and contributes in global warming. Therefore, ozone depletion on one hand results into global warming andon the other hand in cooling of stratosphere.

11.5.3 Skin Tanning and Cancer

One of the predicted effects of increased ultraviolet radiation is a significant increase in the incidences of skin cancer. The most common skin cancers, basal and squamous cell carcinomas are strongly associated with exposure to ultraviolet radiation. During the decade of the 1990s, scientists in New Zealand discovered that due to depletion of stratospheric ozone concentration, harmful ultraviolet radiation increased substantially. By 2000, peak sun burning ultraviolet levels were nearly 12 per cent more as compared with the levels 10 years earlier in New Zealand. Hence, ozone depletion results into increased incidences of sunburns. The fair-skinned and persons exposed for longer durations have higher vulnerability for sunburn and skin cancer.

11.5.4 Reduction in Human Immune System

The increase in harmful ultraviolet radiation has negative impact of the human immune system. It will be reflected in increased vulnerability to infections and diseases. More exposure to ultraviolet radiation also promotes cataracts. In cataract, the clouding of the eye lens not only reduces vision but may also result into blindness if not treated properly. Epidemiological studies have shown a positive correlation between ocular cortical cataracts and ultraviolet B exposure. To counter the threat of ultraviolet radiation, school children in Australia are motivated to use protective hats and sunglasses and also suggested to avoid bright sunlight.

11.5.5 Effect on Crop Yield

The increased ultraviolet radiation has significant effects on plants and animals. One of the major concerns is that the crop yield and quality will be affected negatively. This quantitative and qualitative loss will intensify food insecurity. Exposure of bacteria to additional ultraviolet radiation affects them adversely because of their sensitivity for this type of radiation. Bacteria help in nitrogen fixation and maintenance of soil fertility for economically significant crops. For instance, rice plants for nitrogen depend on cyanobacteria present in their root system. Therefore the production of economically significant crops will decrease.

11.5.6 Effect on Aquatic Life

The additional ultraviolet radiation has potential to eliminate certain forms of aquatic life mainly in the upper layer of water bodies such as oceans, streams and lakes. Some scientists have highlighted the risk of destruction of the microscopic plants, phytoplankton, due to exposure to ultraviolet radiation in waters surrounding the Antarctica. The phytoplankton represents the base of the food chain in marine ecosystems. Therefore, phytoplankton and zooplankton destruction will result into destruction of marine life. On the basis of measurements scholars have concluded that the increase in ultraviolet radiation reduces photosynthesis linearly. The productivity was reported to be declined by a minimum between 6 to 12 per cent.

Table 2: Impact of Ozone Depletion

Human Health	Increase in number and intensity of sunburning cases. Increase in eye cataracts and blindness Increased risk for skin cancer (especially basal, squamous cell carcinomas, and malignant melanoma). Suppression of immune system and increased risk for infections and diseases. Positive impact can be reduction in vitamin D deficiency.
Food and Forest	Declined yields and quality of plant products. Declined seafood supplies due to reduced phytoplankton. Reduced forest productivity for ultraviolet sensitive tree species
Wildlife	Increased eye cataracts in some species. Decline in population of ultraviolet radiation sensitive aquatic species. Reduced phytoplankton and zooplankton. Increased sun burning of animals. Ecological imbalances due to decline in primary production.
Air Pollution and Materials	Increased acid deposition. Increased photochemical smog in lower troposphere. Degradation of outdoor paints and plastics. Toxic ozone risk for asthma and respiratory problems.
Global Warming	Increase in tropospheric ozone, CFCs and decreased marine uptake of carbon dioxide from atmosphere by phytoplankons. Stratospheric cooling due to ozone depletion because less ultra violet radiation will get absorbed.

11.6 Measures to Check Ozone Depletion

In 1976, on the basis of scientific evidences a few countries like United States, Canada, Sweden, Denmark, and Norway banned the use of CFCs in aerosol spray cans. The majority of European countries did not ban CFCs in aerosol sprays. After this ban by these few countries, CFCs production initially declined worldwide. But as CFCs continued in use as refrigerants, solvents, propellants and fire extinguishers, there level by 1986 returned back to the its level of 1976.

In 1985, British Antarctic Survey scientists, Farman, Gardiner and Shanklin, on the basis of scientific evidences discovered ozone hole formation over the Antarctica. Taking into consideration the sharp decline in levels of ozone and associated exposure to ultraviolet radiation, scientists and politicians agreed for some positive measures to address the problem. In response to the global threat of ozone depletion and consequent impact on the life environment in 1985 the Vienna Conference was convened by UNEP (United Nation Environment Programme). Members of 43 nations participated in the Vienna Convention for the Protection of Ozone Layer. The motive of the conference was to promote monitoring, research and sharing of information for the protection of ozone layer to avoid its adverse implications.

In 1987, the Montreal Protocol on substances that deplete ozone layer was signed by the representatives from 43 countries. The participants decided to freeze production of CFCs at 1986 levels by reducing CFCs production by 50 per cent by 1999. In response to ozone depletion trend over the Antarctica and other parts of the world, this protocol was strengthened at a meeting in London (1990). The participants decided to total phase out of CFCs and halon by 2000 by MDCs (More Developed Countries) and by 2010 by LDCs (Less Developed Countries). The phase out date was preponed to 1996 in a meeting at Copenhagen in 1992.

The Montreal Protocol set legally binding limitations on the consumption and production of gases depleting ozone. Over the period of time substitutes were developed and the Montreal Protocol was strengthened and enhanced many times. More than 190 countries have ratified the treaty, including India.

The Montreal Protocol shows a quick and positive international response to a global environmental threat. The outcome of this response is decline in the total abundance of CFCs in the atmosphere. The U.S. Environmental Protection Agencyhas reported that over most of the world the ozone layer has not depleted thinner since 1998. The scholars have projected that between 2060 and 2075, the level of ozone depleting gases will be at the level that existed before the formation of the Antarctic ozone hole.

The hydro chlorofluorocarbons (HCFCs) andhydro fluorocarbons (HFCs) have replaced CFCs. The HFCs do not have chlorine or bromine and therefore, do not result into ozone depletion but they are potent greenhouse gases.An ozone-safe refrigerant known as “Greenfreeze” is in use as an alternative to CFCs.

The Montreal Protocol and use of substitutes and alternatives of CFCs reflect positive results. The ozone levels have stabilized and trends of recovery have been observed (Figure 6). In 2012, UNEP report stated that in the last decade global ozone, including polar areas, showed no depleting trend. The scholars have projected that ozone layer will recover to its pre-1980 levels by some time before the middle of this century and in polar areas by 2060-2075 (Figure 7). Studies have reported a gradual trend towards “healing” of ozone layer in 2016.

The Montreal Protocol and development of alternatives and substitutes of CFCs has shown positive results.Ozone levels stabilized in the 1990s following the Montreal Protocol, and have started to recover. The UNEP report (2007) showed that the hole in the ozone layer was recovering and the smallest it had been for about a decade. The 2010 report found, "Over the past decade, global ozone and ozone in the Arctic and Antarctic regions is no longer decreasing but is not yet increasing. The ozone layer outside the Polar Regions is projected to recover to its pre-1980 levels some time before the middle of this century. In contrast, the springtime ozone hole over the Antarctic is expected to recover by 2060 – 2075). A gradual trend toward "healing" was reported in 2016.

11.7 Ozone depletion and climate change

Ozone depletion and climate change has been the subject of intensive investigation owing to their influence on Earth. Ozone depleting substances such as chlorofluorocarbons (CFCs), hydrofluorocarbons (HCFCs), etc. are all greenhouse gases like ozone itself.

The ozone affects the climate primarily by changing temperature. In stratosphere, ozone generates heat both by absorbing solar ultraviolet radiation and by absorbing infrared radiations coming from troposphere. Obviously, more ozone in stratosphere means its higher temperature. For this reason, a decrease in ozone concentration in stratosphere results in its cooling and its lower temperature.

The strong influence of climate and ozone depletion on each other has been indicated (Shindell et al. 1999). The cooling in stratosphere might be rapid enough that even more ozone depletion takes place possibly due to a feedback mechanism. Stratospheric low winter temperature over poles plays a big role in ozone depletion. When this temperature drops below – 78^{o}C, water, which is in very small quantity, is present as polar stratospheric clouds (PSCs). PSCs are actually ice crystals containing some nitric acid, and H_2SO_4. The chemical reactions on the surface of these PSCs begin with the beginning of summer in Southern pole, when chlorine radicals, responsible for ozone loss are released. Ozone loss lowers the stratospheric temperature and greater formation of PSCs, which in turn leads to faster loss of ozone. The ozone depletion in stratosphere would allow more UV radiation to reach troposphere and Earth surface because ozone is an absorber of these radiation, particularly of UV-B type, in stratosphere.

The greenhouse effect on global warming is likely to cause changes in circulation pattern in the troposphere and that, in turn, may alter stratospheric circulation patterns. There is suspicion that these changes are aiding the cooling in the stratosphere over the poles.

As on today, our understanding of the link between ozone depletion and climate change is only cursory and needs much work to draw any meaningful conclusion.

Summary and conclusions

Ozone layer is a very significant component of our atmosphere. It acts as a protective layer as it absorbs the harmful ultraviolet radiation and does not allow it to reach the earth's surface. Therefore, the presence of the ozone layer is essential factor in the life environment of our planet. In stratosphere, oxygen ↔ ozone cycle operates as Chapman cycle. Ozone is a very reactive molecule. It is easily reduced to more stable oxygen form with the help of catalysts. The ozone destroying catalysts are natural as well as manmade.

Ozone can be destroyed by a number of free radical catalysts such as - OH (hydroxyl), nitrogen oxides (NOx, i.e. NO2 and NO), Chlorine and Bromine. Anthropogenic sources have dramatically increased the levels of chlorine and bromine. Over the decades, many uses were developed for Chlorofluorocarbons (CFCs), including as coolants for air conditioning and refrigeration equipment, cleaning solvents for electronic components, propellants for aerosol sprays, and production of certain plastic foams. Halons used as fire retardants result into ozone depletion. The emission of oxides of nitrogen by supersonic jet planes is also destructive for ozone layer.

Crutzen (1970) and Rowland and Molina (1974) pointed out that emissions of nitrous oxide and CFCs have capacities to destroy ozone. The first significant data about the depletion of ozone layer was presented by Farman (1985), the leader of British Antarctic Survey team. He established that, ozone 'hole' has occurred in the stratospheric ozone layer over Antarctica each spring for the period 1977-84. The ozone abundance declined by about 40 per cent during each spring in this period.Later on ozone depletion was also reported over Arctic and northern hemisphere mid-latitudes.

Ozone depletion results into increase in ultraviolet radiation reaching the earth's surface. The increased ultra violet radiation due to ozone depletion can cause damage to human health, ecosystems and to the global climate. Ozone depletion would magnify all of the negative effects of ultraviolet radiation on human health such as sunburns, skin cancers, and cataracts. The effects of additional ultra violet radiation on animal and plant life are also important. There is serious concern that crop yield and quality will be adversely affected.

In 1987, the Montreal Protocol set legally binding controls on the production and consumption of gases associated with ozone depletion.Montreal Protocol represents a positive international response to a global environment problem. As a result of the action, the total abundance of ozone depleting gases in the atmosphere has started to decrease recently and a healing trend is visible.

References

Adapted from E PG Pathshala, Geography, Climatology, Module 8- Ozone Depletion: Causes and Impacts

Unit 12: Climate Change, Gender and Human Health

Unit Structure

12.0 Learning Objectives

- After completion of this unit you will be able to:
- explain about the changing climate around the globe;
- state the impact of climate change on human health;
- distinguish between direct and indirect effects of climate change;
- describe the influence of changing climate on different sections of society; and
- summarize the impact of climate change on human psychological developments

12.1 Introduction

You have already studied about climate change and it evidences and causes in the previous modules of this course. You have also learnt about the role of human beings as being a major agent of this climate change. The present module deals with the changing climate conditions around the globe and its impact on human health. The learners will gain an outlook about effects of climate change on different sections of the society with special emphasis on the developing countries. They will also get acquainted with the direct and indirect impacts of climate change and their roles in modulating the mortality and morbidity among the population. Insights will be developed regarding the impacts of climate change on mental health and wellbeing.

12.2 Climate Change and Human Health

In the blithe radiance of the rapidly blooming economy and scientific and technological advancements, their impact on nature and environment has usually been overlooked. This has caused severe damage to the human beings who have been sustaining the change in climatic conditions over the earth, in the form of shrunken glaciers, frequent flood incidences, droughts, cyclones, increased global temperature, changes in the precipitation patterns, rise in sea levels etc. These changes in climatic conditions sabotage access to safe water, adequate food, clean air, shelter and security.

As per a report of World Health Organisation (WHO), 12.6 million lives are compromised each year by preventable ecological risk factors. The report further ascertained that climate change is expected to cause approximately 2,50,000 additional casualties per year due to malnutrition, malaria, diarrhoea and heat strokes between the year 2030 and 2050. It is likely to increase the expenses of billions of dollars for the recuperation of human health. The scenario is more or less similar in Asian and Indian perspective with the effects ranging from extreme weather conditions to variations in the incidence of vector-borne diseases.

South Asia has specifically witnessed increased frequency of floods due to heavy rainfall. In 2007, around 2,000 human lives succumbed to floods resulting from monsoon, while more than 20 million people lost their dwellings in Bangladesh, India and Nepal. Floods also create conducive environments for the growth and spread of numerous life-threatening pathogens.

Human or animal waste contaminated floodwater escalates the incidences of faecal-oral route mediated disease transmission, diarrhoeal disease and other bacterial and viral illnesses such as cholera, dysentery and typhoid. The situation is aggravated in developing countries where lack of appropriate flood control mechanisms, poor sanitation infrastructure and sluggish surveillance activities to detect and control outbreaks add fuel to the fire. Flooding provides the breeding grounds for mosquitoes and other insect vectors and thus contributes to increased vector- and rodent-borne infections diseases. Having an idea about the effects of climate change on human health, we are now in a position to categorize them under different sections like its direct and indirect impacts as discussed in the coming sections.

12.3 Direct Impacts of Climate Change on Human Health

The direct impacts of climate change depend mainly on exposure to heat or cold waves or extreme weather events and their subsequent influences on human health in the form of various heat- and cold-related illnesses and sometimes deaths.

12.3.1 Temperature Related Deaths and Illnesses

The daily morbidity and mortality has been shown to have a direct association with the extreme outdoor temperatures especially in the temperate and subtropical countries. Morbidity is a state of diseased, disabled or poor health conditions, while the mortality rate may be defined as a measure of the number of deaths in a given population. Nevertheless, we can easily comprehend that the rate of mortality ascends much more steeply with rising temperatures than with falling temperatures. Both morbidity and mortality could also increase in different regions of the world as a result of the expected increase in the number of days with high daily temperatures (i.e., the persistence of days with above average maximum and minimum temperatures). The impacts would be exacerbated by high humidity, intense solar radiation and frail winds. All of these factors affect the physiological mechanisms of human adaptation for the better survival and ultimately lead to poor living and health conditions among the population. These conditions are magnified with the people with low income as they have lesser capability to cope with. Though, there is impact of increasing temperature to everyone, the most vulnerable are the poor people.

Global warming, the most burning environmental concern of 21st century, is subject we all are familiar with. Global warming could severely augment the number and sobriety of extreme weather events such as storms, floods, and droughts and related landslides and wildfires. A number of slums and human settlements located on hills and flood-prone areas are subjected to periodic natural calamities that adversely impinge on human health. These congested peri-urban settlements with inadequate government services also becomes a potential breeding ground for a plethora of disease hosts (e.g., rats, mice, cockroaches, flies) and infectious microorganisms, thereby challenging the resident population's vulnerability. The communities surrounded by these poverty stricken belts also become more susceptible to episodic pandemics (WHO Commission on Human Health and Environment, 1992).

12.3.2 Pollution

Pollution, especially air pollution, is yet again the most conversed environmental concerns of our times. Here, however, we would try to study its vicious impacts on human health. Elevated amount of air pollutants, especially particulate matters, operate synergistically to influence mortality rate of a population especially in big urban cities, like Mexico City, Santiago and Chile where such conditions enhances the formation of secondary pollutants (e.g., ozone). People inhabiting urban and industrial areas are predominantly prone to various diseases and ailments due to a variety of air pollutants which chiefly include sulphur dioxide, nitrogen dioxide, carbon monoxide, ozone, volatile organic compounds etc. Now let us study the harmful effects of different pollutants on human health separately.

a) Sulphur dioxide (SO_2)

Individuals persistently in contact with Sulphur dioxide have elevated prevalence of cold, cough, fatigue, shortness of breath and bronchitis. A large portion of atmospheric SO_2 is transformed to sulphate salts, which either settle down or contribute to acid rain in the form of sulphuric acid on reaction with the rain water. Exposure to 0.4 ppm (parts per million) SO2 or more results in asthmatics even after 5 minutes long exposure. Children and immunocompromised patients are especially susceptible to cough even with intermittent exposure to 1.0 ppm SO2.

b) Nitrogen dioxide (NO_2)

Similarly, higher levels of NO_2 render human vulnerable to acute respiratory disorders like bronchitis, chronic fibrosis, emphysema and bronchopneumonia and lead to decline in optimum pulmonary operations. An elevation of 20% respiratory tract related maladies have been reported as a consequence of the increase in 30μg/m3 in NO2 levels. Incessant contact with approximately 2.0 ppm NO2may cause far-reaching alterations in lung morphology (bronchiolitis) as well as lung dispensability.

c) Carbon monoxide (CO)

Carbon monoxide is particularly lethal by virtue its tendency to competitively bind to haemoglobin (Hb) with higher affinity (240 times) in red blood cells (RBC) resulting in the formation of Carboxy Haemoglobin (COHb), thereby preventing the binding of oxygen and oxyhaemoglobin (O2Hb) in the normal conditions. Acute decrement in lung functions have been associated with high dose exposure of CO. About 5% CO exposure causes cardiovascular effect in young healthy, non-smoking individuals leading to fatigue and reduced ability to work. It may also lead to cardiac strokes, hypertension etc. Substantial evidences have suggested strong correlation between CO exposures and the consequent decline in birth weight, cardiomegaly, impediment in behavioural development, interference in the development of normal cognitive functions and an incline in even infant death syndrome.

d) Suspended Particulate Matter (SPM)

Further, suspended particulate matter may also get deposited on skin and lead to skin related maladies, such as rashes, skin infections, blockages of pores etc. However, certain groups of particles pass into the respiratory tract through inhalation. The symptoms are often recorded as stuffy or running nose, sinusitis, sore throat, wet cough, head cold, hay fever, burning or red eyes, wheezing, dry cough, phlegm, shortness of breath, chest discomfort and pain. Chronic exposure to such particles leads to asthma and several lung related diseases. The bronchitis or pneumonia with pre-existing heart problems may lead to cardio-vascular mortality.

e) Ozone

The level of ozone in the atmosphere especially in urban population has risen beyond the average values. It is responsible for the onset of serious human health conditions such as irritation in eyes, nose and throat, discomfort in respiration, cough and headache. Ozone irritates the epithelial lining of pulmonary organs. Exposure of even 1 to 3 hours with ozone at a concentration ranging between 235-314µg/m3 may result in acute reversible impairment of lungs functioning and enhanced respiratory disease symptoms. However, prolonged ozone exposure leads to grave pulmonary inflammations, besides increasing the susceptibility of lungs towards an assortment of bacterial infections and compounding the severity of influenza infection.

f) Benzene

Benzene is a hazardous air pollutant which accelerates the generation of carcinogencity (cancer causing ability) in the system and is associated with severalgenetic aberrations and chromosomal anomalies etc. People may suffer from euphoria followed by dizziness, erratic breathing rate, headache, nausea and unconsciousness by long duration exposure to even minor concentrations of benzene. Blood and bone marrow related disorders, anaemia, lower ability of blood clot, immune system impairment along with reproductive and development complications have also been reported with frequent exposures to benzene. Women may be subjected to certain menstrual disorders, while retardation of foetal development has also been reported.

g) Volatile Compounds

The volatile compounds have tremendous impending carcinogenic effects on human beings and are suitably termed as air toxins. They react with oxides of nitrogen in the presence of sun light to generate photochemical smog. We must have heard of this smog being an awfully dense haze that hampers the visibility in the region. These vision obscuring fumes cause irritation to eyes and lungs, besides damaging the plant life.

h) Lead Particles

They may enter human body system through inhalation or ingestion with contaminated food or water. Lead is a dangerous environmental pollutant and has adverse effects on practically every system in human body. It can damage the kidneys, the nervous system, reproductive system and cause high blood pressure. Children are more prone to lead pollution due to higher absorption rate than adults. It affects the development of brain of foetuses and young children resulting in lack of intelligence, neurological problems, behavioural problems and depleted concentration levels. Chronic exposure with elevated blood lead levels is associated with hypertension, headache, confusion, irritability, focal motor dysfunction and insomnia in adult males too. Figure 1 very clearly exhibit some of the pollutants and their negative impacts on several organs of the human body and overall on human health.

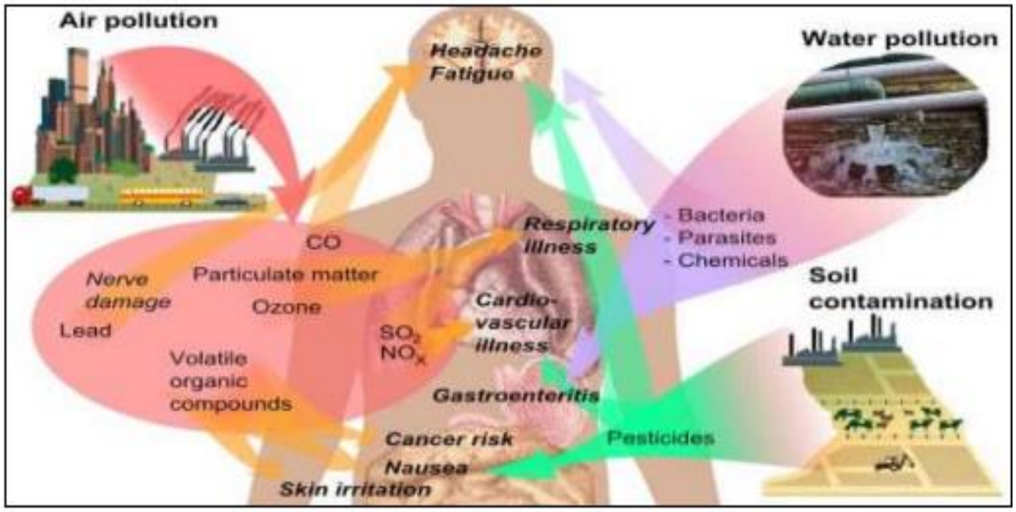


Figure 1: Effects of Pollution on Human Health

Source: upload.wikimedia.org/wikipedia/commons/d/df/Health_effects_of_pollution.png

12.4 Indirect Impacts of Climate Change on Human Health

Now let us get acquainted with the indirect impacts of climate change on human health. These are in the form of diseases such as infectious diseases, vector and water-borne diseases and algal blooms.

12.4.1 Infectious Diseases

Infectious and parasitic diseases are the prime cause of high morbidity in adults and mortality among children since ancient times. Some infectious diseases are more common in tropical and subtropical areas than in temperate or cold areas. Majority of them are food, water-borne infections. Viral, bacterial, and protozoan agents of diarrhoea can survive in warm water for long duration of time and thus spread at increased rates in rainy seasons in the tropical and sub-tropical climates.

12.4.2 Vector-Borne Diseases

Now let us understand the role of changing climate on the prevalence of vector-borne diseases. These mainly encompass vector borne contagions such as dengue and chikungunya fever, parasitic infections like leishmaniasis, lymphatic filariasis, onchocerciasis and tick-borne diseases. The distribution of dengue and chikungunya arboviruses are also influenced by climate, as both share a mutual vector Aedes aegypti. Malaria is another vector borne disease, spread by several species of female Anopheles mosquitoes, whose population is majorly affected by temperature, surface water, and humidity. Climatic factors have also induced human plague, a kind of bacterial disease having rodents as disease carrier and fleas as transmittance agents. Temperature and rainfall are two key determining factors having effects on survival and growth of rodent and flea population, abundance and dispersal. Another disease showing similar climate sensitivity is Murine typhus, a rickettsial disease, also transmitted by fleas.

All the infective agents mentioned above and vectors are sensitive to environmental changes, especially those nurtured by their respective optimum temperatures and humidity. Vectors also are vulnerable to airstream, soil moisture, surface water and variation in vegetation and forest distribution. All these environmental components influence the population distribution of vectors along different geographical locations as well as their behavioural pattern. Precipitation is another crucial factor that provides the aquatic environment required for the completion of a specific life cycle of vectors. Such breeding places are increased and maintained by rainfall. Winds may also contribute to the dispersion of some flying insects, such as mosquitoes, blackflies, and sandflies.

12.4.3 Water-Borne Diseases

Hot and humid climatic conditions bestows upon the water borne pathogens to thrive and proliferate at rapid rate, thereby making the water-borne diseases recurrent. The list of such diseases ranges from cholera to different forms of diarrhoea. Diarrhoeal diseases constitute one quarter of the total childhood fatality and thus are already the foremost cause of morbidity and mortality in South Asia. With the rising temperature, the time period of bacterial survival and propagation is expected to rise, thereby leading to a direct elevation in the incidence of diarrhoeal diseases. Primarily the unsafe drinking water and lack of basic sanitation along with depleting levels of freshwater synergistically aggravate the situation which is likely to worsen in the near future if remained unbridled. Rapid urbanization and industrialization, population explosion, inefficient water use and lethargic and apathetic attitude of people towards water conservation are already causing water shortages several countries around the world. The situation of dearth of freshwater resources is aggravated by the continually deteriorating average annual rainfall with each passing year, which is a direct consequence of climate change in many of these areas. Consequently people are left with limited choices of using comparatively contaminated and unsafe water from other perilous sources which gives the required vent for several water borne disease outbreaks. The situation is worsened in monsoon and floods that presents plenty of such contaminated water sources for the breeding and spread of numerous water borne ailments.

12.4.4 Algal Blooms

Algal blooming may also be associated with contamination of aquatic creatures including fish and shellfish. With the continually warming ocean, temperature sensitive toxins are produced by phytoplankton that contaminates the seafood, resulting in an increased frequency of food poisoning in humans in the coastal areas. The climate induced changes in terms of production of aquatic pathogens and biotoxins may jeopardize seafood safety.

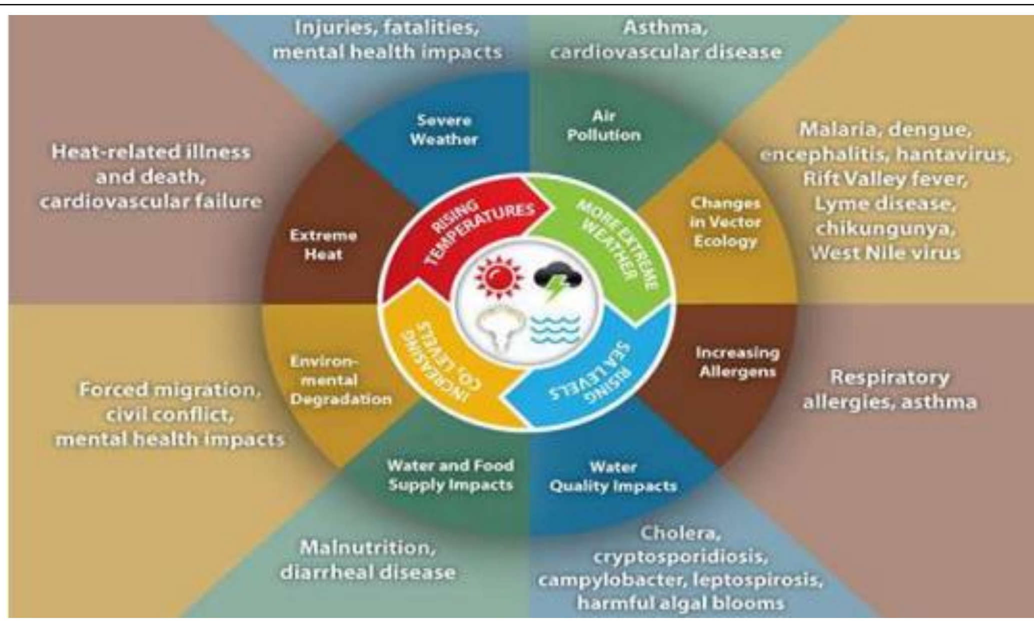


Figure 2: Impact of Climate Change on Human Health

Source: https://www.cdc.gov/climateandhealth/effects/default.htm

Refer to Figure 2 to get a brief idea of the impact of climate change on human health.

12.5 Differential Impacts of Climate Change on Different Sections of Society

So far we have discussed the direct and indirect consequences of climate change on humans. In this section, we shall try to identify how climate change influences different sections of society in terms of gender, age and socio-economic conditions.

12.5.1 Gender Wise

In this regard, it is worth to mention that gender plays a crucial role in deciding an individual's vulnerability. Women are more likely to be affected adversely by climate change than men. Their vulnerability is further increased due to their social and economic status which limits their ability to adapt to the altering climatic conditions. Pregnant women are in particular more prone to malaria than non-pregnant women by virtue of various physiological changes, like increased temperature of exhaled breath and heat dissipation. The condition renders pregnant ladies to be more alluring to malaria carrying mosquitoes, making them particularly vulnerable to malaria. Women in the advanced phase of pregnancy (having gestational age of more than 28 weeks) exhale more than 21% of the average volume as compared to non-pregnant ladies. They also have increased blood flow through their skin, which leads to greater heat dissipation form their epithelial surface especially of the hands and feet. With due significance of immunity and nutrition in mind, physiological and behavioural changes occurring during pregnancy play substantial roles in augmenting the risk of malarial infection in pregnancy, which subsequently pose serious threats of spontaneous abortion, premature delivery, stillbirth and low birth weight.

Floods and water logging is other impacts of climate change that has given rise to differential health effects in women and men in flood affected regions. Women are compelled to stay in close proximity of the community and drink unhygienic water. Pregnant women face additional difficulty with locomotion in marooned and slippery conditions and thus are often advised to stay at home. A large portion of major gynaecological problems usually arise due to unhygienic water usage. Nevertheless, the nutritional status determines the capability of an individual to cope with the aftermath of natural disasters. Girls and women with relatively poor nutritional status often suffer from increased prevalence of anaemia, pregnancy and parturition (process of delivering the baby) related complications, higher intrauterine growth retardation rates, low birth weight of newly born and perinatal mortality.

12.5.2 Age Wise

The effects of climate change seem to be more pronounced on children and aged population as compared to adults. Children have to contend with the immediate and life-threatening dangers of climate-related disasters, food insecurity, rising air pollution, increased risk of vector-borne diseases, acute respiratory infections, diarrhoeal diseases and malnutrition. Evidence is increasingly showing that these risks can have a markedly detrimental impact on a child's early development. Children's vulnerability to vector-borne diseases such as dengue, malaria, and diseases associated with poor water quality, inadequate sanitation and poor hygiene practices, such as diarrhoeal diseases is also far higher than adults. In 2015, malaria is estimated to lead to 4,38,000 deaths, of which more than two-thirds are children under 5 years of age.

Like children, elderly population are also vulnerable to the risks and challenges posed by the changing climate around the globe. With the increasing biological age, people have to confront several challenges including declining physical and mental wellbeing, higher risks of health related disabilities, loss of financial stability and security and ultimately sudden or painful demise. An older person's sensitivity to the effects of climate change is determined by hereditary disposition, their personal history of disease or health conditions, income,family support systems, quality of public health infrastructure and access to relevant local information.

12.5.3 Social and Economic Status Wise

Climate change compounds the miseries of people with low income and social status. The adverse impacts of varying environmental conditions are prominent in the developing nations due to their geographical location and native climatic conditions. Their high dependence on natural resources and their limited capacity to adapt to a changing climate makes situation worse. Alterations in both temperature and rate and amount of precipitation vary from region to region, affecting higher and lower latitudes differently. This would change the frequency of natural disasters such as droughts and floods which may adversely affect agricultural production, fisheries, marine life, water resource availability, industry and human health. All these are expected to increase the disparity in wealth between the developed and developing world. The effects are perceptible not only in terms of disparity in wealth but also in relation to health and survival of the two groups of population. In the absence of effective and well implemented policies of protection, the coastal flooding could grow tenfold or more by the 2080s and affect more than 100 million people per year due to sea-level rise alone.Pollution has its own role in aggravating the hardships and misery of poor. In the eastern parts of India and Bangladesh, having predominantly higher arsenic contamination of groundwater, inundations resulting from severe downpour or oceanic calamity compounds the trials and tribulations of socially and economically deprived sections of the society. Arsenic poisoning has been observed to be drastically impacting the educational and nutritional status of the members of these groups. Physiologically arsenic toxicities are reflected in the form of skin related maladies like lesions, hardening, dark spots on the hands and feet, swollen limbs and loss of sensation.

12.6 Impact of Climate Change on Mental Health and Well-Being

The effects of climate change and its related environmental consequences are not only confined to the physical health but also affect mental and psychological wellbeing of a person. In this section we shall try to surface and correlate the different ways by which any alteration in average weather conditions affect the intellectual integrity of sufferers. To start with, we know that global warming has led to an unprecedented increase in the optimum universal temperature, a trend that is likely to continue. This rise in global temperature has been associated with the increasing aggressiveness and violence among people. A direct relation between higher incidences of criminal activities in summers substantiates the above statement. This aggressive behaviour and aggressive mentality often leads to several suicide attempts, the counts of which have been found to soar in hot summers indicating a relationship between these violent activities with the recent rise in mercury.

Heat waves have also been linked with anomalous psychological and behavioural responses. An Australian study reported the complementary effects of heat waves in increased prevalence of mental disorders in conjunction with other physiological ailments includingcardiovascular, hepatic and renal illnesses. Different mood disorders, anxiety disorders, dementia etc. are the common cerebral limited consequences of heat waves. We have all experienced that severe heat exposure renders us physically and psychologically exhausted.Occupational heat exposure, i.e. prolonged contact with elevated temperatures at workplace adversely affects the workers' cerebral consistency and causes severe mental stress as reported by a study from Thailand, which is often reflected in their deteriorating performances.

Besides, certain environmental calamities have their own roles in causing stress related psychiatric symptoms among the survivors. Disasters like floods, hurricanes, and bush-fires often leave drastic traumatic mental indentations that sometimes take years to heal. People subjected to life threatening circumstances often develop serious Post-Traumatic Stress Disorder (PTSD), the symptoms of which encompass regular disturbing flashbacks of the calamity.

Drought is another major consequence of climate change whose frequency of occurrence is expected to rise in the near future. With aberrant patterns of precipitation and soaring temperatures, droughts are already showing their grave corollaries in the form of severe water scarcity, drop in ground water levels, extreme weather conditions and many others. All these unanimously result in awful agricultural losses in terms of crop productivity, which ultimately leads to increased distress to farmers. Those farmers who are not able to cope with these hardship, they are taking extreme steps and ultimately suicide. The incidents are expected to even aggravate the present situation with increased drought due to climate change in near future. Such events have been observed in the developed as well as developing nations like India. Psychosomatic anxieties are thus amplified subsequent to disasters, especially for the families who are completely dislocated from their native settlements and forced by the destiny to subsist in any relief camps under emergency situations. Complete breakdown of normal daily routines along with excessive congestion at these emergency camps and lack of privacy add up to the already existing traumatic frame of mind of the victims and give vent to excessive annoyance, disappointment and aggression, with women and children forming the most vulnerable groups.

Summary and Conclusions

Extreme environmental conditions including floods, droughts, forest fires, and tropical cyclones are becoming more prominent these days. Changing climate conditions around the globe have remarkable impact on human health. The impacts of the climate change on human being could be grouped into two – direct and indirect.

The direct impacts of climate change are probably due to exposure to heat or cold waves orextreme weather events which are basically temperature and humidity related changes in climate. Air pollution in the form of rise of certain greenhouse gases like SO2, NO2 and also CO, lead, benzene, SPM in air also directly impact human health. Indirect impacts of climate change on human health are due to certain infectious diseases, vector-borne and water-borne diseases. Algal blooms are the rapid growth of algae that can cause harm to animals, human, or the local ecology.

Climate change influences different sections of society in terms of gender, age and socioeconomic conditions of the people. Women are more likely to be affected adversely by climate change than men. The effects of climate change seem to be more pronounced on children and aged population as compared to adults. Climate change compounds the miseries of people with low income and social status. The effects of climate change and its related environmental consequences are not only confined to the physical health but also affect mental and psychological wellbeing of a person.

References

Adapted from E PG Pathshala, Geography, Climatology, Module 38, Climate Change, Gender and Human Health.

Unit 13: Climate Change and Its Impacts: Role of Human Beings

Unit Structure

13.0 Learning Objectives

After completion of this unit you will be able to:

- describe climate change due to human activities;
- analyse the relationship between greenhouse gas emission and climate change;
- establish the linkages between radiative forcing and human induced climate change;

- analyse the role of different sectors of economy in climate change; and
- suggest some mitigation and adaptation measures to overcome the effects of climate change.

13.1 Introduction

We have already discussed about various natural and human induced causes of climate change in the previous module. We have also analysed about the evidences and impacts of climate change both at global as well as national level in the same module. It has now been established that the present climate change is human induced. This is due to alarming rate of releasing of anthropogenic Green House Gases (GHG). The most significant aspect about the increases in all the major Green House Gases is that they have occurred after the industrial revolution in 18th Century which is not more than 400 years old. That is why this small historical period is named as Anthropocene (in the line of geological periods named) era. The term was coined by ecologist, Eugene F. Stoermer but has been widely popularized by the atmospheric chemist, Paul Crutzen. This is because of influence of human behaviour on the earth's atmosphere in recent centuries is so significant that it has been affecting the living organisms on the earth. This has been reinforced by the recently published IPCC Fifth Assessment Report.

In this unit, we shall start our discussion by describing consensus among scientific community about climate change due to human activities as presented in theIPCC Fifth Assessment Report. This is followed by discussion about greenhouse gas emission and radiative forcing highlighting human contribution that led to climate change. We will also discuss about the greenhouse gas emission by different sectors of economy. In the concluding section an attempt has been made to highlight major mitigation and adaptation strategies to overcome or reduce the effect of climate change.

13.2 Climate Change: Views of Scientific Community

In the beginning, people were not in in favour of accepting the idea that the climate change is happening due to human activities. It has already been mentionedin the Module 33.However, after about two decades of scientific research conducted all over the world and compiled and produced in the form of Five Assessment Reports by Intergovernmental Panel on Climate Change (IPCC) have been able to create a consensus among scientific community about human induced climate change. These reports presented peer-reviewed, consensus opinions among experts in the scientific community concerning the causes of climate change. Further research areas were identified to study in detail to remove any uncertainties. The latest IPCC Fifth Assessment Report concludes that the primary cause of climate change is human activities in 95%–100% of the cases. The Report has also concluded with 95% certainty that humans are responsible for the temperature increase during the period of 1951- 2010.

The evidence for human influence on the climate system has grown since the IPCC Fourth Assessment Report (AR4). It is extremely likely that more than half of the observed increase in global average surface temperature from 1951 to 2010 was caused by the anthropogenic increase in GHG concentrations and other anthropogenic forcings together. The Report has also concluded that anthropogenic forcings have made a substantial contribution to surface temperature increases since the mid-20th century over every continental region except Antarctica.

For better understanding of climate change due to anthropogenic activities, we need to understand the trend of GHG emission and its radiative properties. Before discussing about the trend of GHG emission and its radiative properties, let us discuss the anthropogenic sources of GHGs.

13.3 Sources of Anthropogenic Greenhouse Gases

Do you know, from where these GHGs are emanating? Practically, these emissions are coming from almost all the sectors of our economy. Let us discuss four major GHGs and their sources of origin due to anthropogenic activities. As mentioned in the module on “Climate Change: Evidences and Causes” the four major GHGs are Carbon Dioxide (CO2), Methane (CH4), Nitrous Oxide (N2O)and Fluorinated gases (mostly HFCs). Let us now discuss about major sources of emission of these four principal greenhouse gases particularly arising out of human activities.

The major sources of CO2 are mainly originated from burning coal, oil, and gas (about 75%).

13.3.1 Carbon Dioxide (CO2)

About 20% of the total CO_2 emissions come from deforestation and decomposition of peat lands, crop residues, and organic materials in agricultural soils. Smaller amounts are produced from turning oil and gas into plastics and other compounds that eventually are decomposed into CO_2 again (about 3%) as well as from manufacture of cement through decomposition of one of the main ingredients, limestone (about 3%).

13.3.2 Methane (CH_4)

It comes from a variety of sources.The largest source is livestock, particularly cattle and sheep (25%). This is followed by leaks from extraction, processing, and distribution of natural gas (15%). Other important sources are rice cultivation (12%), associated gas from coal production (10%), and decomposition of organic waste in waste water treatment (9%) and landfills (7%).

13.3.3 Nitrous Oxide (N_2O)

It mainly comes from fertilized grasslands and croplands, where nitrogen fertilizers are decomposed in the soil (35%).This is followed by animal waste (26%). Surface water polluted with nitrogen accounts for about 15%. Small amounts come from chemical factories, such as those for nylon production (5%) and waste water treatment (2%). A small quantity of N_2O (about 1% of the total) comes from Cars with catalytic converters.

13.3.4 Fluorinated Gases (mostly HFCs)

These gases are mainly emitted from air conditioners in cars and refrigerators, as well as from the production of industrial chemicals. SF_6 is mainly used as an insulator in electrical equipment.

Let us discuss in brief about global warming potential

13.4 Global Warming Potential of Anthropogenic Greenhouse Gases

Do you know what is the Global Warming Potential (GWP) of anthropogenic GHGs and how do we calculate it? GWP was developed for comparing the global warming impacts of different gases. In other words, it is a measure to calculate how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO_2). Therefore, calculation of GWPtakes into account both the radiative properties of a particular greenhouse gas molecule and its lifetime existence in the atmosphere, once emitted. The larger the GWP value, the more is the warming capacity of that particular given gas incomparison to CO2 over that particular time period. The time period usually used for GWPs is 100 years. This is the atmospheric life time of CO2.

GWP of CO2 is 1 because it is the gas being used as the reference. On the other handmethane is considerably more short-lived in the atmosphere than CO2, persisting for decades rather than centuries (Table 1). This measurement is helpful for formulation of mitigation policies.If we need to avoid a dangerous short-term climate tipping point, we might focus more effort on reducing methane because it is a particularly potent, if short lived, greenhouse gas. On the other hand, if our goal is to stabilize long-term greenhouse gas concentrations, we would be better served by focusing purely on CO2 emissions.

Table 1:Atmospheric Lifetime and GWP of Major Greenhouse Gases
***Gases emitted solely from human sources**

Sr. No.	Green House Gases	Atmospheric Lifetime in Years	Global Warming Potential
1	Carbon dioxide (CO2	Approx. 100	1
2	Methane (CH4)	12	23
3	Nitrous oxide (N2O)	120	310
4	Hydrofluorocarbons (HFCs)	1.5 to 264	140 to 11,700
5	Perfluorocarbons (PFCs)	3,200 to 50,000	6,500 to 9,000
6	Sulphur hexafluoride (SF6)	3,200	23900

To have a better understanding about the global warming and climate change due to GHG emission by anthropogenic activities, we have to understand the processes of radiative forcing.

13.5 Radiative Forcing

You have already read in other modules on climatology about heat budget. Theoretically, we can say that Earth's energy balance is zero. What does this mean? This means that the amount of energy arriving at Earth's surface is equal to the amount of energy eventually radiated back to space. However, Earth's climate has cycled through periods where this balance is not achieved and Earth systems are either gaining or losing heat. The term radiative forcing is also known as climate forcing. In other words, any change in the radiative balance caused by changes in atmospheric composition. Therefore, it describes the amount by which some perturbation causes Earth's energy balance to deviate from zero. A positive forcing indicates a warming condition whereas a negative forcing indicates cooling.Scientists at National Oceanic and Atmospheric Administration (NOAA)have measured the radiative forcing caused by major long-lived greenhouse gases for the period 1979-2015.This is quantified in watts of energy affecting Earth's energy budget. Figure 1, shows Annual Greenhouse Gas Index, as measured by NOAA. According to the figure the Annual Greenhouse Gas Index value reached 1.32 in 2012. Do you know what does this indicator convey? This indicator converts the total radiative forcing for each gas into an index by using the ratio of the Radiative Forcing (RF) for a particular year compared with the RF in 1990 (the baseline year). The graph shows that RF has increased steadily for all gases, with the

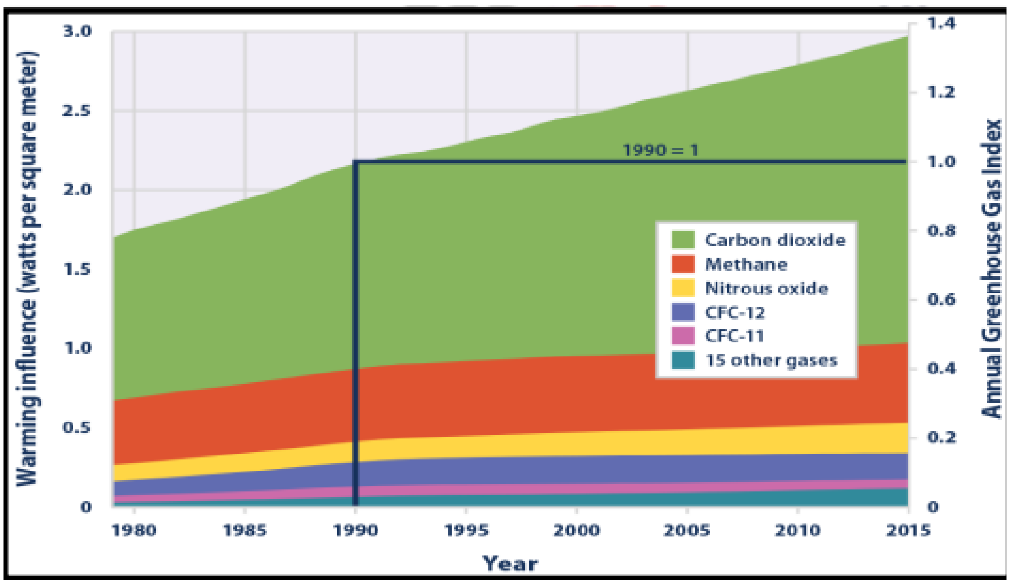


Figure 1: Radiative Forcing Caused by Major Long-Lived GHGs 1979-2015

Source: https://www.epa.gov/sites/production/files/styles/large/public/2016-07/climate-forcing-download1-2016.png

proportion attributed to CO2 increasing the most (Figure 1).

According to the Report given by Working Group I of the Fifth Assessment Report of the IPCC which deals with the Physical Science Basis show that there is a difference in the scientific understanding of different RF effects.It has been observed that emissions can result either in an increase or a decrease in RF at the global scale.Over the past 260 years (1750-2010), emissions of CO2, CH4, N2O, F-gases, black carbon, CO, and NMVOC all resulted in an increase in RF. On the other hand, emissions of SO2, organic carbon and mineral dust all contributed to a decrease in RF. Emissions of halocarbons had both a positive and negative impact on RF. Also, the emissions of NOX and NH3 have had both a positive and negative RF effect, but with a negative net impact on RF. Figure 2 further

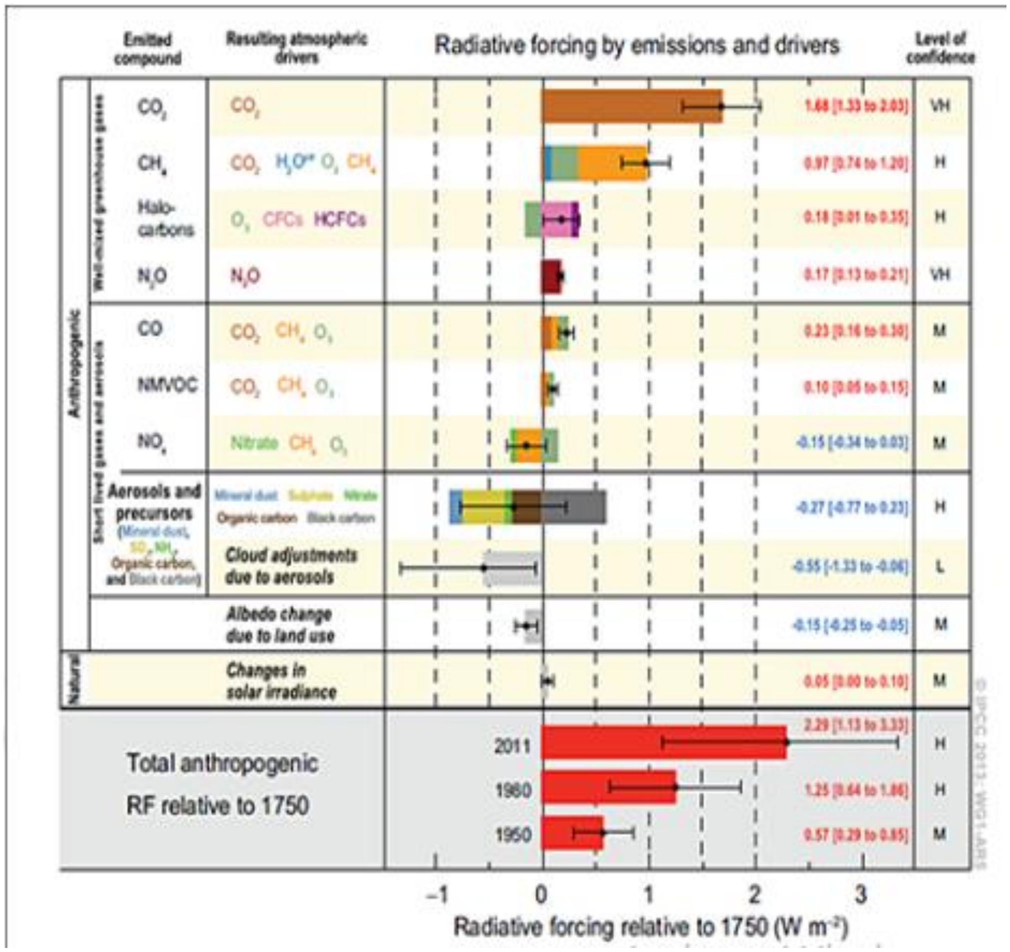


Figure 2: Radiative Forcing Estimates in 2011 in relation to 1750

Source: https://www.eea.europa.eu/data-and-maps/figures/radiative-forcing-estimates-in-2011/image_original

highlights that interactions between aerosols and clouds resulted in a negative RF, but that the contribution of individual emitted compounds within mixes of aerosols is unknown.

13.6 Anthropogenic Greenhouse Gas Emission and Climate Change

As mentioned in the previous module as well as in the initial section of this module that the increasing concentration of atmospheric CO2and other greenhouse gases due to anthropogenic activities is the major cause for global climate change has now been established. According to an analysis undertaken by Mann and Kump has revealed that out of all the major greenhouse gases, percentage share of CO2 emission is highest. Therefore, it plays a significant role in human induced climate change. If we analyse contribution of major GHGs, it has been observed that CO2 accounted for more than three fourth of the

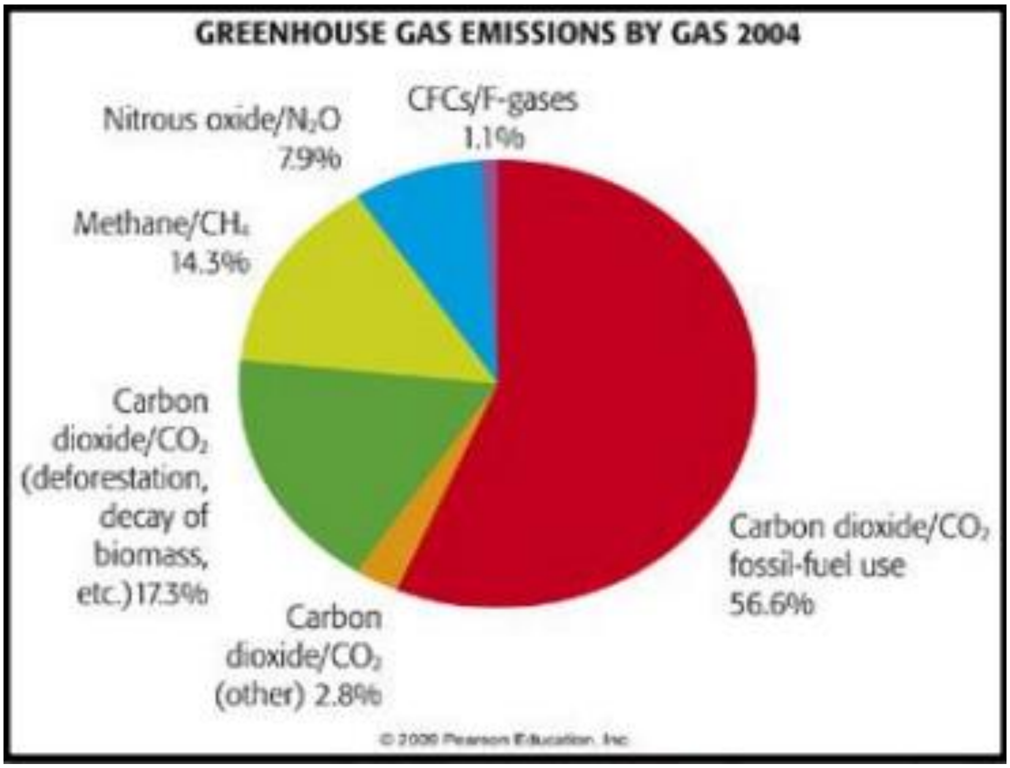


Figure3: Greenhouse Gas Emissions by Gas: 2004

Source: https://www.e-education.psu.edu/meteo469/node/181

emission (about 77%). The other GHGs which plays a significant role are methane (about 14%), nitrous oxide (about 8%), and the chlorofluorocarbons constitute the remaining 1% (Figure 3). The same has also been reported by IPCC Fourth Assessment Report (AR4).

According to IPCC Fifth Assessment Report titled 'Climate Change 2014 Synthesis Report,cumulative anthropogenic CO2 emissions to the atmosphere between 1750 and 2011 were 2040 ± 310 GtCO2(Gt=Gigatonne, one gigatonne is equal to one billion tonnes). Out of the total cumulative anthropogenic CO2 emissions, about 40% have remained in the atmosphere (880 ± 35 GtCO2). The remaining was removed from the atmosphere and stored in plants and soils on land and in the ocean. These vegetation and soil on land and in oceans are major source of carbon sinks. If we analyse CO2 emission over the time period, it has been observed that about half of the anthropogenic CO2 emissions between 1750 and 2011 have occurred in the last 40 years. The trend analysis has also revealed that total anthropogenic GHG emissions have continued to increase over 1970 to 2010 with larger absolute increases between 2000 and 2010 (Figure 4).This has happened despite of a growing number of climate change mitigation policies implemented across the world.

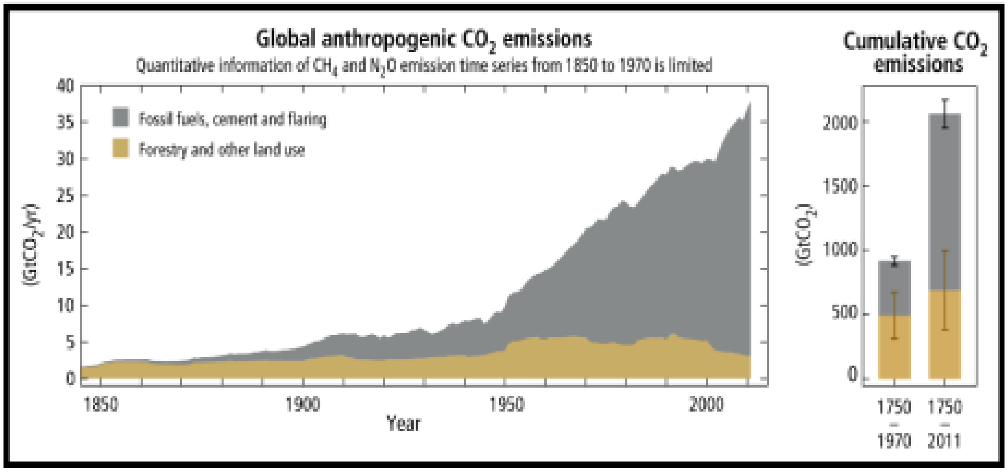


Figure 4: Trends of Global Anthropogenic CO2 Emissions: 1750-2011

Source:https://www.ar5-syr.ipcc.ch

Anthropogenic GHG emissions in 2010 have reached 49 ± 4.5 GtCO2-eq/yr. Emissions of CO2 from fossil fuel combustion and industrial processes contributed about 78% of the total GHG emissions increase from 1970 to 2010, with a similar percentage contribution for the increase during the period 2000 to 2010. As mentioned earlier, at global level, economic and population growth continued to be the most important drivers of increases in CO2 emissions from fossil fuel combustion. The contribution of population growth between 2000 and 2010 remained roughly identical to the previous three decades, while the contribution of economic growth has risen sharply. Increased use of coal has reversed the long-standing trend of gradual decarbonisation of the world's energy supply.Do you know what decarbonisation is? Decarbonisation refers to reducing the carbon intensity of energy. Therefore, major strategies for reducing the greenhouse gas emissions are to control the release of greenhouse gases from fossil fuel combustion, land-use change and the burning of vegetation. If we succeed in doing so, then this would lead to decrease in the projected rate and magnitude of warming. In other words, future climate change would be determined by historic, current and future emissions of these greenhouse gases.

13.7 Impact of Human activities on Climate Change

Analysis of Economic Sectors Analysis of the main sources of greenhouse gas emissions according to the sectors of the economy (Figure 5) reveals that energy supply is the largest (26%) contributors of GHG, followed by industry (19%), the forest sector (17%), agriculture (14%), transport (13%), the building sector (8%), and waste management (3%). Confusion can arise around sector contributions because emissions can be counted in different ways. The numbers given above are based on emissions at the point where they enter the

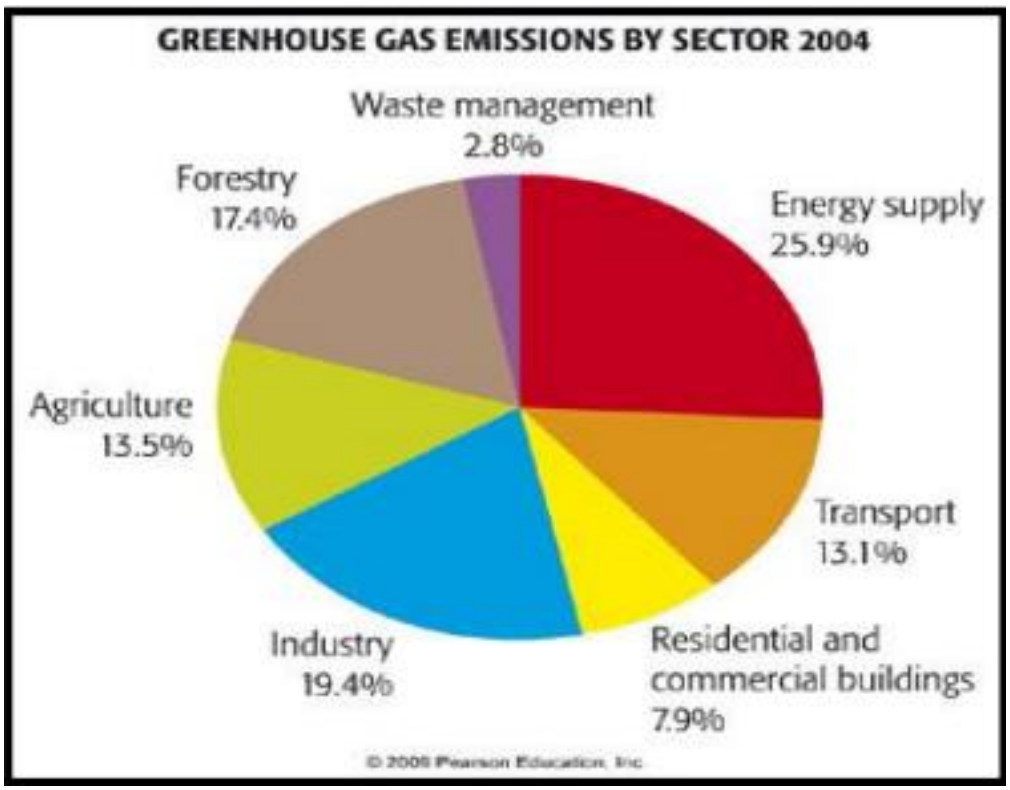


Figure 5: Greenhouse Gas Emissions by Sector: 2004

Source: https://www.e-education.psu.edu/meteo469/node/181

atmosphere (so-called 'point of emission allocation'). So emissions from electricity generation are counted under the energy supply sector. However, it can be more useful to count such emissions under the sector where that electricity is used (socalled ''end-use allocation''). That can give a better picture of how electricity emissions

It is useful to know what the historical contributions to our emissions have been from the various sectors. Looking forward towards the future, it is also important to know which sectors are growing most rapidly in their contribution to anthropogenic greenhouse emissions. By comparing emissions rates during the middle of the past decade with those at the beginning of the 1990s, it has been observed that the largest absolute increase (an increase of nearly 3 gigatons / year of CO2 released) has been in the energy sector.Other sectors such as transport and forestry have shown similar (35-40%) increases in emissions over this time frame. It is logical to conclude that these sectors might demand special attention in considering possible emissions mitigation approaches.

According to the latest IPCC Fifth Assessment Report 2014, the total annual anthropogenic GHG emissions have increased by about 10 GtCO2-eq between 2000 and 2010. This increase directly came from the energy (47%), industry (30%), transport (11%) and building (3%) sectors (medium confidence). Accounting for indirect emissions raises the contributions by the building and industry sectors (high confidence). Since 2000, GHG emissions have been growing in all sectors, except in agriculture, forestry and other land use (AFOLU). In 2010, 35% of GHG emissions were released by the energy sector, 24% (net emissions) from AFOLU, 21% by industry, 14% by transport and 6.4% by the building sector(Figure 6). When emissions from electricity and heat production are attributed to the sectors that use the final energy (i.e., indirect emissions), the shares of the industry and building sectors in global GHG emissions are increased to 31% and 19%, respectively.

Globally, economic and population growth continue to be the most important drivers of increases in CO2 emissions from fossil fuel combustion. According to the Working Group III Report on Summary for Policy Makers revealed that the contribution of population growth between 2000 and 2010 remained roughly identical to that of the previous three decades, while the contribution of economic growth has risen sharply (high confidence). The Report has also revealed that between 2000 and 2010, both drivers outpaced emission reductions from improvements in energy intensity of gross domestic product (GDP). This has happened due to increased use of coal relative to other energy sources. This has reversed the longstanding trend in gradual decarbonisation of energy of the world's energy supply.

13.8 Remedial Measures to Overcome the Effects of Climate Change

In climate change discourse, there are two approaches to address human induced climate change. These are mitigation and adaptation. Mitigation has the long history in the climate policy, whereas the adaptation has recently gained importance.

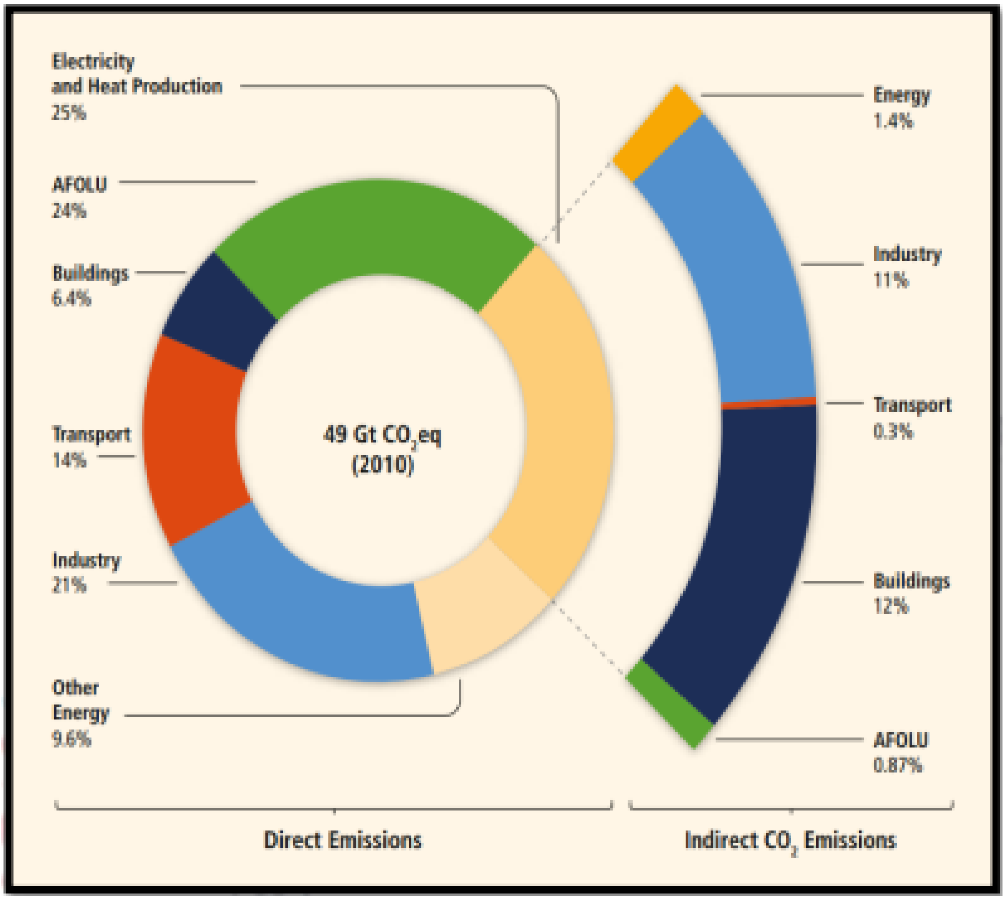


Figure 6: Greenhouse Gas Emission by Economic Sector: 2010

Source: http://www.bestclimatepractices.org/wp-content/uploads/2015/02/IPCC-WGIII-AR5-2014-emissions-by-economicsectors-fig-TS3-Crop.png

13.8.1 The Concept of Mitigation and Adaptation

The concept 'mitigation' in general means the reduction of the atmospheric GHGs, and hence, we can avoid the likelihood of the occurrence of the climatic variability and extreme events. IPCC defines mitigation as"an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases." On the other hand, the notion 'adaptation' in general refers to the individual, communities, and societies to adjust their activities, life courses and location to take an opportunity, to get advantage from the fluxes of the social-ecological systems. The climate change literature views it as "the adjustment in human and natural systems to actual or expected climatic stimuli, which can reduce the negative impacts and take advantage of the positive" (UNFCC 1992).

13.8.2 The Need for Mitigation and Adaptation

As mentioned above, climate change has severe non-linear impacts on the wellbeing of the human society. Many developing nations have already experienced weather related extreme events in terms of floods, droughts, heat waves and tropical cyclones that are more frequent or intense than previous experiences. In general, it affects different sectors, such as fresh water resources and their management, food and fibre and forest products, coastal system and low lying areas, and health etc. The resulting impacts will have significant consequences on the environment, production systems and livelihood from future climate variability and change. Importantly, the developing nations are facing more burdens as compared to the developed nations (Stern, 2006; and Mendelsohn et al., 2006). Meanwhile, Stern has estimated “if we don’t act, the overall damage cost will be equivalent to at least 5 percent of GDP now and forever, and if wider range of risks and impacts is taken into account, the estimates of damage could rise to 20 percent of the GDP or more” (Stern, 2006).

13.8.3 Mitigation and Adaptation Measures by AR5 for Policy Makers

IPCC Fifth Assessment Reporthas giventhe following major suggestions related to mitigation and adaptation. There are two broad suggestions related to mitigation and adaptation. Under these two broad suggestions, there are five important specific suggestions. Let us discus broad suggestions as well as specific suggestions given under broad suggestions.

13.8.4 Future Pathways for Adaptation, Mitigation and Sustainable Development

Adaptation and mitigation are complementary strategies for reducing and managing the risks of climate change. Substantial emissions reductions over the next few decades can reduce climate risks in the 21st century and beyond, increase prospects for effective adaptation, reduce the costs and challenges of mitigation in the longer term and contribute to climate-resilient pathways for sustainable development.

a) Climate Change Risks Reduction by Mitigation and Adaptation

Without additional mitigation efforts beyond those in place today, and even with adaptation, warming by the end of the 21st century will lead to high to very high risk of severe, widespread and irreversible impacts globally (high confidence). Mitigation involves some level of co-benefits and of risks due to adverse side effects, but these risks do not involve the same possibility of severe, widespread and irreversible impacts as risks from climate change, increasing the benefits from near-term mitigation efforts.

b) Characteristics of Adaptation Pathways

Adaptation can reduce the risks of climate change impacts, but there are limits to its effectiveness, especially with greater magnitudes and rates of climate change. Taking a longer-term perspective, in the context of sustainable development, increases the likelihood that more immediate adaptation actions will also enhance future options and preparedness.

c) Characteristics of Mitigation Pathways

here are multiple mitigation pathways that are likely to limit warming to below 2°C relative to pre-industrial levels. These pathways would require substantial emissions reductions over the next few decades and near zero emissions of CO2 and other long-lived greenhouse gases by the end of the century. Implementing such reductions poses substantial technological, economic, social and institutional challenges, which increase with delays in additional mitigation and if key technologies are not available. Limiting warming to lower or higher levels involves similar challenges but on different timescales.

13.8.5 Adaptation and Mitigation

Many adaptation and mitigation options can help address climate change, but no single option is sufficient by itself. Effective implementation depends on policies and cooperation at all scales and can be enhanced through integrated responses that link adaptation and mitigation with other societal objectives.

a) Common Enabling Factors and Constraints for Adaptation and Mitigation Responses

Adaptation and mitigation responses are underpinned by common enabling factors. These include effective institutions and governance, innovation and investments in environmentally sound technologies and infrastructure, sustainable livelihoods and behavioral and lifestyle choices.

b) Response Options for Adaptation

Adaptation options exist in all sectors, but their context for implementation and potential to reduce climate-related risks differs across sectors and regions. Some adaptation responses involve significant co-benefits, synergies and trade-offs. Increasing climate change will increase challenges for many adaptation options.

c) Response Options for Mitigation

Mitigation options are available in every major sector. Mitigation can be more cost-effective if using an integrated approach that combines measures to reduce energy use and the greenhouse gas intensity of end-use sectors, decarbonize energy supply, reduce net emissions and enhance carbon sinks in land-based sectors.

d) Policy Approaches for Adaptation and Mitigation, Technology and Finance:

Effective adaptation and mitigation responses will depend on policies and measures across multiple scales: international, regional, national and sub-national. Policies across all scales supporting technology development, diffusion and transfer, as well as finance for responses to climate change, can complement and enhance the effectiveness of policies that directly promote adaptation and mitigation.

e) Trade-offs, Synergies and Interactions with Sustainable Development:

Climate change is a threat to sustainable development. Nonetheless, there are many opportunities to link mitigation, adaptation and the pursuit of other societal objectives through integrated responses (high confidence). Successful implementation relies on relevant tools, suitable governance structures and enhanced capacity to respond (medium confidence).

(Source: Climate Change 2014, Synthesis Report, Summary for Policy Makers, Contribution to the Fifth Assessment Report of the IPCC, pp. 17-31.)

Summary and Conclusions

IPCC Fifth Assessment Report concludes that the primary cause of climate change is human activities in 95%–100% of the cases. The Report has also concluded with 95% certainty that humans are responsible for the temperature increase during the period of 1951- 2010. Between 1990 and 1999, an estimated 6.3 GtCO2/year was released due to the combustion of fossil fuels, and another 1.6 GtCO2/year was released due to the burning of forest vegetation.

This was offset by the absorption of 2.3 GtCO2/year each by growing vegetation and the oceans. This left a balance of 3.3 GtCO2/year in the atmosphere. Controlling the release of greenhouse gases from fossil fuel combustion, land-use change and the burning of vegetation are therefore, obvious opportunities for reducing greenhouse gas emissions and can decrease the projected rate and magnitude of warming.

The term radiative forcing describes the amount by which some perturbation causes Earth’s energy balance to deviate from zero. A positive forcing indicates a warming condition whereas a negative forcing indicates cooling.

If we organize the main sources of greenhouse gas emissions according to the sectors of the economy, we see that energy supply is the largest (26%) contributors of GHG, followed by industry (19%), the forest sector (17%), agriculture (14%), transport (13%), the building sector (8%), and waste management (3%).

Remedial measures to overcome or reduce the effects of climate change can be addressed by undertaking both adaptation and mitigation measures. According to IPCC mitigation refers to an anthropogenic intervention to reduce the sources or enhance the sinks of greenhouse gases. According to UNFCC adaptation refers to the adjustment in human and natural systems to actual or expected climatic stimuli, which can reduce the negative impacts and take advantage of the positive.

IPCC Fifth Assessment Reporthas giventhe following major suggestions related to mitigation and adaptation. There are two broad suggestions related to mitigation and adaptation. Under these two broad suggestions, there are five important specific suggestions.

References

E-PG Pathshala, Geography, Climatology - Climate Change and Its Impacts: Role of Human Being Module CL-34

Unit 14: Institutions and Protocols

Unit Structure

14.0 Learning Objectives

After completion of this unit you will be able to:

- Learn about the international efforts made to combat, mitigate and adapt to climate change and
- Know about India's initiatives in combatting climate change

14.1 Introduction

Climate change induced by anthropogenic causes is a global concern and is likely to affect all nations of the world including developed and developing nations. Some countries are particularly vulnerable to adverse impacts of climate change including countries with low lying coastal zones which are likely to be affected by increased sea level caused by global warming. World leaders recognized that if human activities are not controlled, the adverse effects on climate change would be irreversible and would be detrimental to human survival and ecosystems.

Having acknowledged that human activities have caused the emission of Greenhouse gases whose concentration in the atmosphere is perpetrating climate change, the global community initiated negotiations for international instruments and for establishing institutions for dealing with, preventing, mitigating and adapting to climate change. Establishment of Intergovernmental Panel on Climate Change (IPCC) led the way from the front. It led to enactment of UN Framework Convention on Climate Change which is a major step in this direction which provided an impetus to developing instruments and institutions for dealing with climate change. Adoption of UNFCCC led to enactment of Kyoto Protocol which spelt out the specific targets for reduction of emission of GHG. Paris Agreement is another step in this direction.

14.2 International Efforts to Contain and Combat Climate Change

The international community became active to climate change and its likely impact on the plant and humans especially in the late twentieth century. Accordingly, various efforts were made to contain, combat and mitigate the effects of climate change. These can be broadly discussed under the following heads

- Vienna Convention
- Montreal Protocol
- Kyoto protocol
- Setting up of IPCC
- Adoption of UNFCCC

14.2.1 Vienna Convention, 1985

Vienna Convention was the outcome of efforts of twenty countries who were largely responsible for producing Chlorofluorocarbons (CFC). These countries signed a treaty in Vienna which is known as Vienna Convention for the Protection of the Ozone Layer, 1985. Vienna Convention is a framework treaty which sets out the general obligation of the parties. The Convention laid down the general obligations of the parties to cooperate, promote research and exchange information on adverse impact of human activities on the Ozone layer and to take appropriate legal, administrative and policy measures to control, limit and replace the activities which have adverse impact on the ozone layer in accordance with their means and capabilities (Article 2). The Convention called upon the parties to undertake and promote research on the physical and chemical processes which affect the ozone layer and is impact on human health, climate and ecosystems and to discover alternatives to such substances which adversely affect the ozone layer (Article 3). The Convention identified various substances which were likely to have adverse impact on ozone like Carbon substances (CO2, methane, carbon monoxide), Nitrogen substances (Nitrous oxide and Nitrogen oxides), Chlorine substances and Bromine substances. The country parties were recommended to conduct research on these substances to find out the scientific data and to find out their alternatives. However, the Convention did not lay down any mandatory actions to be taken by the parties though it provided for the adoption of Protocols in accordance with scientific discovery of the effects of various substances on the Ozone layer. This provided a framework for negotiating international regulations on ODS.

Vienna Convention entered into force on 22nd September 1988. Vienna Convention is the first international treaty to have achieved universal ratification. It achieved universal ratification in 2009.

14.2.2 Montreal Protocol to Vienna Convention

Vienna Convention for the protection of ozone layer was signed in 1985. The Convention was the result of the efforts of the world community to protect ozone layer when a huge hole was detected in it over Antarctica. Vienna Convention was aimed at promoting cooperation among nations regarding the depletion of ozone layer and to promote research and information exchange on the impact of human activities on ozone layer. However, the

Convention was not a binding document and it provided for adoption of Protocols of binding nature for reducing the emission of Ozone Depleting Substances (ODS). To have a legally binding instrument, Montreal Protocol to Vienna Convention was adopted in 1987 which is a supplementary agreement to the Protocol. Montreal Protocol aimed at controlling and curbing global emission of substances that deplete the Ozone layer or modify the Ozone Layer and ultimately elimination of ODS. Though originally the Protocol was adopted to protect the Ozone Layer yet the potential effects of emission of ODS on climate change have been recognized since ODS are also potent greenhouse gases and contribute significantly to climate change. So far Protocol has been amended six times i.e. London Amendment, 1990; Copenhagen, 1992; Vienna Accord, 1995; Montreal Amendment, 1997; Beijing Amendment, 1999 and; Kigali Amendment, 2016. These amendments have added list of controlled substances which are required to be phased out for protection of Ozone layer. Kigali amendment added HFC's as a controlled substance and provided schedule for reduction of use of HFCs by 80-85%. HFC phasing out is expected to prevent 105 million tonnes of carbon dioxide equivalent of greenhouse gases and will help to avoid 0.5 degree temperature rise by 2100 (UNEP).

Discovery of abnormally low ozone concentration levels near South Pole in 1985 later termed as Ozone hole led to increased international emphasis on taking concrete measures to control, limit and phase out ODS in a time bound manner. Initially when it was pointed out that this ozone layer is the result of increased level of CFCs in the atmosphere, the CFC industry opposed it on the ground that there is no enough scientific evidence to suggest that the hole is caused by the CFC emissions. Further, it was argued that in the absence of certainty in scientific information, it was not worthwhile to take concrete action as they thought that there was no imminent danger at that point of time. However, further research and the results of such research showed the linkage between depletion of ozone layer and ODS emissions which led to the negotiations for establishing a framework and for creating legally binding responsibilities to identify and phase out ODS in a time bound manner to protect the ozone from further depletion. The negotiations led to the adoption of a Protocol in Montreal on Substances that Deplete the Ozone Layer. The Protocol was agreed in September 1987 by forty six countries and it entered into force on January 1, 1989. Like Vienna Convention, Montreal Protocol also achieved universal ratification in 2009.

Montreal Protocol is based on two important principles of international environmental jurisprudence i.e.

- Precautionary Principle
- Principle of Common but Differentiated Responsibilities

As stated earlier that at the time when Vienna Convention and Montreal Protocol were adopted, there was lack of scientific certainty and therefore, the reduction of emission of ODS was basically adopted on Precautionary Principle to save the ozone layer from probable effect of emission of ODS. Further, it was recognized that the damage to ozone is the result of emission of ODS particularly by developed countries, therefore, the primary responsibility was theirs to control, limit and phase out ODS. Furthermore, the developing countries also had their right to development and to tap their resources, therefore, greater onus was put on developed countries while recognizing the need of developing countries on the basis of the Principle of Common but Differentiated Responsibilities and Respective Capabilities. Accordingly, special provisions were made for developing countries in the phase out schedules. Developing countries with reference to the Protocol imply a country where consumption of Annex A controlled substances was less than 0.3 kg per capita till 01st January 1999 (Article 5).

14.2.2.1 Control Measures under the Protocol

As stated earlier, Montreal Protocol laid down legally binding responsibilities for the parties to phase out ODS in a time bound manner. These ODS have been identified from time to time in accordance with new scientific and technological advancements and are included in the list of controlled substances under various provisions of Article 2 by way of amendment to the Protocol. Various controlled substances identified so far and for which phase out schedule has been laid down are CFCs (Chlorofluorocarbons), Halons, Fully Halogenated CFCs, Carbon Tetrachloride, Methyl Chloroform, Hydrochlorofluorocarbons (HCFC), Hydrobromofluorocarbons (HBFC), Methyle Bromide and Bromocholoromethane and HFCs. The time schedule for the phasing out of these ODS is given in the next section after discussion on amendments to Montreal Protocol.

In addition, Protocol has prohibited trade i.e. import or export of controlled substances with nonparties with a view to compel non-parties to join the Protocol and therefore to achieve control over controlled circumstances so as to protect Ozone layer from depletion (Article 4). Protocol further provides that if a party is unable to stop production of a controlled substance even after its best efforts during the time frame provided in the Protocol, in such an eventuality, such party must stop export of used, recycled or reclaimed quantities of such substance except for the purpose of destruction (Article 4A). The parties to the Protocol are obligated to establish a system of licensing of import and export of the controlled substances in a time bound manner (Article 4B).

Special provisions have been incorporated for developing countries based on the Principle of Common but Differentiated Responsibilities and respective capacities. For developing countries, the phase out schedule has been delayed/relaxed keeping in view their development needs. The details of the same are given in the phase out schedule discussed in the table given hereinafter.

Further, the parties have been obligated to report data regarding production, import and export of controlled substances for the base year and subsequently (Article 7). Protocol mandates parties to cooperate in conducting research and development on controlled substances and in creating public awareness and exchange of Information (Article 9). Parties are required to submit a summary of activities every two years. The Protocol obligates parties to cooperate –

- For finding out best technologies for improvement, recovery, recycling or destruction of controlled substances, for reducing their emissions
- To find out Alternatives to controlled substances
- To promote public awareness on environmental effects of emissions of controlled substances

14.2.2.2 Amendments to the Protocol

Mechanism for monitoring and reviewing the implementation of the Protocol and for making adjustments and amendments to the Protocol has been vested in Meeting of Parties (MOP). Parties are required to meet at regular intervals. MOP is required to take decisions regarding reduction/alteration in emission targets and to review the implementation of the Protocol. MOP has in various meetings adopted six amendments to the Montreal Protocol keeping in view scientific and technological advancements. These are discussed hereinafter

London Amendment, 1990: London Amendment was adopted in the Second MOP on 29th June 1990. After entry into force of the Protocol, new ODS were identified who were also contributing to depletion of Ozone layer and need was felt to put them into the list of controlled substances and accordingly, London Amendment added fully halogenated CFCs, Carbon Tetrachloride, and Methyl Chloroform to the list of substances needing to be controlled because of their effect on the ozone layer (Annexes A and B) by inserting Articles 2C, 2D and 2E. The amendment called for the elimination of the production and consumption of CFCs, Halons, and Carbon Tetrachloride by January 1, 2000 (January 1, 2010 for developing countries) and of Methyl Chloroform by January 1, 2005 (January 1, 2015 for developing countries) and barred trade of controlled substances with non parties. The important contribution of London Amendment was the establishment of Multilateral Fund to help developing countries meet their obligations wherein voluntary contributions from developed countries were mandated.

Copenhagen Amendment, 1992: Copenhagen Amendment was adopted in Fourth MOP on 25th November 1992 and it entered into force on 14th June 1994. The features of Copenhagen amendment were :

- It provided for accelerated phase-out of consumption and production of CFCs (including fully halogenated CFCs), Methyl Chloroform, and Carbon Tetrachloride by January 1, 1996, and of Halons by January 1, 1994.
- HBFCs and Methyl Bromide were also added to the controlled substances list by inserting Articles 2G, 2H
- HCFCs added to the controlled substances list (inserting Article 2F)

Vienna Accord, 1995: MOP in its seventh meeting at Vienna took a decision on 07th December 1995 to phase out consumption of Methyl Bromide in developed country by 2010. It was further decided to make adjustments to the phase out schedule of HCFC. Protocol provides flexibility in the matter of amending the phase out schedule. The amendments have been divided into amendments and adjustments. Those adjustments which are within the existing authority of MOP are not required to be submitted further to the Senate

Montreal Amendment, 1997: Montreal Amendment was adopted on 17-09-1997 in the 9th MOP. The amendment made the following changes to Montreal Protocol

- Imposed prohibition on trade in Methyl bromide with non parties (Article 4A)
- Required all Parties to institute a system of licensing for the import and export of all new, used, recycled, and reclaimed controlled substances, including methyl bromide (Article 4B)

Beijing Amendment, 1999: On 03-12-1999, Parties to Protocol in 11th MOP adopted Beijing Declaration on Renewed Commitment to the Protection of Ozone Layer. 11th MOP made adjustments and series of amendments to the Protocol. Keeping in view the advancements in science and technology and the new scientific wisdom gained, new ODS were identified and added to the list of controlled substances. The Beijing Amendment entered into force on 25-02-2002. The main features of Beijing Amendment are:

- Addition of Bromochloromethane to the list of controlled substances (Article 2I)
- Complete prohibition on trade of HCFCs and Bromochloromethane between Parties to the amendment and non-Parties
- Annual reporting regarding volume of Methyl Bromide used for quarantine and pre-shipment purposes made mandatory

Kigali Amendment, 2016: Kigali Amendment was adopted in the 28th MOP held at Kigali, Rwanda on 15th October 2016. The Amendment is to enter into force on 01st January 2019. Kigali Amendment has added Hydrofluorocarbons (HFCs) to the list of controlled substances (Article 2j). The parties have agreed to phase out production and consumption of HFCs from 2019 in case of developed countries and from 2024 for developing countries. The amendment mandates phasing out of more than 80% of the consumption of HFCs in a time span of thirty years. Further, the Amendment, requires all HCFC-22 producing facilities to destroy HFC-23, a by-product of HCFC and a super pollutant and a very potent GHG from 2020 to the possible extent. The developed countries have been obligated to provide financial support to developing countries for financing HFC reduction. The phase out schedule of HFCs under Kigali Amendment is given in Table II.

Table I – Phase-out Schedule of Controlled Substances		
ODS	**DEVELOPED COUNTRIES**	**DEVELOPING COUNTRIES**
Article 2 A Chlorofluorocarbons (CFCs)	Phased out by 01st January 1996	Phased out by 01st January 2010 (India also phased out CFC except

CFC-11 CFC-12 CFC-113 CFC-114 CFC-115		use of CFC in manufacturing of Metered Dose Inhalers for Asthma and Chronic Obstructive Pulmonary Diseases
Article 2B Halon 1211, Holon 1301, Halon2402	Phased out by 01st January 1994	Phased out by 01st January 2010
Article 2D Carbon tetrachloride	Phased out by 01st January 1996	Phased out by 1st January 2010
Article 2 C Other fully halogenated CFCs CFC-13, CFC-111, CFC-112 CFC-211, CFC-212, CFC-213 CFC-214, CFC-215, CFC-216 CFC-217	Phased out 1 st January 1996	Phased out by 1st January 2010 (India also phased out CFC except use of CFC in manufacturing of Metered Dose Inhalers for Asthma and Chronic Obstructive Pulmonary Diseases
Article 2E Methyl Chloroform	Phased out by 01st January 1996	Phased out by 1st January 2015
Article 2F Hydrochlorofluorocarbons (HCFC) (Consumption) 40 substances of HCFC, Group I, Annex C	Freeze 1996 35% January 1, 2004 75%, January 1, 2010 90% January 1. 2015 100% January 1, 2020	Freeze 2013 10% January 1, 2015 35%, January 1, 2020 67.5% January 1. 2025 100% January 1, 2030
Article 2F Hydrochlorofluorocarbons (HCFC) (Production) 40 substances of HCFC, Group I, Annex C	Freeze 2004 75%, January 1, 2010 90% January 1. 2015 100% January 1, 2020	Freeze 2013 10% January 1, 2015 35%, January 1, 2020 67.5% January 1. 2025 100% January 1, 2030
Article 2G Hydrobromofluorocarbons (HBFC22B1), Annex C	Article 2G Hydrobromofluorocarbons (HBFC22B1), Annex C	Phased out before 01st January 1996
Article 2H Methyle bromide, Annex E	Phased out before 01st January 2005	Phased out before 01st January 2015
Phased out before 01st January 2015	Phased out before 01st January 2002	Phased out before 01st January 2002

Table – II, Phasing out of HFC Adopted by Kigali Amendment			
SUBSTANCE	**Developing Countries Group I**	**Developing Countries Group 2**	**Developed Countries**
Baseline formula	Average HFC consumption levels for 2020-2022 65% of HCFC baseline	Average HFC consumption levels for 2024-2026 65% of HCFC baseline	Average HFC consumption levels for 2011-2013 15% of HCFC Baseline
Freeze	2024	2028	
	2029 – 10%	2032 – 10%	2019 – 10%
	2035 – 30%	2037 – 20%	2024 – 40%
	2040 – 50%	2042 – 30%	2029 – 70%
	2045 – 80%	2047 – 85%	2034 – 80%
			2036 – 85%

Group 2: Bahrain, India, the Islamic Republic of Iran, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia and the United Arab Emirates

The phasing out of HFCs under Kigali Amendment is likely to contribute towards the goals of Paris Agreement of containing the temperature rise upto 1.5 degree Celsius above pre-industrial levels as it is expected to prevent 105 million tonnes of carbon dioxide equivalent of GHG from entering the atmosphere and it will help to avoid 0.5 degree temperature rise by 2100.

14.2.2.3 Financial Mechanism – Article 10

Article 10 of the Protocol mandates the establishment of Multilateral Fund for achieving the purposes of the Protocol. The provision for Multilateral Fund was added by London Amendment to the Montreal Protocol. Fund has been constituted to help Developing countries i.e. countries operating under Para 1 of Article 5 to meet their obligations under the Protocol. The corpus of the Fund comes in the shape of donations from developed countries. It is managed by Executive Committee having equal representation of Developed and Developing countries and has its Secretariat at Montreal. Since 1991, out of the MLF, activities including industrial conversion, technical assistance, training and capacity building have been approved worth 3.45 billion US $. Projects approved and supported out of Multilateral Fund are implemented by various implementation agencies of UN i.e. United Nations Environment Programme (UNEP), United Nations Development Programme (UNDP), United Nations Industrial Development Organization (UNIDO) and World Bank.

14.2.2.4 Technology Transfer – Article 10 A

As discussed earlier, the Protocol is based on CBDR and RC and accordingly, Protocol recognizes that the developing countries will need assistance, financial as well as technical, in phasing out ODS. Therefore, the developed countries owe responsibilities commensurate with their capabilities to ensure that the best available environmentally safe substitutes and related technologies are expeditiously transferred to developing countries i.e. parties operating under paragraph 1 of Article 5 and that these transfers occur under fair and most favourable conditions.

14.2.2.5 Non Compliance Procedure

Article 8 the Protocol obligated the first MOP to discuss and devise suitable procedure for dealing with non-compliance with the provisions of the Protocol and to cope up with parties, who have failed to comply with the Protocol. Accordingly, the MOP has in its various meetings held from time to time devised and updated the non-compliance procedure as per the obligation imposed under Article 8. The Non-compliance procedure is applicable without prejudice to the settlement of disputes provisions laid down in Vienna Convention. MOP has established an Implementation Committee of 10 parties to be elected by MOP based on equitable geographical distribution. The tenure of the Committee is 2 years. After the expiry of the tenure, party may be elected for one immediate consecutive term. However, thereafter gap of one year is required. Implementation Committee is required to meet atleast twice a year. The main function of this Implementation Committee is to receive non-compliance reports and to investigate and identify the facts regarding the same and make appropriate recommendations to MOP. The main features of Non Compliance Procedure are as under:

- Any party having reservation about other country's laxity in implementation of the obligations or non compliance with the obligations under the Protocol can send a communication to the Secretariat. Any submission is required to be substantiated by evidence.
- The Secretariat is required to send that representation to the party whose non-compliance is at issue within two weeks of the receipt of submission
- If no reply is received within three months, reminder is to be sent to the party who has not complied with the provisions of the Protocol
- The party is required to reply along with other information to the Implementation Committee as early as possible but in any case not later than six months
- If the Secretariat finds that there is non-compliance by a party, it can request for information and if no response is received or if the issue is not resolved, then the Secretariat is required to inform Implementation Committee and to include this fact in its report to the MOP
- Implementation Committee after considering the information received and the reply shall send a report to MOP including its recommendations, if any. The report shall be sent not later than six weeks before MOP

- MOP to decide the future course of action to ensure full compliance with the Protocol. MOP may recommend and take various measures including providing assistance to the noncomplying party to implement its obligations under the Protocol. The MOP may also issue Caution to the Party and in the worst case, the MOP may order suspension from the Protocol in accordance with the rules of international law.

14.2.2.6 Implementation of Montreal Protocol in India

India is a developing country but it has made its contribution in acceding to international instruments and in discharging international obligations concerning environment. Regarding ODS, India became party to Vienna Convention on 18th March 1991 and to Montreal Protocol on 19th June 1992. To implement the Protocol Implementation authority has been vested in the Union Ministry of Environment, Forests and Climate Change. The Ministry has established an Empowered Steering Committee Chaired by Secretary, Environment Forests and Climate Change. This apart, Ministry has also established Technology and Finance Standing Committee (TFSC) and the Standing Committee on Monitoring for implementing the objectives and provisions of the Protocol. In addition, Ozone Cell has been constituted. To implement the objectives of Montreal Protocol a detailed Country Plan was prepared in 1993 to phase out ODS in accordance with the requirements of the Protocol. In accordance with the aims and purposes of the Protocol, India has taken the following steps:

- India has phased out the production and consumption of CFCs, CTC and Halons before 1st January, 2010 (except use of pharmaceutical grade CFCs in manufacturing of Metered Dose Inhalers (MDIs) for Asthma and Chronic Obstructive Pulmonary Diseases.
- India has Phased-out production and consumption of Methyl Chloroform and Methyl Bromide
- On the eve of Kigali Amendment, India mandated its chemical industry to collect and destroy HFC-23 with immediate effect. As per the estimates, it is expected to prevent half Billion tonnes of CO2 equivalent emissions in next 15 years (Business Wire, 2016)
- 304 projects have been approved and funded by the Executive Committee of the MLF for Implementation of the Montreal Protocol. A total amount of US

$279,342,203 has been approved by the Executive Committee of the MLF to phase-out 58,980 ODP tonne of ODSs (Ozone Cell, 2016). As of 2017, total 379 projects have been approved and funded by the Executive Committee of the MLF for Implementation of the Montreal Protocol and the total assistance as reached US $ 30,43,89,305 (OZONE Cell, 2017)

This apart, India has also enacted Ozone Depleting Substances (Regulation and Control) Rules, 2000. Salient features of these rules are:

- To regulate production, consumption, import and export of ODS - Registration of ODS producers, manufacturers of ODS based products, importers, exporters and stockists has been made compulsory.
- Monitoring Mechanism has been established in the form of maintenance of records and periodic filing of returns
- Rules have provided for obtaining compulsory licences for import and export of ODS
- Rules have prohibited the use of CFCs in manufacturing various products except Metered Dose Inhalers
- Use of Halons, CTC, methyl chloroform, methyl bromide has been prohibited
- Import of Air-conditioning and refrigeration equipments and other products using HCFCs has been banned

From the above, it is clear that India has taken steps to reduce emission of ODS controlled substances commensurate with the capabilities of the country keeping in mind the development needs of the country.

From the foregoing discussion, it is safe to conclude that Vienna Convention and Montreal Protocol of Vienna Convention are one of the most successful international treaties which have achieved universal ratification. The success story of the Convention and the Protocol is owing to the application of the Principle of Common but Differentiated Responsibilities wherein the developing countries have been given an extended time frame to phase out ODS and provisions have also been made for financial support and technology transfer. Unlike the more glamorous Paris agreement that will come into force by 2020 and which does not legally bind countries to their promises to cut emissions, the amended Montreal Protocol will bind countries to their HFC reduction schedules from 2019

14.2.3 Intergovernmental Panel on Climate Change (IPCC)

IPCC was set up in 1988 by World Meteorological Organization and United Nations Environment Programme (UNEP) with the following objectives:

- To assess climate change, the scientific basis of climate change and submit reports thereon so that governments can take steps and frame policies to deal with climate change on scientific basis
- To study the effects of Climate Change
- To study and analyse future risks associated with climate change and
- Develop a suitable approach to combat, mitigate and adapt to climate change

Since its establishment IPCC has completed five assessment cycles and is currently in sixth assessment cycle. IPCC assessments are authored by select leading scientists and the reports are meticulously drafted, reviewed and finalized to provide factsheet and scientific data. It has established three working groups on the following basis

- Physical Science Basis
- Impacts Adaptation and Vulnerability
- Mitigation of Climate Change

In addition, special reports dealing with special issues are also prepared and published so as to create scientific database for taking future steps.

14.2.4 United Nations Framework Convention on Climate Change (UNFCCC)

UNFCCC is an intergovernmental treaty which has been entered into for coping up with the issue of climate change and it provides a framework for dealing with climate change. It was recognized and acknowledged at a time when there was not much certainty and clarity in scientific knowledge about climate change. However, the global leaders went ahead with the Convention to limit/regulate and control those human activities which were having adverse impacts on the climate. UNFCCC was opened for signature in Rio Earth Summit in June 1992 i.e. in United Nations Conference on Environment and Development (UNCED) and it entered into force on 21st March 1994. The Convention has been ratified by 197 countries.

The Convention defines climate change to mean such changes in climate, caused directly or indirectly by human activities, which change the composition of global atmosphere. As per the Convention, the change induced by anthropogenic causes must be in addition to natural changes.

The main aim of UNFCCC is to stabilize greenhouse gas concentration in a time bound manner so as to reduce and contain the impact of GHG on climate change. UNFCCC recognizes and is based on the Doctrine of 'Common but Differentiated Responsibilities and respective capabilities'. This principle takes into account that the damage to environment and climate as a result of emission of GHG is caused primarily by developed nations since their emission levels and per capita emissions are much higher than developing countries but the adverse impact of the emission of GHG is on the entire community. Therefore, it is the common responsibility of all nations to reduce the emission of GHG but at the same time it recognizes special needs of developing and least developed countries to develop and therefore, it is recognized that their level of emission of GHG is likely to increase yet and they are also likely to cause damage to environment and contribute to climate change. The onus is cast on Developed countries which are detailed in Annex A to reduce emission of GHG and also to help developed and developing countries in containing GHG by technology transfer and financial support. UNFCCC mandates preparation of annual inventory of GHG emissions including data for base year (1990). It is worth mentioning here that initially the thrust of UNFCCC was on mitigating the climate change and therefore to contain the emission of GHG. However, after the adoption of Cancun Adaptation Framework (CAF) at Cancun Climate Change Conference, 2010, the focus on adaptation to climate change has also been made. The purpose of CAF is to accord same level of priority to adaptation as is given to mitigation and accordingly to prepare the developing countries to adapt to climate change so as to reduce their vulnerability.

14.2.4.1 Obligations and Commitments under the Convention

The Convention binds the developed countries and economies in transition to market economy (European countries, erstwhile socialist countries) i.e. Annex I countries to prepare national inventory of GHG emissions on an annual basis within six months of the entering into force of the Convention and thereafter periodically. The Convention also mandates annex I parties to enact national policies for mitigation of climate change by limiting the emission of GHG to the base year level i.e. 1990 levels and by enhancing and preserving sinks of GHG i.e. forests and oceans. Therefore, the parties are required to report GHG emission of the base year and the emissions for subsequent periods on periodical basis. The parties are also required to submit information on policies and measures taken to control the emission and the effect of those measures on the climate. The information submitted by the parties is reviewed by the Conference of Parties (COP).

Convention mandates the developed parties to provide financial resources, assistance to developing countries to enable them to meet the cost of implementing their obligations under the Convention. Other obligations of the developed countries are:

- To assist the developing countries particularly those which are vulnerable to adverse effects of climate change
- To provide financial assistance
- To provide support by facilitating technology transfer to developing countries
- To take all steps for promoting and developing technology and for transfer of the same.

Those nations which are not listed in Annex I can also submit their intention to be bound by the commitments under the Convention. All nations who are bound by the Convention are required to:

- Prepare national inventory of GHG emission of all GHG not controlled by Montreal Protocol
- To formulate programmes for mitigation of climate change and to update those plans and programmes on regular basis
- To promote sustainable development

- To promote technology development and transfer to developing and LDC
- To ensure conservation and enhancement of sinks of GHG
- To enable observation of climate change data and to collect and compile the same
- To promote and cooperate in education, training and awareness regarding climate change and adverse effects of climate change.

The Convention established Conference of Parties (COP) as an institution to periodically examine the implementation of the Convention, the measures undertaken, the adequacy of the Convention, need to adopt amendments and Protocols. The COP oversees the institutional arrangement and the compliance with the obligations by the parties. It facilitates information exchange on the measures taken by the parties and the best practices. The COP sessions are generally held on annual basis wherein the assessment reports of the climate measures and the adequacy of those measures are discussed and the reports are reviewed and adopted.

UNFCCC has established Secretariat at Bonn, Germany. The Secretariat has been established

- To make arrangements for meeting of COP and the subsidiary bodies established under the Convention
- To compile and submit reports to the COP
- To assist the developing countries in collection and compilation of data
- To submit report on activities
- To ensure coordination among various bodies and institutions dealing with climate change

In addition, UNFCC has also established Subsidiary Body for Scientific and Technological Advice and Subsidiary Body of Implementation. Further, Adhoc Working groups have been constituted.

Article 11 of UNFCCC contemplates setting up of financial mechanism for provision of financial resources on grant or concessional basis to developing countries to help them implement their obligations under the Convention. The financial mechanism is also meant to ensure facilitation of technology transfer. Under the Convention, Green Climate Fund

(GCF) has been created by the 16th. COP held at Cancun in 2010. The GCF is presently being administered by the GCF Board consisting of the Trustee i.e. the World Bank. The Fund is an international initiative to ensure contribution to the united global response to climate change. The Fund has been created to ensure low emission and climate-resilient development. The independent review mechanism is required to review the decisions made by the Board and it will ensure that the Fund functions smoothly and efficiently. (Laura, Green Climate Fund).

It is worth mentioning here that initially the thrust of UNFCCC was on mitigating the climate change and therefore to contain the emission of GHG. However, after the adoption of Cancun Adaptation Framework (CAF) at Cancun Climate Change Conference, 2010, the focus on adaptation to climate change has also been made. The purpose of CAF is to accord same level of priority to adaptation as is given to mitigation and accordingly to prepare the developing countries to adapt to climate change so as to reduce their vulnerability.

14.2.4.2 Intergovernmental Panel on Climate Change (IPCC)

IPCC is having its headquarters in Geneva. It was established in 1988 by World Meteorological Organization and United Nations Environment Programme (UNEP). The aim of establishing IPCC was to provide scientific data on climate change and its likely impacts on environment and the socioeconomic conditions. The primary aim of establishing IPCC were:

- To make assessment of climate change and to provide scientific information on climate change so that its reports can form the basis of international and national legal instruments to control and combat climate change
- To analyze the impacts of climate change on the environment and socio-economic conditions and also to explore the future risks involved
- To provide policy guidance on developing approaches to combat, mitigate and adapt to climate change

14.2.4.3 Organizational Structure of IPCC

Membership of IPCC is open to all members of United Nations and World Meteorological Organization and presently 195 countries are members of IPCC. IPCC has a huge team of experts and scientists from across the globe. IPCC has established three working groups and a Task Force

- Working Group – I - Physical Science Basis
- Working Group – II – Impacts, Adaptation and Vulnerability
- Working Group – III - Mitigation of Climate Change
- Task Force on National Greenhouse Gas Inventories These working groups and Task Force are assisted by Technical Support Units. IPCC has the following organizational structure

IPCC Plenary – All major decisions are taken in the Plenary sessions of IPCC wherein governmental representatives of member states including research organizations meet generally once a year and take decisions. All decisions pertaining to election of IPCC Bureau, the Chair of IPCC, Task Force, work plan, budget etc are taken in the Plenary Meetings of IPCC. This apart, the reports of IPCC are presented in Plenary meetings wherein they are approved and adopted. Plenary sessions also lay down the structure and mandate of working groups, task force and the principles and procedures of IPCC.

IPCC Bureau – IPCC Bureau is elected by IPCC Plenary for duration of an assessment cycle. Currently IPCC is in its sixth assessment cycle. Presently there are 34 members of IPCC Bureau which includes the IPCC Chair, Chairs and Vice-Chairs of Working Groups and Task Force. IPCC Plenary has laid down the Principles Governing IPCC work and in accordance with these principles, IPCC Bureau provides technical and scientific guidance to the IPCC on strategic issues.

Executive Committee – Executive Committee has been constituted to ensure timely implementation of IPCC work and to facilitate coordination between various Working Groups. Executive Committee consists of Advisory Members i.e. Four heads of Technical Support Groups and Head of Secretariat. It includes other members i.e. IPCC Chair, Vice Chair, Co-chairs of Working Groups and Task Force. The main function of Executive Committee is to deal with issues pertaining to IPCC programmes requiring urgent attention and to oversee the reports of IPCC and responding to the possible errors in the report. In addition, Executive Committee is also required to facilitate the coordination between

Working Groups and Task Force. Since its establishment IPCC has completed five assessment cycles and is currently in sixth assessment cycle which is likely to be completed in 2022. IPCC assessments are authored by select leading scientists and the reports are meticulously drafted, reviewed and finalized to provide factsheet and scientific data. Special reports dealing with special issues are also prepared and published so as to create scientific database for taking future steps. Scientific database generated by IPCC in its first assessment cycle brought Climate Change to the forefront and paved the way for the adoption of UNFCCC. The Second Assessment Report led to adoption of Kyoto Protocol. Because of unique structure of IPCC i.e. blend of scientists, experts and intergovernmental representatives, IPCC has an edge in providing credible scientific data for policy making.

14.2.5 Kyoto Protocol

UNFCCC provided for a framework to deal with climate change. Immediately after adoption of UNFCCC and its entry into force in 1994, it was felt that UNFCCC should be further strengthened by enacting a Protocol which should lay down mandatory targets for reduction of GHG emissions and accordingly, negotiations began to enter into a Protocol. The negotiations resulted in adoption of Kyoto Protocol in December 1997 in Kyoto, Japan. The Protocol entered into force on 16th February 2005. The Protocol has provided mandatory targets for reduction of GHG emissions by Annex 1 countries i.e. developed countries and countries with economies in transition to market economy. The object of the Protocol was to reduce emission of GHG by atleast 5% below 1990 levels during the first commitment period i.e. 2008-2012. The Protocol was based on CBDR and therefore the targets were different for different countries like the target was 8% for European Union, 6% for Canada, 7% for USA and 6% for countries like Hungry, Japan, Poland, New Zealand, Russia, Ukraine etc. Higher targets have been prescribed for second commitment period i.e. for 2013 to 2020 e.g. European Union has agreed to have joint target of 20% reduction of GHG of its 1990 level. The Protocol offers flexibility to the nations to reduce emissions in their own territory or to finance projects in other countries to reduce emissions. Further, the emission targets can be compensated by increasing sinks of carbon dioxide. Oceans and forests are the sinks of carbon dioxide therefore increasing forest cover can reduce increased carbon dioxide from the atmosphere. Protocol has also established Clean Development Mechanism (CDM) which allows flexibility to developed countries to achieve their emission reduction targets by sponsoring emission reduction projects in developing countries and earning saleable Certified Emission Reduction (CER) credits which can be used to achieve reduction targets.

In 2001, at Marrakesh, Morocco, detailed rules for implementation of Kyoto Protocol were adotped. It called for establishment of Special Climate Change Fund to finance projects for mitigation and adaptation to climate change and for development and transfer of technology to developing countries. In addition, Least Developed Countries Fund was also created. In 2003, reporting guidelines for reporting under the Protocol were adopted on the recommendations of IPCC. It is worth mentioning here that USA did not ratify the Protocol and it was only when Russian Federation ratified the Protocol in November 2004 that the path was set for the entry into force of the Protocol. The Protocol entered into force on 16th February 2005.

The object of the Protocol was to reduce emission of GHG by atleast 5% below 1990 levels during the first commitment period i.e. 2008-2012. The Protocol was based on CBDR and RC and therefore the targets were different for different countries like the target was 8% for European Union, 6% for Canada, Hungary, Japan, Poland, 7% for USA. As a matter of fact, European Union was able to go beyond their stipulated targets during the first commitment period. USA indicated that it shall not ratify Kyoto Protocol and Canada withdrew from the Kyoto Protocol in 2011 claiming that the Protocol is not workable because the highest emitters of GHG viz USA and China have not ratified the Protocol.

The Protocol was made for the period upto 2012 and was set to expire thereafter. Accordingly on December 8, 2012 at Doha, Qatar, Doha Amendment to Kyoto Protocol was adopted. Doha Amendment introduced Second Commitment Period i.e. from 01st January 2013 to 31st December 2020. The amendment introduced revised list of GHG and the commitment of parties to reduce GHG emission. Doha Amendment added seventh GHG to the list of gases whose emission is to be limited i.e. Nitrogen Trifluoride. It has prescribed higher emission reduction targets for the second commitment period. Annex II countries decided to reduce their GHG emission by 18% of their 1990 level. European Union has agreed to have joint target of 20% reduction of GHG of its 1990 level.

The Protocol offers flexibility to the nations to reduce emissions in their own territory or to finance projects in other countries to reduce emissions. Further, the emission targets can be compensated by increasing sinks of carbon dioxide. Oceans and forests are the sinks of carbon dioxide therefore increasing forest cover can reduce increased carbon dioxide from the atmosphere.

14.2.5.1 Mechanism under Kyoto Protocol

a) Clean Development Mechanism: Protocol has also established Clean Development Mechanism (CDM) which allows flexibility to developed countries to achieve their emission reduction targets by sponsoring emission reduction projects in developing countries and earning saleable Certified Emission Reduction (CER) credits each credit being equivalent to one tonne of carbon dioxide which can be used to achieve reduction targets. CDM project may include Rural Electrification projects based on solar power. Mechanism became operational in 2006 and since then it has more than 1650 projects registered under it.

b) Joint Implementation: Kyoto Protocol offers flexibility in the form of Joint Implementation as well. This mechanism allows a party (annex B party) which is obligated to have reduction in emission of GHG to have a project in another country having emission reduction target i.e. another annex B country and earn units which can be utilized to achieve their targets.

c) Emission Trading: First Commitment Period allowed parties with emission reduction responsibility to sell their unused units of emission reduction targets i.e. the parties, who have been allowed to have emissions upto certain level but have not utilized them, can sell their assigned units which is known as Carbon Trading.

As of date only 108 parties have ratified Doha Amendment to the Kyoto Protocol as against total of 144 countries required for entry into force of Doha Amendment. Moreover, New Zealand, Japan and Russia have decided not to participate in the second commitment period. India has ratified Second Commitment Period of the Kyoto Protocol in 2017. Further, in the absence of US, China, Russia, the total emission of countries who have ratified the Doha Amendment is not more than 20% of the total global GHG emission. (www.bmub.bund.de). Hence, the gains made by reduction of emission of GHG by select developed countries are offset by increased emission of developing countries like China and

India. The problem is further aggravated by non-participation of various developed countries like Russia, USA, New Zealand and Canada.

14.2.6 Paris Agreement

Paris Agreement was seen as a turning point in international concern for climate change wherein instead of select countries under Kyoto Protocol, all nations of the world would have to contribute in mitigating to climate change by limiting emission of GHG. Kyoto Protocol was set to expire in 2012 but Doha Amendment bridged the gap between the Kyoto Protocol and the new instrument on climate change which was set to be operational by 2020. Accordingly, negotiations began at the international level to conclude an agreement under UNFCCC which would obligate all parties to contribute in mitigating climate change and in adapting to climate change. Therefore, parties entered into Paris Agreement under UNFCCC at 21st COP in 2015. The agreement was due to enter into force when the parties who account for atleast 55% of the total GHG emission ratified the agreement, accordingly, the agreement entered into force on 04th December 2016 on ratification by requisite number of states. Much celebrated Paris Agreement under UNFCCC was entered into in 2015 in 21st Conference of Parties of UNFCCC. The Paris Agreement is viewed as a major breakthrough in climate change efforts wherein the countries of the world came together and agreed for reduction in emissions so as to limit increase in global average temperature upto 2 degree Celsius above pre-industrial levels. The ambitious aim of the Paris Agreement is to contain temperature increase upto 1.5 degree Celsius above pre-industrial levels. Paris Agreement, being entered into under the Framework Convention, also recognized and applied principle of CBDR and therefore, it recognizes that the emissions of developing countries and least developed countries are yet to peak to meet their developmental needs. Therefore, the agreement desires that the global emissions of GHG should peak as early as possible and there should be rapid reductions thereafter. The Agreements calls for ensuring that the global emission of GHG during the period 2050 to 2100 should be to that level only which can be absorbed by natural sinks. Agreement mandated parties to submit Intended National Determined Contributions (INDC) containing the action plan of the country parties to contain climate change and to reduce the emission of GHG. Agreement provides for revisions of targets periodically i.e. every five years. Like the CAF, it also stresses 'adaptation' strategies so as to adapt to climate change to reduce the vulnerability to the adverse impacts of climate change.

14.2.6.1 Aims and Objectives of Paris Agreement

The agreement has been entered into for enhancing global response to climate change and for furthering the objectives of UNFCCC. The aims of Paris agreements are:

- To contain average increase in global temperature upto 2 degrees from pre-industrial levels, however, the ambitious aim is to contain it upto 1.5 degree.
- To increase adaptability to climate change and to promote low GHG emission development maintaining balance between food production and development. The agreement sets out the goal of enhancing adaptive capacity, strengthening resilience and to promote sustainable development (Article 7).
- To ensure financial flows and assistance in consonance with low GHG emissions and climate resilience development (Article 2).

Paris Agreement, being entered into under the Framework Convention, also recognized and applied principle of Equity, CBDR and RC and therefore, it recognizes that the emissions of developing countries and least developed countries are yet to peak to meet their developmental needs. Therefore, the agreement desires that the global emissions of GHG should peak as early as possible and there should be rapid reductions thereafter. The Agreement calls for ensuring that the global emission of GHG during the period 2050 to 2100 should be to that level only which can be absorbed by natural sinks. Agreement mandated parties to submit Intended National Determined Contributions (INDC) containing the action plan of the country parties to contain climate change and to reduce the emission of GHG (Article 4). INDC are required to be communicated every five years (Article 4, para 10). Paris agreement calls for enhancing and conservation of sinks and reservoirs of GHGs. The agreement also calls for inter-country cooperation and coordinated approach in implementation of INDC.

Like the CAF, it also stresses 'adaptation' strategies so as to adapt to climate change to reduce the vulnerability to the adverse impacts of climate change. In this context, the agreement provides for strengthening CAF with regard to Sharing information; strengthening institutional arrangments; strengthening scientific knowledge and; improving the effectiveness and durability of adaptation actions. The parties are called upon to submit adaptation strategy periodically and to update the same on periodical basis (Article 7).

It is worth mentioning here that in 19th COP of UNFCCC held in Warsaw, Poland in November 2013, Warsaw International Loss and Damage Mechanism was established to assess the loss and damage associated with the climate change including loss and damage due to extreme events and slow onset events in developing countries which are vulnerable to adverse effects of climate change. This mechanism has been constituted not only to assess the loss and damage but also to improve coordination among various climate change institutions/bodies under UNFCCC and to convene meetings of experts, stakeholders and thereby to provide technical guidance and support. Paris Agreement has provided for working of this mechanism for and under the Paris agreement subject to the authority of COP of UNFCCC. The agreement provides for strengthening of this mechanism including increased cooperation and coordination in various actions including early warning systems, slow onset events, emergency preparedness etc.

Paris Agreement also provides that developed countries should help the developing countries and LDC financially so that the developing countries are in a position to meet their responsibilities regarding climate change. Green Climate Fund constituted under UNFCCC and Kyoto Protocol shall also function for Paris Agreement and accordingly, agreement calls for increased and enhanced financial support to developing and LDC towards adaptation and mitigation. This apart, Paris agreement makes provisions for cooperation in technology transfer, capacity building increased awareness towards climate change, education and training etc.

All parties to the agreement have been obligated to provide national inventory report of anthropogenic emissions of GHG and their removal by sinks of GHG. The information is required to be submitted periodically. The information is required to be reviewed by technical experts. The information on climate change impacts and adaptation is also required to be provided on periodical basis. The first global stock-take of actions to address climate change shall take place in 2023 and thereafter every five years.

Paris Agreement has, therefore, attempted to establish a wider framework than under the Kyoto Protocol and is therefore set to replace the Kyoto Protocol and has aimed to further strengthen international efforts to combat climate change and to mitigate and adapt to climate change. However, the effect of Paris Agreement on Climate Change is yet to be seen. Further, the withdrawal of US from Paris agreement is a blow to the international efforts as US is one of the leading GHG emitters. Further, the agreement has not laid down any specific targets for reduction of GHG as were laid down in Kyoto Protocol. It is further to be noted that Kyoto also dealt only with less than 20% emissions of GHG. Further, Kyoto had provided for Carbon Trading and created Carbon Market, what will be future of such carbon market will also be visible in the years to come (Javier de Cendra, 2016)

14.2.7 Climate Change Performance Index (CCPI)

After having briefly discussed about climate change, its impact and the international efforts to combat, mitigate and adapt to climate change induced by human activities. It is worthwhile to look at the performance of countries in this direction. Climate Change Performance Index is published annually since 2006 by Germanwatch and Climate Action Network, Europe. Since thirteen years, they are monitoring the efforts of countries responsible for emission of 90% GHGs. The aim of CCPI is to ensure transparency in actions taken by various governments in meeting with their responsibilities regarding climate change and to monitor implementation of international commitments. It is an instrument for measuring efforts of countries regarding GHG emission, energy use, renewable energy, policy measures etc. It was first published in 2006. In November 2017, CCPI, 2018 has been published i.e. thirteenth edition has been published. If we look at the list, we find that first three positions, as usual, have been unoccupied since no country made efforts commensurate with their international commitments. Most of the developed countries such as USA, Russia, Australia, Canada, Japan are in red zone. Only few developed countries like UK and France are in green zone. India has improved its position from 20th spot in CCPI, 2017 to 14th spot in CCPI, 2018.

14.3 Climate Change and Indian Efforts

As discussed earlier, the Kyoto Protocol has set binding targets for Annex I countries. India is a nonannex I country and hence had no binding targets in the first commitment period. Further, it cannot be lost sight of that India is a developing countries and millions of people still does not have access to electricity. Thus the developmental needs of the country coupled with energy needs are likely to increase India's GHG emissions in the decades to come. However, India is also prone to adverse effects of climate change including subsidence of coastal areas. Therefore, India has been participating in climate change programmes and fulfilling its commitments under the international law. India has actively participated in Clean Development Mechanism (CDM) established under Kyoto Protocol. India has also ratified Second Commitment Period targets under the Kyoto Protocol in August 2017. A brief analysis of India's efforts in this direction is given hereinafter.

India has not enacted a legislation to deal with climate change however, Government of India constituted Prime Minister's Council on Climate Change in June 2007. The main aim of this Council is to advise the government regarding climate change policies and effects. The objectives of PM's Council on Climate Change are as under:

– To coordinate National Plan for assessment, adaptation and mitigation of Climate Change

– To advise the government

– To facilitate inter-ministerial coordination

Since its establishment, the Council has been reconstituted by successive governments to advise the national government regarding climate change action plan and for adaptation and mitigation of climate change. The Council is chaired by the Prime Minister and various Union ministers like Finance Minister, External Affairs Minister, Power Minister, Minister of Environment, Forests and Climate Change, Minister of Agriculture etc are members alongwith members from TERI (The Energy and Resource Institute) and BEE (Bureau of Energy Efficiency).

India has also launched a **National Action Plan on Climate Change (NAPCC)** in 2008. The Action Plan consists of eight national Missions which are briefly discussed hereunder:

14.3.1 Jawahar Lal Nehru National Solar Mission

Mission was launched in 2008 to establish India as a global leader in solar energy to contribute towards clean energy and clean development. The aim of the mission is to develop 20000 MW of solar energy. To facilitate the generation of solar energy, 20 million square meter thermal collector area is required. The country has also established Clean

CCPI Climate Change Performance Index

Overall Results CCPI 2018

Rank	Country
1.*	–
2.	–
3.	–
4.	Sweden
5.	Lithuania
6.	Morocco
7.	Norway
8.	United Kingdom
9.	Finland
10.	Latvia
11.	Malta
12.	Switzerland
13.	Croatia
14.	India
15.	France
16.	Italy
17.	Denmark
18.	Portugal
19.	Brazil
20.	Ukraine
21.	European Union (28)
22.	Germany
23.	Belarus
24.	Slovak Republic
25.	Luxembourg
26.	Romania
27.	Mexico
28.	Egypt
29.	Cyprus
30.	Estonia
31.	Slovenia
32.	Belgium
33.	New Zealand
34.	Netherlands
35.	Austria
36.	Thailand
37.	Indonesia
38.	Spain
39.	Greece
40.	Poland
41.	China
42.	Bulgaria
43.	Czech Republic
44.	Hungary
45.	Algeria
46.	Argentina
47.	Turkey
48.	South Africa
49.	Ireland
50.	Japan
51.	Canada
52.	Malaysia
53.	Russian Federation
54.	Chinese Taipei
55.	Kazakhstan
56.	United States
57.	Australia
58.	Republic of Korea
59.	Islamic Republic of Iran
60.	Saudi Arabia

Energy Fund in 2010 and levied cess on Coal i.e. Clean Energy Cess which 15 Environmental Sciences Environmental Law and Policies Climate Change has been renamed as Clean Environment Cess in 2017. The purpose of this fund is to finance clean energy project and promote clean energy. To further contribute towards clean energy, Electricity Act, 2003 has mandated purchase of grid based power from renewable sources.

14.3.2 National Mission for Enhanced Energy Efficiency

The aim of this mission is to ensure energy efficiency improvement in large energy intensive industries and to facilitate Energy Efficient Economic Development. For this purpose, country is focusing on development and use of energy efficient appliances and equipments e.g. super-efficient ceiling fans have been developed. India has also been promoting and distributing LED bulbs so as to promote energy efficiency and thereby lower energy consumption. Target is to save fuel and avoid capacity addition.

14.3.3 National Mission on Sustainable Habitat

The target of this mission is to make cities sustainable by improvements in energy efficiency and by promoting use of public transport. The chief features of this mission are:

- Extension of Energy Conservation Building Code, 2007 to all new and existing buildings
- To optimize energy demands of large commercial buildings
- Shift to energy efficient and convenient Public Transport
- Utilization of Urban Waste to derive fuel – Refuse derived Fuel (RDF)

14.3.4 National Water Mission

One of the components of NAPCC is national water mission. The aim of this mission is

- To Conserve Water, minimize wastage and equitable distribution of water
- Creation of Ground Water Monitoring Wells
- Development of water database
- India has made efforts for revision of National Water Policy, 2012 in line with these aims

14.3.5 National Mission for Sustainable Agriculture

This mission aims at developing sustainable agriculture as a climate resilient system and at the same time to ensure food security which is an important need of developing country like India. For the purpose, the mission promotes

- On farm water use efficiency
- Soil health management
- Development of degraded land and
- Micro irrigation

14.3.6 National Mission for Sustaining the Himalayan Ecosystem

Himalayan Ecosystem is very important not only for India but for the world at large and it is important that adequate efforts are made to sustain the Himalayan Ecosystem. For this purpose, this mission has promoted following steps

- Sustaining and safeguarding Himalayan glaciers and mountain ecosystems
- Protection of Biodiversity, wildlife of Himalaya
- Identification of institutions for studies on Himalayan ecosystems
- Creation of centres for bridging knowledge gaps
- Identification and training of experts
- Creating and strengthening Observational network

14.3.7 National Mission for a Green India

Green India is an important mission on which both the Union and State governments have been working in cohesion. States have been asked to make State level plans for the same and many states have submitted and are implementing their plans. The aim of this mission in consonance with National Forest Policy is to increase the forest cover on 5 million hectares of forest and non-forest land and also to increase forest based livelihood.

14.3.8 National Mission on Strategic Knowledge for Climate Change

The purpose of this mission is to promote research and development on climate change and the likely impact of climate change on India so as to make mitigation and adaptation strategy accordingly. The mission aims at providing and ensuring funding for research on climate change.

The PM's Council on Climate Change and Ministry of Environment, Forests and Climate Change is working on strengthening and revamping NAPCC and it is expected to launch three more missions under NAPCC on Impact of Climate Change on Health, Coastal Zones and regarding Waste to Energy (The Hindu, 2017)

Summary and Conclusion

From the foregoing discussion, it is clear that mankind has forced climate change due to their unregulated and rampant industrial and other activities. After industrialization, there has been increase in global surface air temperature and it is likely to continue in future also. The main reason for anthropogenic climate change is the emission of GHGs by humans whose concentration is forcing the climate change including global warming which is going to affect a vast majority of world population including India. If the pace of climate change continues like this, it would adversely affect the survival of humans in various parts of the world especially coastal areas. Accordingly, recognising these adverse effects, international community entered into UNFCCC and thereunder Kyoto Protocol was entered into in 1997 which became effective in 2005. Binding targets for reduction of GHGs by developed countries were fixed in the Kyoto Protocol. Paris Agreement has also been entered into in 2015 with the ambitious target of containing temperature increase upto 1.5 degree Celsius of preindustrial levels. However, despite the international instruments, the performance of the developed countries is far from satisfactory. India has also made its efforts regarding mitigating and adapting to climate change though Indian efforts also fall short of the requisite level e.g. Clean Environment Cess though has been levied and huge funds are collected thereunder but as per CAG Reports, the fund has not been utilized for promoting and financing Clean energy.

References

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