Ozone Layer Depletion and Its Effects: A Review

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Ozone Layer Depletion and Its Effects: A Review

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Abstract - **There are many situations where human activities have significant effects on the environment. Ozone layer damage is one of them. The objective of this paper is to review the origin, causes, mechanisms and bio effects of ozone layer depletion as well as the protective measures of this vanishing layer. The chlorofluorocarbon and the halons are potent ozone depletors. One of the main reasons for the widespread concern about depletion of the ozone layer is the anticipated increase in the amounts of ultraviolet radiation received at the surface of the earth and the effect of this on human health and on the environment. The prospects of ozone recovery remain uncertain. In the absence of other changes, stratospheric ozone abundances should rise in the future as the halogen loading falls in response to regulation. However, the future behaviour of ozone will also be affected by the changing atmospheric abundances of methane, nitrous oxide, water vapour, sulphate aerosol, and changing climate.**

Index Terms **– Bio effects, chlorofluorocarbon, Ozone Layer Depletion, Protection.**

I. INTRODUCTION

The ozone layer is a layer in Earth's atmosphere which contains relatively high concentrations of ozone (O_3). This layer absorbs 93-99% of the sun's high frequency ultraviolet light, which is potentially damaging to life on earth [1]. Over 91% of the ozone in Earth's atmosphere is present here.[1] It is mainly located in the lower portion of the stratosphere from approximately 10 km to 50 km above Earth, though the thickness varies seasonally and geographically[2]. The ozone layer was discovered in 1913 by the French physicists Charles Fabry and Henri Buisson. Its properties were explored in detail by the British meteorologist G. M. B. Dobson, who developed a simple spectrophotometer (the Dobson meter) that could be used to measure stratospheric ozone from the ground. Between 1928 and 1958 Dobson established a worldwide network of ozone monitoring stations which continues to operate today. The "Dobson unit", a convenient measure of the total amount of ozone in a column overhead, is named in his honor.

A. Ozone

Without ozone, life on Earth would not have evolved in the way it has. The first stage of single cell organism development requires an oxygen-free environment. This type of environment existed on earth over 3000 million years ago. As the primitive forms of plant life multiplied and evolved, they began to release minute amounts of oxygen through the photosynthesis reaction (which converts carbon dioxide into oxygen) [3].

The buildup of oxygen in the atmosphere led to the formation of the ozone layer in the upper atmosphere or stratosphere. This layer filters out incoming radiation in the "cell-damaging" ultraviolet (UV) part of the spectrum. Thus with the development of the ozone layer came the formation of more advanced life forms. Ozone is a form of oxygen. The oxygen we breathe is in the form of oxygen molecules (O_2) - two atoms of oxygen bound together. Normal oxygen which we breathe is colourless and odourless. Ozone, on the other hand, consists of three atoms of oxygen bound together (O_3). Most of the atmosphere's ozone occurs in the region called the stratosphere. Ozone is colourless and has a very harsh odour. Ozone is much less common than normal oxygen. Out of 10 million air molecules, about 2 million are normal oxygen, but only 3 are ozone. Most ozone is produced naturally in the upper atmosphere or stratosphere. While ozone can be found through the entire atmosphere, the greatest concentration occurs at altitudes between 19 and 30 km above the Earth's surface. This band of ozone-rich air is known as the "ozone layer". [4] Ozone also occurs in very small amounts in the lowest few kilometres of the atmosphere, a region known as the troposphere. It is produced at ground level through a reaction between sunlight and volatile organic compounds (VOCs) and nitrogen oxides (NO_x), some of which are produced by human activities such as driving cars. Ground-level ozone is a component of urban smog and can be harmful to human health. Even though both types of ozone contain the same molecules, their presence in different parts of the atmosphere has very different consequences. Stratospheric ozone blocks harmful solar radiation - all life on Earth has adapted to this filtered solar radiation. Ground-level ozone, in contrast, is simply a pollutant. It will absorb some incoming solar radiation, but it cannot make up for ozone losses in the stratosphere.

B. Ozone Hole

In some of the popular news media, as well as in many books, the term "ozone hole" has and often still is used far too loosely. Frequently, the term is employed to describe any episode of ozone depletion, no matter how minor. Unfortunately, this sloppy language trivializes the problem and blurs the important scientific distinction between the massive ozone losses in Polar Regions and the much smaller, but nonetheless significant, ozone losses in other parts of the world. Technically, the term "ozone hole" should be applied to regions where stratospheric ozone depletion is so severe that levels fall below 200 Dobson Units (D.U.), the traditional measure of stratospheric ozone. Normal ozone

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concentration is about 300 to 350 D.U [3]. Such ozone loss now occurs every springtime above Antarctica, and to a lesser extent the Arctic, where special meteorological conditions and very low air temperatures accelerate and enhance the destruction of ozone loss by man-made ozone depleting chemicals (ODCs).

C. *Ozone Layer*

The ozone layer is not really a layer at all, but has become known as such because most ozone particles are scattered between 19 and 30 kilometers (12 to 30 miles) up in the Earth's atmosphere, in a region called the stratosphere. The concentration of ozone in the ozone layer is usually under 10 parts ozone per million [5]. Without the ozone layer, a lot of ultraviolet (UV) radiation from the Sun would not be stopped reaching the Earth's surface, causing untold damage to most living species. In the 1970s, scientists discovered that chlorofluorocarbons (CFCs) could destroy ozone in the stratosphere. Ozone is created in the stratosphere when UV radiation from the Sun strikes molecules of oxygen (O_2) and causes the two oxygen atoms to split apart. If a freed atom bumps into another O_2, it joins up, forming ozone (O_3). This process is known as photolysis. Ozone is also naturally broken down in the stratosphere by sunlight and by a chemical reaction with various compounds containing nitrogen, hydrogen and chlorine. These chemicals all occur naturally in the atmosphere in very small amounts. In an unpolluted atmosphere there is a balance between the amount of ozone being produced and the amount of ozone being destroyed. As a result, the total concentration of ozone in the stratosphere remains relatively constant. At different temperatures and pressures (i.e. varying altitudes within the stratosphere), there are different formation and destruction rates. Thus, the amount of ozone within the stratosphere varies according to altitude. Ozone concentrations are highest between 19 and 23 km [6]. Most of the ozone in the stratosphere is formed over the equator where the level of sunshine striking the Earth is greatest. It is transported by winds towards higher latitudes. Consequently, the amount of stratospheric ozone above a location on the Earth varies naturally with latitude, season, and from day-to-day. Under normal circumstances highest ozone values are found over the Canadian Arctic and Siberia, whilst the lowest values are found around the equator. The ozone layer over Canada is normally thicker in winter and early spring, varying naturally by about 25% between January and July. Weather conditions can also cause considerable daily variations.

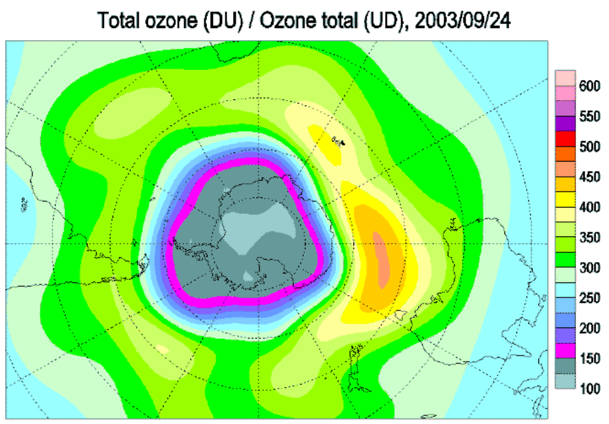

Fig.1 ozone layer depletion over Antarctica

D. *Ozone depletion over India*

With so much worry about the rapid ozone depletion taking place in various parts of the earth, Indian scientists are closely monitoring the ozone layer over India for possible depletion trends. Opinions are many and varied. According to S K Srivastava, head of the National Ozone Centre in New Delhi, there is no trend to show total ozone depletion over India. V.Thaphyal and S M Kulshresta of the Indian Meteorological Department also point out that for the period 1956 to 1986 "ozone measurements exhibit year to year variability, but do not show any increasing or decreasing trend over India." However, former director of the National Ozone Centre, K Chatterji, now with Development Alternatives, warns that there is no case for complacency. He asserts that his calculations exhibit an ozone depletion trend in the upper, layers of the stratosphere over New Delhi and Pune from 1980 to 1983 in the month of October when the Antarctic ozone hole is at its maximum. Since India already receives high doses of ultraviolet (UV-B) radiation, and is at the threshold go to speak, effects of ozone layer depletion could he far more disastrous in India. A P Mitra, former director general of the Council of Scientific and Industrial Research, clarifies that while there is no trend in the total ozone value, there is some evidence of ozone depletion at higher altitudes - at about 30 to 40 km - even over the tropics. He argues, however, that there is insufficient data and that the depletion may be due to solar cycles and other natural phenomena. However, the effects of CFCs and belong cannot be ruled out. Total column ozone data has been recorded over India for a long time. A network of stations using Dobson spectrophotometers to mea- sure total ozone, some six times a day, covers Srinagar, New Delhi, Varanasi, Ahmedabad, Pone and Kodaikanal. Ozone profiles are also regularly recorded using balloons. Ozone levels are the lowest during November and December and the highest in summer. Across the country, variations do exist. In Kodaikanal, the total ozone is 240 to 280 Dobson units (DU), in New Delhi 270 to 320 DU and in Srinagar 290 to 360 DU. One Dobson unit is the equivalent of 0.01 mm of compressed gas at a pressure of 760 rare mercury and 0°C.B N Srivastava of the National Physical Laboratory, who been working on incident UV-radiation levels, says that during summer, at noon, the UV-B radiation with a wavelength of 290 nanometer (nm) is equivalent to levels attained in the Antarctica during the ozone hole period. He warns that even a slight depletion of the ozone layer over India may lead to large percentage changes in UV-B radiation over the country. According to eminent skin specialists in New Delhi, the incidence of skin cancer in India is low, but they admit that the surveys conducted to identify any trends are inadequate. Controlled studies to observe the effects of changing UV- B radiation concentrations on crops are on, they said. However no field surveys have been done in the country as yet.

E. *Measuring Ozone Depletion*

The most common stratospheric ozone measurement unit is the Dobson Unit (DU). The Dobson Unit is named after the atmospheric ozone pioneer G.M.B. Dobson who carried out the earliest studies on ozone in the atmosphere from the 1920s to the 1970s. A Dobson Unit measures the total amount of ozone in an overhead column of the atmosphere. Dobson Units are measured by how thick the layer of ozone would be if it were compressed into one layer at 0 degrees Celsius and with a pressure of one atmosphere above it. Every 0.01

millimeter thickness of the layer is equal to one Dobson Unit [8]. The average amount of ozone in the stratosphere across the globe is about 300 DU (or a thickness of only 3mm at 0°C and 1 atmospheric pressure!). Highest levels of ozone are usually found in the mid to high latitudes, in Canada and Siberia (360DU). When stratospheric ozone falls below 200 DU this is considered low enough to represent the beginnings of an ozone hole. Ozone holes of course commonly form during springtime above Antarctica, and to a lesser extent the Arctic.

F. The Ozone Hole 2009

I. Situation at 2009

November the 2009 ozone hole is now waning, with much of the continent experiencing a stratospheric spring warming. The residual vortex is over the Weddell Sea and Antarctic Peninsula and here minimum values are around 160 DU and depletion exceeds 50%. Ozone values outside the polar vortex have dropped to near 400 DU, and inside the vortex ozone values are increasing as the atmosphere warms [7]. The temperature of the ozone layer over Antarctica is now rising, though a small area is still cold enough for polar stratospheric clouds (PSCs) to exist. During the early winter, the polar vortex was often rather more elliptical than it was in 2008, and this lead to some early depletion in circumpolar regions as stratospheric clouds became exposed to sunlight. It reverted to a more circular circulation as winter progressed and this led to another relatively slow start to the growth of the ozone hole (as measured by NASA/SBUV2), with the "hole" not beginning until mid August. The vortex became more elliptical again in late August, with South Georgia being affected by the fringes of the ozone hole between September 2 and 6. The hole grew to reach an area of around 24 million square kilometers by mid September, but had declined to 12 million square kilometres by mid November. It is now a little larger than the average for the past decade. The tip of South America and South Georgia were affected by the fringes of the ozone hole from September 24 to September 30 and again from October 3 to October 7.

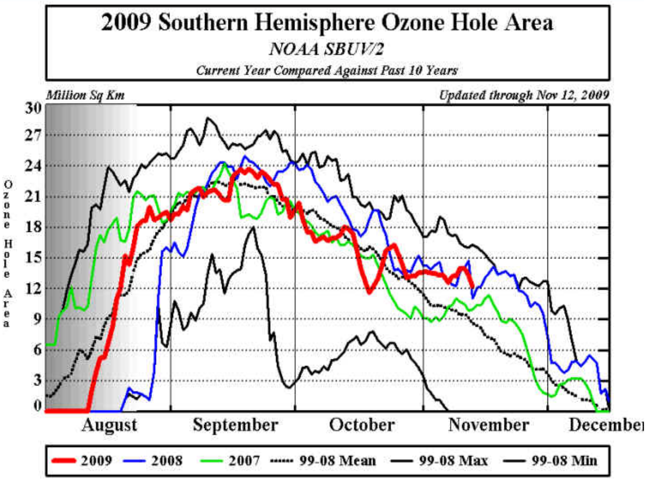

Fig.2 ozone hole area variation

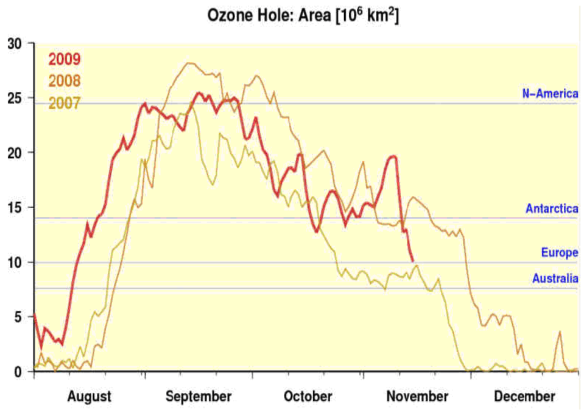

Fig.3 ozone hole area variation over different continent

G. Ozone Layer Recovery

The ozone depletion caused by human-produced chlorine and bromine compounds is expected to gradually disappear by about the middle of the 21st century as these compounds are slowly removed from the stratosphere by natural processes. This environmental achievement is due to the landmark international agreement to control the production and use of ozone-depleting substances. Full compliance would be required to achieve this expected recovery. Without the Montreal Protocol and its Amendments, continuing use of chlorofluorocarbons (CFCs) and other ozone-depleting substances would have increased the stratospheric abundances of chlorine and bromine tenfold by the mid-2050s compared with the 1980 amounts [9]. Such high chlorine and bromine abundances would have caused very large ozone losses, which would have been far larger than the depletion observed at present. In contrast, under the current international agreements that are now reducing the human-caused emissions of ozone-depleting gases, the net troposphere concentrations of chlorine- and bromine-containing compounds started to decrease in 1995. Because 3 to 6 years are required for the mixing from the troposphere to the stratosphere, the stratospheric abundances of chlorine are starting to reach a constant level and will slowly decline thereafter. With full compliance, the international agreements will eventually eliminate most of the emissions of the major ozone-depleting gases. All other things being constant, the ozone layer would be expected to return to a normal state during the middle of the next century. This slow recovery, as compared with the relatively rapid onset of the ozone depletion due to CFC and bromine-containing halons emissions, is related primarily to the time required for natural processes to eliminate the CFCs and halons from the atmosphere. Most of the CFCs and halons have atmospheric residence times of about 50 to several hundred years [7].

II. Causes of Ozone Depletion

Ozone depletion occurs when the natural balance between the production and destruction of stratospheric ozone is tipped in favour of destruction. Although natural phenomena can cause temporary ozone loss, chlorine and bromine released from man-made compounds such as CFCs are now accepted as the main cause of this depletion [10]. It was first suggested by Drs. M. Molina and S. Rowland in 1974 that a man-made group of compounds known as the chlorofluorocarbons (CFCs) were likely to be the main source of ozone depletion. However, this idea was not taken seriously until the discovery of the ozone hole over Antarctica in 1985 by the Survey. Chlorofluorocarbons are not "washed" back to Earth by rain or destroyed in reactions with other chemicals. They simply do not break down in the lower atmosphere and they can remain in the atmosphere from 20 to 120 years or more. As a consequence of their relative stability, CFCs are instead transported into the stratosphere where they are eventually broken down by ultraviolet (UV) rays from the Sun, releasing free chlorine. The chlorine becomes actively involved in the process of destruction of ozone. The net result is that two molecules of ozone are replaced by three of molecular oxygen, leaving the chlorine free to repeat the process:

$Cl + O_3 = ClO + O_2$

$ClO + O = Cl + O_2$

Ozone is converted to oxygen, leaving the chlorine atom free to repeat the process up to 100,000 times, resulting in a reduced level of ozone. Bromine compounds, or halons, can also destroy stratospheric ozone. Compounds containing chlorine and bromine from man-made compounds are known as industrial halocarbons. Emissions of CFCs have accounted for roughly 80% of total stratospheric ozone depletion. Thankfully, the developed world has phased out the use of CFCs in response to international agreements to protect the ozone layer. However, because CFCs remain in the atmosphere so long, the ozone layer will not fully repair itself until at least the middle of the 21st century. Naturally occurring chlorine has the same effect on the ozone layer, but has a shorter life span in the atmosphere.

A. Chlorofluorocarbons

Chlorofluorocarbons or CFCs (also known as Freon) are non-toxic, non-flammable and non-carcinogenic. They contain fluorine atoms, carbon atoms and chlorine atoms. The 5 main CFCs include CFC-11 (trichlorofluoromethane - $CFCl_3$), CFC-12 (dichloro-difluoromethane - CF_2Cl_2), CFC-113 (trichloro-trifluoroethane - $C_2F_3Cl_3$), CFC-114 (dichloro-tetrfluoroethane - $C_2F_4Cl_2$), and CFC-115 (chloropentafluoroethane - C_2F_5Cl).CFCs are widely used as coolants in refrigeration and air conditioners, as solvents in cleaners, particularly for electronic circuit boards, as a blowing agents in the production of foam (for example fire extinguishers), and as propellants in aerosols. Indeed, much of the modern lifestyle of the second half of the 20th century had been made possible by the use of CFCs.Man-made CFCs however, are the main cause of stratospheric ozone depletion [11]. CFCs have a lifetime in the atmosphere of about 20 to 100 years, and consequently one free chlorine atom from a CFC molecule can do a lot of damage, destroying ozone molecules for a long time. Although emissions of CFCs around the developed world have largely ceased due to international control agreements, the damage to the stratospheric ozone layer will continue well into the 21st century.

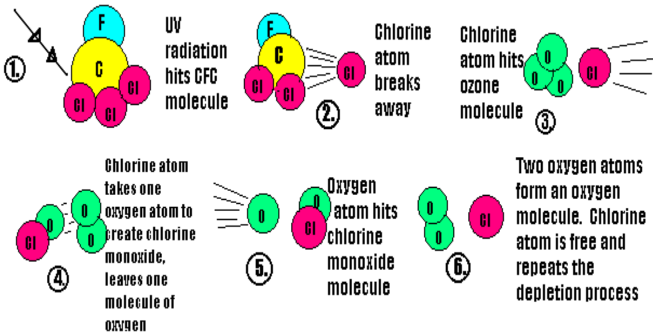

Fig.4 ozone depletion reaction

B. Rocket Launches

The global market for rocket launches may require more stringent regulation in order to prevent significant damage to Earth's stratospheric ozone layer in the decades to come, according to a new study by researchers in California and Colorado. Future ozone losses from unregulated rocket launches will eventually exceed ozone losses due to chlorofluorocarbons, or CFCs, which stimulated the 1987 Montreal Protocol banning ozone-depleting chemicals, said Martin Ross, chief study author from The Aerospace Corporation in Los Angeles. The study, which includes the University of Colorado at Boulder and Embry-Riddle Aeronautical University, provides a market analysis for estimating future ozone layer depletion based on the expected growth of the space industry and known impacts of rocket launches." As the rocket launch market grows, so will ozone-destroying rocket emissions," said Professor Darin Toohey of CU-Boulder's atmospheric and oceanic sciences department. "If left unregulated, rocket launches by the year 2050 could result in more ozone destruction than was ever realized by CFCs."Since some proposed space efforts would require frequent launches of large rockets over extended periods, the new study was designed to bring attention to the issue in hopes of sparking additional research, said Ross. "In the policy world uncertainty often leads to unnecessary regulation," he said. "We are suggesting this could be avoided with a more robust understanding of how rockets affect the ozone layer." Current global rocket launches deplete the ozone layer by no more than a few hundredths of 1 percent annually, said Toohey. But as the space industry grows and other ozone-depleting chemicals decline in the Earth's stratosphere, the issue of ozone depletion from rocket launches is expected to move to the forefront. Highly reactive trace-gas molecules known as radicals dominate stratospheric ozone destruction, and a single radical in the stratosphere can destroy up to 10,000 ozone molecules before being deactivated and removed from the stratosphere.

III. Evidence for Ozone Depletion

In 1974, after millions of tons of CFCs had been manufactured and sold; chemists F. Sherwood Rowland and Mario Molina of the University of California began to wonder where all these CFCs ended up. Rowland and Molina theorized that ultraviolet (UV) rays from the Sun would break up CFCs in the stratosphere, and that the free chlorine atoms would then enter into a chain reaction, destroying ozone[12]. Many people, however, remained unconvinced of the danger until the mid-1980s, when a severe springtime depletion of ozone was first monitored by the British Antarctic Survey above Antarctica. The depletion above the South Pole was so severe that the British geophysicist, Joe Farman, who first measured it, assumed his spectrophotometer must be broken and sent the device back to England to be repaired. Once the depletion was verified, it came to be known throughout the world through a series of NASA satellite photos as the Antarctic Ozone Hole. Laboratory studies backed by satellite and ground-based measurements, show that free chlorine reacts very rapidly with ozone. They also show that the chlorine oxide formed in that reaction undergoes further processes that regenerate the original chlorine, allowing the sequence to be repeated up to 100,000 times. This process is known as a "chain reaction". Similar reactions also take place between bromine and ozone. Observations of the Antarctic ozone hole have given a convincing and unmistakable demonstration of these processes. Scientists have repeatedly observed a large number of chemical species over Antarctica since 1986. Among the chemicals measured were ozone and chlorine monoxide, which is the reactive chemical identified in the laboratory as one of the participants in the ozone-destroying chain reactions. The satellite maps shown in the figure below relate the accumulation of chlorine monoxide observed over Antarctica and the subsequent ozone depletion that occurs rapidly in a few days over very similar areas.

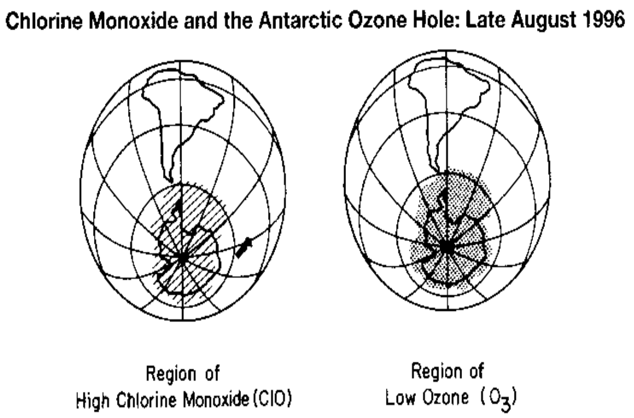

Fig.5 ozone depleting agents over earth

A. *Cosmic ray theory for ozone hole*

A University of Waterloo scientist says that an observed cyclic hole in the ozone layer provides proof of a new ozone depletion theory involving cosmic rays, a theory outlined in his new study, just published in Physical Review Letters. Qing-Bin Lu, a professor of physics and astronomy and an ozone depletion expert, said it was generally accepted for more than two decades that the Earth's ozone layer is depleted by chlorine atoms produced by the sun's ultraviolet light-induced destruction of chlorofluorocarbons (CFCs) in the atmosphere. But mounting evidence supports a new theory that says cosmic rays, rather than the sun's UV light, play the dominant role in breaking down ozone-depleting molecules and then ozone. Cosmic rays are energy particles originating in space.

Ozone is a gas mostly concentrated in the ozone layer, a region located in the stratosphere several miles above the Earth's surface. It absorbs almost all of the sun's high-frequency ultraviolet light, which is potentially damaging to life and causes such diseases as skin cancer and cataracts. The Antarctic ozone hole is larger than the size of North America. In his study, Lu analyzes reliable cosmic ray and ozone data in the period of 1980-2007, which cover two full 11-year solar cycles. The data unambiguously show the time correlations between cosmic ray intensity and global ozone depletion, as well as between cosmic ray intensity and the ozone hole over the South Pole. The Schwabe solar cycle or Schwabe-Wolf cycle is the eleven-year cycle of solar activity of the sun. It was named after Samuel Heinrich Schwabe (October 25, 1789 April 11, 1875) a German astronomer remembered for his work on sunspots. At periods of highest activity, known as solar maximum or solar max, sunspots appear. Periods of lowest activity are known as solar minimum. The last solar maximum was in 2001. The solar cycle is not strictly 11 years; it has been as short as 9 years and as long as 14 years in recent years.

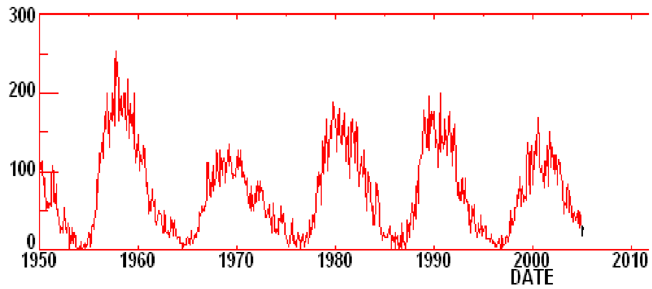

Fig.6 based on cosmic theory ozone layer thickness variation

This finding not only provides a fingerprint for the dominant role of the cosmic-ray mechanism in causing the ozone hole, but also contradicts the widely-accepted photochemical theory," Lu said. "These observations cannot be explained by that photochemical model. Instead, they force one to conclude that the cosmic ray mechanism plays the dominant role in causing the hole. His study quantitatively predicted that the mean total ozone in the October hole over Antarctica would be depleted to around 187 Dobson units (DU). The latest NASA OMI satellite data sets, released on March 13, show that the mean total ozone in the ozone hole in October 2008 was 197 DU, within five per cent of Lu's prediction. "The total ozone values in the ozone hole in November and December nearly reached the minimum values in the months on record," Lu said. "The 2008 ozone hole shrank quite slowly and persisted until the end of December, making it one of the longest lasting ozone holes on record." He added that in earlier studies he and former colleagues found a strong spatial correlation between cosmic ray intensity and ozone depletion, based on the data from several sources, including NASA satellites. "Lab measurements demonstrated a mechanism by which cosmic rays can cause drastic reactions of ozone-depleting halogens inside polar clouds." Cosmic rays are concentrated over the North and South Poles due to Earth's magnetic field, and have the highest electron-production rate at the height of 15 to 18 km above the ground -- where the ozone layer has been most depleted. Lu says that years ago atmospheric scientists expressed doubts about the cosmic ray mechanism, but now observed data shows which theory is the correct one. For instance, the most recent scientific assessments of ozone depletion by the World Meteorological Organization and the United Nations Environment Program using photochemical models predicted that global ozone will recover (or increase) by one to 2.5 per cent between 2000 and 2020 and that the Antarctic springtime ozone hole will shrink by five to 10 per cent between 2000 and 2020. In sharp contrast, the cosmic ray theory predicted one of the severest ozone losses over the South Pole in 2008-2009 and another large hole around 2019-2020.

IV. Effect of ozone layer depletion

A. *Effects on Human and Animal Health*

Increased penetration of solar UV-B radiation is likely to have profound impact on human health with potential risks of eye diseases, skin cancer and infectious diseases [6]. UV radiation is known to damage the cornea and lens of the eye. Chronic exposure to UV-B could lead to cataract of the cortical and posterior subcapsular forms. UV-B radiation can adversely affect the immune system causing a number of infectious diseases. In light skinned human populations, it is likely to develop nonmelanoma skin cancer (NMSC). Experiments on animals show that UV exposure decreases the immune response to skin cancers, infectious agents and other antigens

B. *Effects on Terrestrial Plants*

It is a known fact that the physiological and developmental processes of plants are affected by UV-B radiation. Scientists believe that an increase in UV-B levels would necessitate using more UV-B tolerant cultivar and breeding new tolerant ones in agriculture. In forests and grasslands increased UV-B radiation is likely to result in changes in species composition (mutation) thus altering the bio-diversity in different ecosystems [9]. UV-B could also affect the plant community indirectly resulting in changes in plant form, secondary metabolism, etc. These changes can have important implications for plant competitive balance, plant pathogens and bio-geochemical cycles.

C. *Effects on Aquatic Ecosystems*

While more than 30 percent of the world's animal protein for human consumption comes from the sea alone, it is feared that increased levels of UV exposure can have adverse impacts on the productivity of aquatic systems. High levels of exposure in tropics and subtropics may affect the distribution of phytoplanktons which form the foundation of aquatic food webs. Reportedly a recent study has indicated 6-12 percent reduction in phytoplankton production in the marginal ice zone due to increases in UV-B. UV-B can also cause damage to early development stages of fish, shrimp, crab, amphibians and other animals, the most severe effects being decreased reproductive capacity and impaired larval development.

D. *Effects on Bio-geo-chemical Cycles*

Increased solar UV radiation could affect terrestrial and aquatic bio-geo-chemical cycles thus altering both sources and sinks of greenhouse and important trace gases, e.g. carbon dioxide (CO2), carbon monoxide (CO), carbonyl sulphide (COS), etc. These changes would contribute to biosphere-atmosphere feedbacks responsible for the atmosphere build-up of these gases. Other effects of increased UV-B radiation include: changes in the production and decomposition of plant matter; reduction of primary production changes in the uptake and release of important atmospheric gases; reduction of bacterioplankton growth in the upper ocean; increased degradation of aquatic dissolved organic matter (DOM), etc. Aquatic nitrogen cycling can be affected by enhanced UV-B through inhibition of nitrifying bacteria and photodecomposition of simple inorganic species such as nitrate. The marine sulphur cycle may also be affected resulting in possible changes in the sea-to-air emissions of COS and dimethylsulfied (DMS), two gases that are degraded to sulphate aerosols in the stratosphere and troposphere, respectively.

E. *Effects on Air Quality*

Reduction of stratospheric ozone and increased penetration of UV-B radiation result in higher photo dissociation rates of key trace gases that control the chemical reactivity of the troposphere. This can increase both production and destruction of ozone and related oxidants such as hydrogen peroxide which are known to have adverse effects on human health, terrestrial plants and outdoor materials. Changes in the atmospheric concentrations of the hydroxyl radical (OH) may change the atmospheric lifetimes of important gases such as methane and substitutes of chlorofluoro carbons (CFCs). Increased troposphere reactivity could also lead to increased production of particulates such as cloud condensation nuclei from the oxidation and subsequent nucleation of sulphur of both anthropogenic and natural origin (e.g. COS and DMS).

F. *Effects on Materials*

An increased level of solar UV radiation is known to have adverse effects on synthetic polymers, naturally occurring biopolymers and some other materials of commercial interest. UV-B radiation accelerates the photo degradation rates of these materials thus limiting their lifetimes. Typical damages range from discoloration to loss of mechanical integrity. Such a situation would eventually demand substitution of the affected materials by more photo stable plastics and other materials in future. In 1974, two United States (US) scientists Mario Molina and F. Sherwood Rowland at the University of California were struck by the observation of Lovelock that the CFCs were present in the atmosphere all over the world more or less evenly distributed by appreciable concentrations. They suggested that these stable CFC molecules could drift slowly up to the stratosphere where they may breakdown into chlorine atoms by energetic UV-B and UB-C rays of the sun. The chlorine radicals thus produced can undergo complex chemical reaction producing chlorine monoxide which can attack an ozone molecule converting it into oxygen and in the process regenerating the chlorine atom again. Thus the ozone destroying effect is catalytic and a small amount of CFC would be destroying large number of ozone molecules. Their basic theory was then put to test by the National Aeronautic Space Authority (NASA) scientists and found to be valid, ringing alarm bells in many countries and laying the foundation for international action.

G. *Effects on Climate Change*

Ozone depletion and climate change are linked in a number of ways, but ozone depletion is not a major cause of climate change. Atmospheric ozone has two effects on the temperature balance of the Earth. It absorbs solar ultraviolet radiation, which heats the stratosphere. It also absorbs infrared radiation emitted by the Earth's surface, effectively trapping heat in the troposphere. Therefore, the climate impact of changes in ozone concentrations varies with the altitude at which these ozone changes occur. The major ozone losses that have been observed in the lower stratosphere due to the human-produced chlorine- and bromine-containing gases have a cooling effect on the Earth's surface. On the other hand, the ozone increases that are estimated to have occurred in the troposphere because of surface-pollution gases have a warming effect on the Earth's surface, thereby contributing to the "greenhouse" effect. In comparison to the effects of changes in other atmospheric gases, the effects of both of these ozone changes are difficult to calculate accurately. In the figure below, the upper ranges of possible effects for the ozone changes are indicated by the open bars, and the lower ranges are indicated by the solid bars.

H. *Effects on Ultraviolet Radiation*

The depletion of the ozone layer leads, on the average, to an increase in ground-level ultraviolet radiation, because ozone is an effective absorber of ultra-violet radiation. The Sun emits radiation over a wide range of energies, with about 2% in the form of high-energy, ultraviolet (UV) radiation. Some of this UV radiation (UV-B) is especially effective in causing damage to living beings, the largest decreases in ozone during the past 15 years have been observed over Antarctica, especially during each September and October when the ozone hole forms. During the last several years, simultaneous measurements of UV radiation and total ozone have been made at several Antarctic stations. In the late spring, the biologically damaging ultraviolet radiation in parts of the Antarctic continent can exceed that in San Diego, California, where the Sun is much higher above the horizon. In areas where smaller ozone depletion has been observed, UV-B increases are more difficult to detect. In particular, detection of trends in UV-B radiation associated with ozone decreases can be further complicated by changes in cloudiness, by local pollution, and by difficulties in keeping the detection instrument in precisely the same condition over many years. Prior to the late 1980s, instruments with the necessary accuracy and stability for measurement of small long-term trends in ground-level UV-B were not available. Therefore, the data from urban locations with older, less-specialized instruments provide much less reliable information, especially since simultaneous measurements of changes in cloudiness or local pollution are not available. When high-quality measurements have been made in other areas far from major cities and their associated air pollution, decreases in ozone have regularly been accompanied by increases in UV-B. This is shown in the figure below, where clear-sky measurements performed at six different stations demonstrate that ozone decreases lead to increased UV-B radiation at the surface in amounts that are in good agreement with that expected from calculations (the "model" curve).

V. International Actions

The first international action to focus attention on the dangers of ozone depletion in the stratosphere and its dangerous consequences in the long run on life on earth was focused in 1977 when in a meeting of 32 countries in Washington D.C. a World plan on action on Ozone layer with UNEP as the coordinator was adopted. As experts began their investigation, data piled up and in 1985 in an article published in the prestigious science journal, “Nature” by Dr. Farman pointed out that although there is overall depletion of the ozone layer all over the world, the most severe depletion had taken place over the Antarctica. This is what is famously called as "the Antarctica Ozone hole". His findings were confirmed by Satellite observations and offered the first proof of severe ozone depletion and stirred the scientific community to take urgent remedial actions in an international convention held in Vienna on March 22, 1985. This resulted in an international agreement in 1987 on specific measures to be taken in the form of an international treaty known as the Montreal Protocol on Substances That Deplete the Ozone Layer. Under this Protocol the first concrete step to save the Ozone layer was taken by immediately agreeing to completely phase out chlorofluorocarbons (CFC), Halons, Carbon tetrachloride (CTC) and Methyl chloroform (MCF) as per a given schedule

A. *Montreal Protocol*

In 1985 the Vienna Convention established mechanisms for international co-operation in research into the ozone layer and the effects of ozone depleting chemicals (ODCs). 1985 also marked the first discovery of the Antarctic ozone hole. On the basis of the Vienna Convention, *the Montreal Protocol on Substances that Deplete the Ozone Layer* was negotiated and signed by 24 countries and by the European Economic Community in September 1987. The Protocol called for the Parties to phase down the use of CFCs, halons and other man-made ODCs. The Montreal Protocol represented a landmark in the international environmentalist movement. For the first time whole countries were legally bound to reducing and eventually phasing out altogether the use of CFCs and other ODCs. Failure to comply was accompanied by stiff penalties. The original Protocol aimed to decrease the use of chemical compounds destructive to ozone in the stratosphere by 50% by the year 1999. The Protocol was supplemented by agreements made in London in 1990 and in Copenhagen in 1992, where the same countries promised to stop using CFCs and most of the other chemical compounds destructive to ozone by the end of 1995. Fortunately, it has been fairly easy to develop and introduce compounds and methods to replace CFC compounds. In order to deal with the special difficulties experienced by developing countries it was agreed that they would be given an extended period of grace, so long as their use of CFCs did not grow significantly. China and India, for example, are strongly increasing the use of air conditioning and cooling devices. Using CFC compounds in these devices would be cheaper than using replacement compounds harmless to ozone. An international fund was therefore established to help these countries introduce new and more environmentally friendly technologies and chemicals. The depletion of the ozone layer is a worldwide problem which does not respect the frontiers between different countries. It can only be affected through determined international co-operation.

B. *Australian Chlorofluorocarbon Management Strategy*

It provides a framework for the responsible management and use of CFCs in Australia. The strategy recognizes some continuing need for these chemicals in pharmaceutical and laboratory uses, but commits to their gradual phasing out.

C. *Environmental Protection (Ozone Protection) Policy2000*

This WA policy aims to minimize the discharge of ozone-depleting substances into the environment, and has been extended to cover use of alternative refrigerants (where relevant). This has been done to prevent current stocks of ozone-depleting substances from being released to the atmosphere by trade's people that are not accredited, or with inadequate training and/or equipment working on systems that contain these substances.

D. United Nations Environment Programme

Has published several assessments of the environmental effects of ozone depletion (United Nations Environment Programme, 1998; World Meteorological Organization, 2002).

E. Ozone Protection and Synthetic Greenhouse Gas Management Act 1989 ***(and associated regulations and amendments)***

Was implemented by the Commonwealth Government to meet its commitments under the Montreal Protocol.

F. *Ultraviolet index forecast*

The Bureau of Meteorology has developed a model to predict the amount of ultraviolet exposure and the times of day at which it will occur for 45 WA locations. It is designed to help people minimize their exposure to dangerous levels of ultraviolet radiation.

VI. Conclusion

Under the auspices of United Nations Environment Programme (UNEP), Governments of the world, including the United States have cooperatively taken action to stop ozone depletion with the "The Montreal Protocol on Substances that Deplete the Ozone Layer", signed in 1987. Scientist's are concerned that continued global warming will accelerate ozone destruction and increase stratospheric ozone depletion. Ozone depletion gets worse when the stratosphere (where the ozone layer is), becomes colder. Because global warming traps heat in the troposphere, less heat reaches the stratosphere which will make it colder. Greenhouse gases act like a blanket for the troposphere and make the stratosphere colder. In other words, global warming can make ozone depletion much worse right when it is supposed to begin its recovery during the next century. Maintain programs to ensure that ozone-depleting substances are not released and ongoing vigilance is required to this effect. In fact, global warming, acid rain, ozone layer depletion, and ground-level ozone pollution all pose a serious threat to the quality of life on Earth. They are separate problems, but, as has been seen, there are links between each. The use of CFCs not only destroys the ozone layer but also leads to global warming.

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