Ozone depletion, Climate change
And
Interactions

What is Ozone

Ozone is a gas made up of three oxygen atoms ($O_{3)}$ which occurs naturally in small amounts in the upper region of the atmosphere. The total mass of ozone in the atmosphere is about 3 billion metric tons which is only 0.00006 percent of the atmosphere. Ninety percent of the ozone in the atmosphere sits in the stratosphere, the layer of atmosphere between about 10 and 50 kilometers altitude.

Ozone Depletion

The ozone hole is caused by chlorine and bromine gases in the stratosphere that destroy ozone. Accumulation of Chlorine and Bromine atoms in the upper atmosphere make ozone destruction process faster which leads to lowering of ozone level. The severe depletion of ozone first observed in 1980s and the region where ozone concentration was very low, known as "ozone hole" due to destructive reactions of halogen.

These man made substances are the main source of carrying chlorine and Bromine into the upper atmosphere where ozone is situated. Substances used in industrial and agricultural sectors such as Chlorofluorocarbon (CFC), Halons, Carbon tetrachloride, Hydro Chloro Flouro Carbon (HCFCs) and Methyl Bromide (MeBr) are mainly responsible for ozone depletion.

Ozone and UV radiation

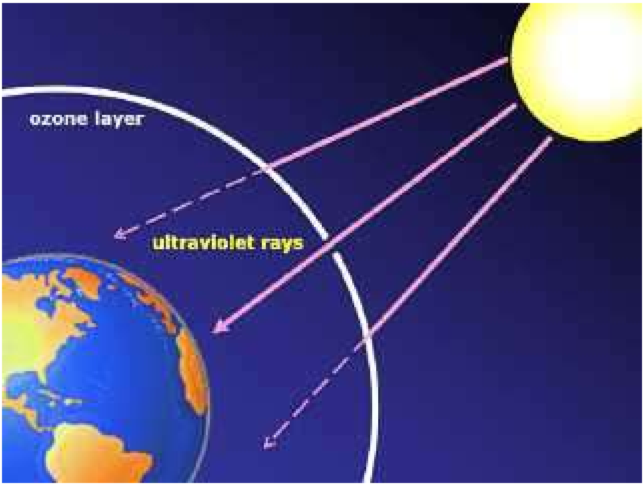

Fig 01:Ozone layer filters dangerous ultra-violet rays coming from the sun
(hubpages.com)

Ultra Violet (UV) radiation emanating from the sun has significant influences on biology of our living planet. UV-B radiation is harmful to human, animal and plant life. Solar UV radiation is attenuated through many absorption and scattering processes and is strongly absorbed by atmospheric Ozone especially at the upper region (Stratospheric Ozone). The ozone layer blocks 90-99 percent of the sun's ultraviolet radiation from making contact with Earth. So this protective shield that help to serve life on the planet.

Reduction in stratospheric ozone mainly due to anthropogenic (man made) emissions directly influences amount of UV-B radiation reaching the earth surface.

Increases in UV-B irradiance have occurred over the period of ozone depletion.
It has been revealed that the ozone depletion in polar regions affects the ozone level in mid latitudes. For example, the export of ozone poor air from Antarctica contributes approximately 50% of the ozone depletion at mid-southern latitudes. According to UNEP (2006) increase in UV-B irradiance have occurred over the period of ozone depletion and the increase from about1980 to the end of the 20th century have been larger than the long term natural variability.

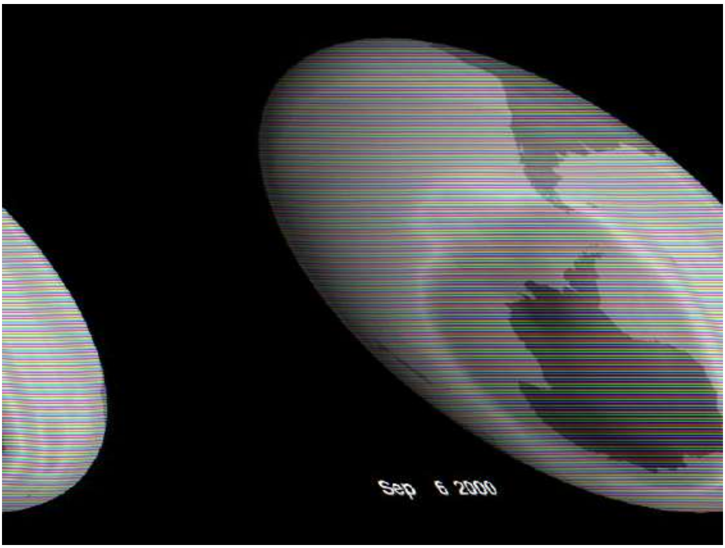

Fig 02: The largest-ever Antarctic ozone hole, roughly three times the size of the U.S., was detected on September 6, 2000

*by NASA's Total Ozone MappingSpectrometer.***(gsfc.nasa.gov)**

How does increased UV affect natural ecosystems?

Many field studies show that growth and morphology (external features) of plants are changed by enhanced levels of UV reaching the surface of the earth. Although photosynthesis of higher plants and mosses are often changed, hence reduce their primary production. This leads to diminish the crop yield of many staple food species. Microbes play an important role in natural element cycles as decomposers.

Enhanced UV can lead to changes in species composition of microbial community, thus affects litter decomposition process, through which essential nutrients are recycled .Micro organisms such as bacteria and fungi are more vulnerable to increased UV than higher plants.Physiochemical changes in plants induced by UV-B radiation affects insect herbivory population.

This may accounts for reduced herbivory because of altered behaviors within them. Aquatic organisms such as phytoplankton, zooplankton, fish larvae and other primary and secondary consumers have shown a reduction in their productivity due to exposure to high UV. Decreases in biomass production at primary levels have negative impacts on survival of wide variety consumers representing higher levels of the food web such as copepods, corals, sea urchins and fishes. Reduced primary production may also responsible for lowering atmospheric carbon dioxide sequestration capacity, which in turn enhances global warming.

For e.g. increases in UV-B radiation due to ozone depletion have been found to severely impact some species of amphibians. Thinning of the ozone layer allows more UV radiation to reach the earth surface. Overexposure to UV brings out range of health effects and threatens the life on the earth.

Scientists reveal that enhanced levels of UV near the earth surface has caused increase in skin cancers, eye damages (including cataracts) and immunity suppression. The development of skin cancer is the main adverse health outcome of excessive UV exposure.

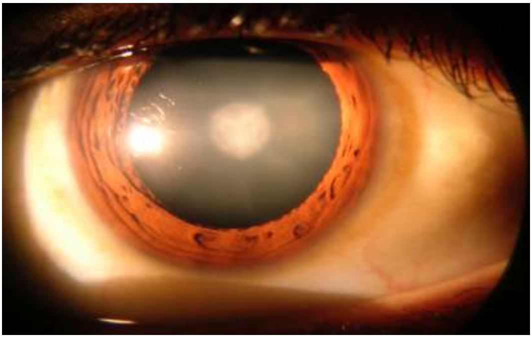

Fig 03 :Cataract due to overexposure to UV radiation (manfredkaiser.com)

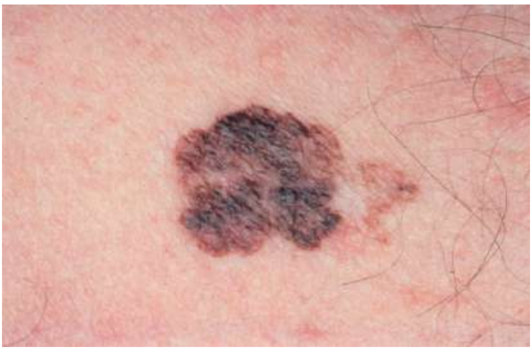

Fig 04: Melanoma, the most fatal of all skin cancers.
(www.metrohealth/org)

The degree of suppression in immunity depends on the quality, quantity and timing of the UV radiation and frequency and extent of the exposure.

Climate Change

Climate change simply refers to changes in long term average weather condition for a particular location. According to United Nations Framework Convention on Climate Change (UNFCCC) climate change is change of 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 a comparable period.

The general state of the Earth's climate depends on the amount of energy stored by the climate system (earth-atmosphere system) and in particular the balance between the amounts of energy it receives from the Sun and the amount of energy re emitted back to the space. Causes of climate change can alter this global energy balance known as "climate forcing.” This forcing can be due to external factors as well as internal factors of the system.

The work of climatologists has found that only a limited number of natural factors are responsible for most of the past episodes of climate change on the Earth. These include variations in the Earth's orbital characteristics, volcanic eruptions, continental drift, ocean currents, meteorites and variations in solar output. The following diagram illustrates the basic components that influence the state of the Earth's climatic system.

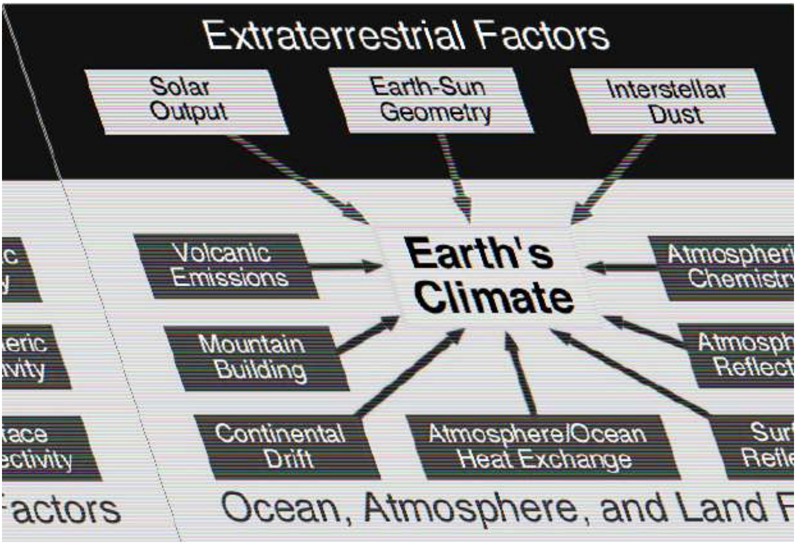

Fig 05: basic components that influence the state of the Earth's climatic system (:Source:http://www.physicalgeography.net/fundamentals/7y.html)

Man made activities primarily include burning of fossil fuels and permanent forest losses have made significant changes in our climate. Since the industrial revolution, humans have been changing the global climate by emitting considerable amounts of greenhouse gases into the atmosphere, potentially resulting in increased global warming and related climatic variability.

The most abundant greenhouse gases are, in order of their relative abundance are water vapor, carbon dioxide, methane, nitrous oxide ozone and CFCs.Increased levels of greenhouse gases as a result of man made activities leads to continuous temperature rice near the earth. Developed countries are mainly responsible for emitting these greenhouse gases into the atmosphere. As illustrated in the graph, emissions of

carbon dioxide from fossil fuels have increased greatly (Fig: 06).
The atmospheric CO2 concentration has increased drastically since the industrial revolution (Fig: 07)

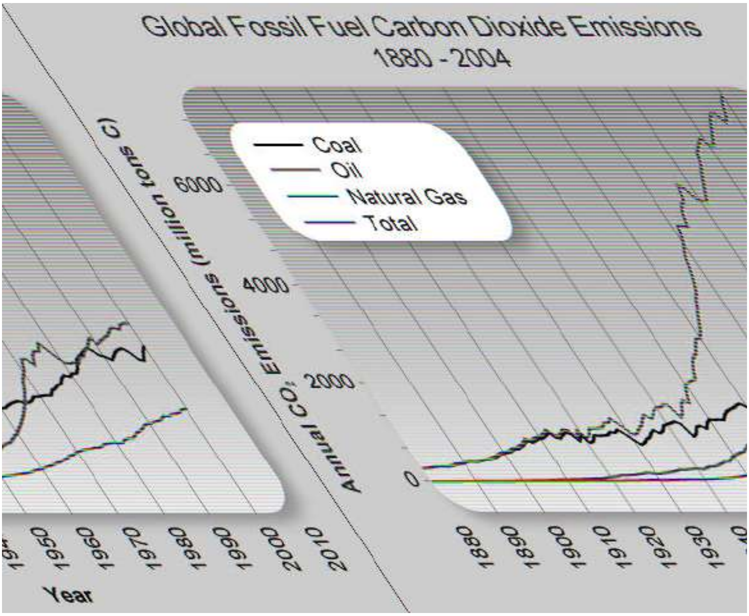

Fig 06: Global fossil fuel $C0_2$ emission (*polardiscovery.whoi.edu*)

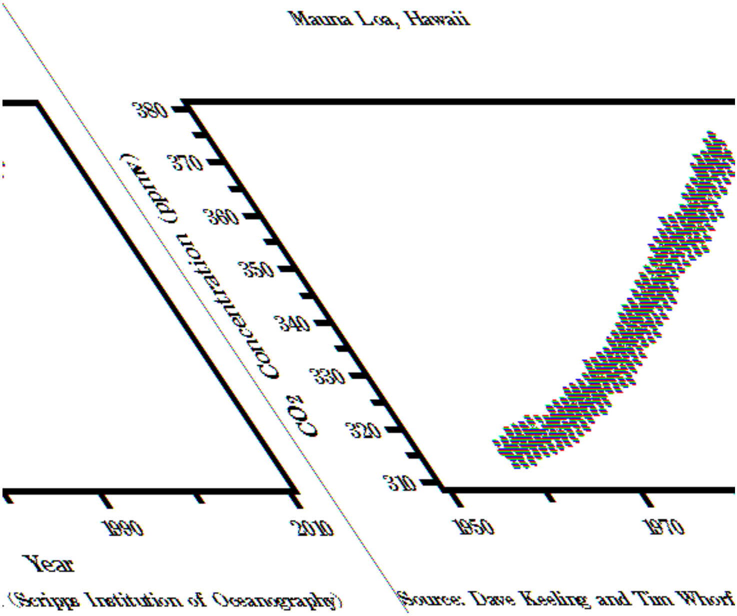

Fig 07: Increase of atmospheric CO2 concentration since industrial revolution (http://www.freewebs.com/usegreenenergy/whatisglobalwarming.htm)

Impacts of climate change

Climate Change stands to affect the entire world. Its effects are felt in all sectors and all parts of the world but magnitude of the impact change from region to region.

Global warming

Global warming simply refers to increase of the average temperature on earth. The global average temperature has risen by about $0.2^{0}C$ per decade.

The IPCC predicts global average temperature will rise 2-4ºC this century based on rapid economic growth, population peaking mid-century and energy demands met by a balance between fossil and non-fossil fuels (planet earth, 2009). According to the graph shown below the Sun's energy out put has followed its natural cycle of small ups and downs with no net increase. Over the same period the global temperature has risen significantly (fig 08).

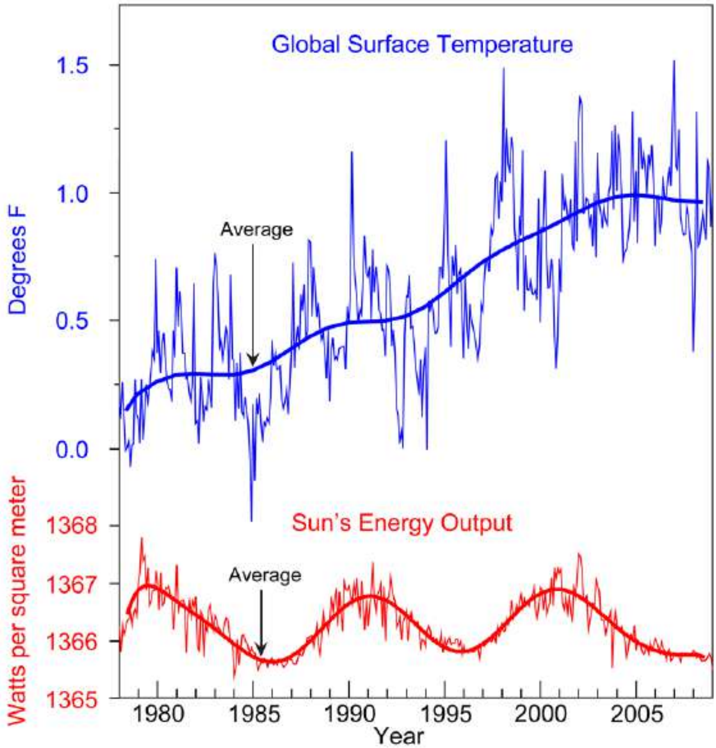

Fig 08: Global temperature change and sun's out put over the few decades
(globalchange.gov)

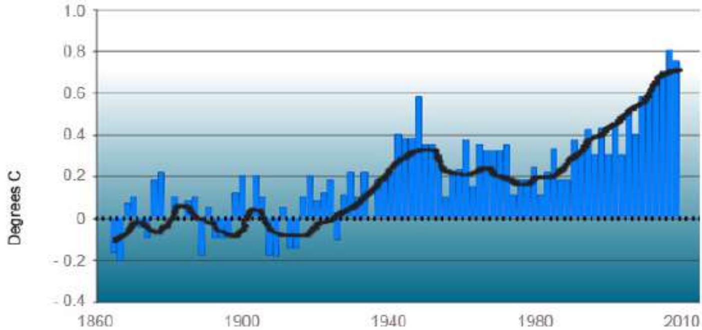

Fig 09: The graph shows us the average temperature for the years 1860 to present, and also include prediction for temperature up to 2010. The graph covers the period since the industrial revolution, and as we saw in the graph above, this was when human induced emission of CO_2 level begin to increase. We see a dramatic increase in the temperatures, with a particularly steep increase from the 1980's onwards which is set to continue.

(http://www.emissionzero.ie/index.)

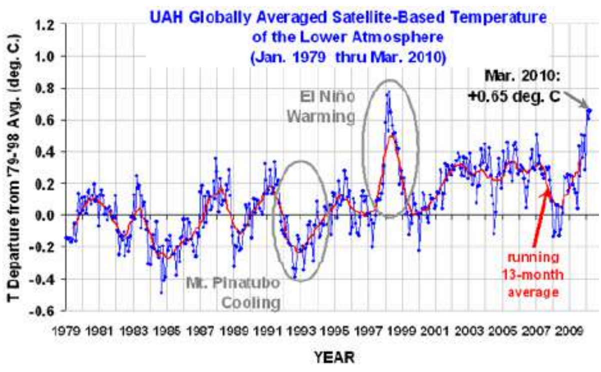

Fig 10; Temperature variation since 1979. Year 1998 was an unusual hot year due to strong El Nino effect. (colli239.fts.educ.msu.edu)

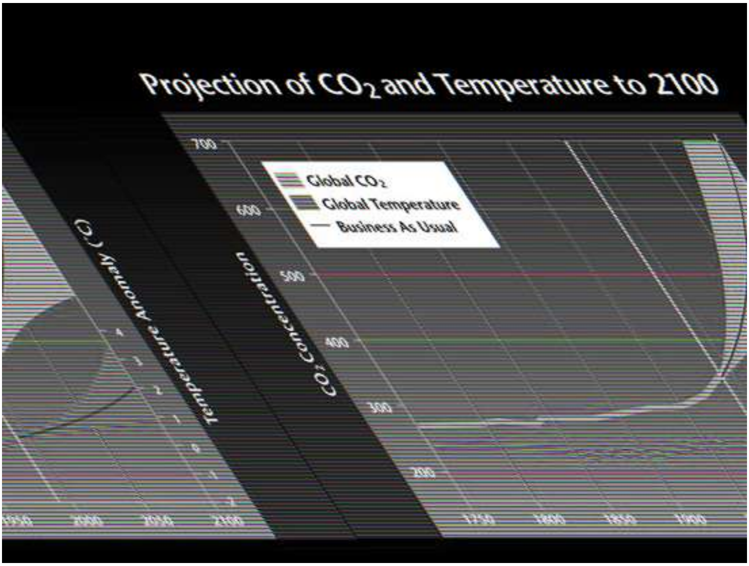

Fig11. Projected concentration of atmospheric CO2 and temperature rise.
(ldeo.columbia.edu)

Sea level rise

Global warming leads to sea level rise through thermal expansion of sea water and melting of Glaciers. The scientists say that thermal expansion accounts for about one-third to one-half of global sea level rise. The upper layer of the world's ocean has warmed since 1993, indicating a strong climate change signal, according to a new study. Newly detected rising sea levels in parts of the Indian Ocean, including the coastlines of the Bay of Bengal, the Arabian

Sea, Sri Lanka, Sumatra and Java, appear to be at least partly a result of human-induced increases of atmospheric greenhouse gases.
Human induced global warming is likely to amplify regional sea level rise changes in parts of the Indian Ocean which would make potential impact on coastal inhabitants. Research studies show that accelerated sea level rise would aggravate monsoon flooding in India and Bangaladesh.

The Indo-Pacific warm pool, has heated by about 1 degree Fahrenheit, or 0.5 degrees Celsius, in the past 50 years, primarily caused by human-generated increases of greenhouse gases (*Insciences, 2010*). Scientists have shown that mid-ocean islands such as the Mascarenhas Archipelago, coasts of Indonesia, Sumatra and the north Indian Ocean may experience significantly more sea level rise than the global average.

Complex circulation patterns in the Indian Ocean are likely to have heavy precipitation especially eastern tropical regions of the Indian Ocean and would increase drought in the western equatorial Indian Ocean region, including east Africa,
New results show that human-caused changes of atmospheric and oceanic circulation over the Indian Ocean region, which have not been studied previously, are the major cause for the regional variability of sea level change. (Insciences*, 2010*)

IPCC published the predictions in 2007, that the sea would rise close to half a metre in the next 100 years but new results are that the sea level will rise between 0.7 and 1.2 meters during the next 100 years (Insciences*, 2010*). The difference depends on what mankind does to stop the emission of greenhouse gases into the atmosphere. If we seriously reduce the emissions of CO_2 globally, the sea will only rise 0.7

meters, while there will be a dramatic rise of 1.2 meter if we continue indifferent with the current use of energy based on fossil fuels.

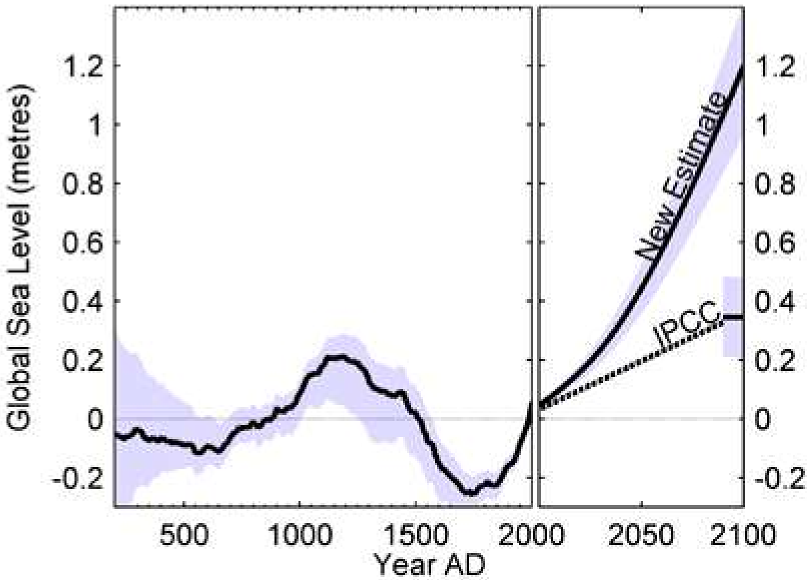

Fig 13: The sea level rise over the last 2000 years, and extrapolated to 2100.
(*planetearth.nerc.ac.uk)*

Melting of glaciers

Warming effect on the earth has resulted in melting of ice caps. Since the early 1960s; mountain glaciers around the world have experienced a great loss. Projections show that 4^0c rise in average global temperature would results in melting of all of the world's glaciers.

Part of this change is due to the albedo effect, with white, reflective ice replaced by dark water, which absorbs more of the sun's heat. The removal of ice has also led to more

summer evaporation of water, which acts as a powerful greenhouse gas in the atmosphere, and accelerates temperature rise. Speed and extent of melting sea ice has accelerated in recent years.
The new figures show that global sea ice extent is currently down to 4.4m square kilometres (1.7m square miles) and still falling. From 1979 to 2000 the average sea ice extent was 7.7m square kilometres. The main culprit was man-made global warming.

Huge mass of sea ice in the Arctic help control the global temperature, as white ice reflects some 80% of sunlight. Usually ice reflects sunlight more than land. The following graph shows that Greenland ice mass has been decreased markedly due to temperature increase.

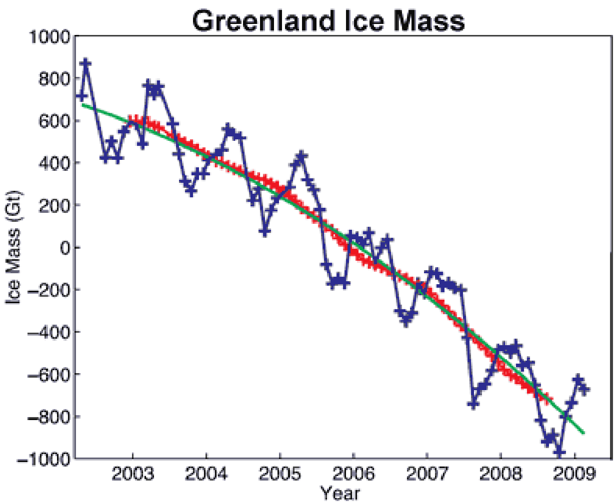

Fig 14: Decrease of Greenland Ice mass (www.climate-skeptic movie.com)

Impact on biodiversity

Climate change has emerged as one of greatest threats to biodiversity. In general, species worldwide are expected to try to move to higher elevations as temperatures rise.

For example Global warming has caused to alter the preferred locations of endangered loggerhead turtles due to changes in thermal gradients in the ocean. It has been found that North American songbirds have become lighter and grown shorter wings in recent decades in response to warming temperatures (Interlinked climate change and energy challenges, 2010). Migrating patterns and distance of many species have changed as temperature has changed. E.g. Purple finch

Fig 15: Purple finch *(Carpodacus purpure)*

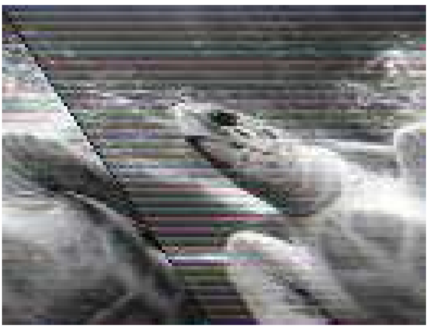

Fig 16: Loggerhead turtle (*Caretta caretta***)**

Most of agricultural crops cultivated are being carefully bred for traits that fit the present climate. According to future climatic models, climate change will adversely affect the global agricultural production in many ways. For example reduction in yields and making crop lands climatically unsuitable which lead to make a food crisis in near future. Many studies show that 16 to 22 per cent of wild species of plants could go extinct by 2050.

The world must grow 70 percent more food by 2050 to feed a rising population. Scientists warn that Climate change and pollution may cut yields for soybeans and other crops by 2050 unless plants are adapted. Recent climate change has shifted the flowering time of many plant species

Higher water temperature levels as a result of global warming leads to coral bleaching. Researchers warn that most of the world coral species have already been destroyed by global warming.

Increased climatic extremes

Global climate change affects different regions of the earth in different ways. Warmer atmosphere will result in a greater number of tropical storms, extreme heat waves, droughts, and floods. With the oceans getting warmer each year, the probability that tropical storms would occur is also getting higher. In 2005, there was the largest number of hurricanes in one year in recorded history. The annual number of storms has doubled from around 8 (early 1970s) to 18 (2000- 2004).

Climate change may greatly responsible for the relatively extreme character of El Nino related weather over the last few years in many parts of the world.

El Niño's have occurred more often since 1975.With global climate change a significant change in the occurrence and frequency of tropical and extra- tropical cyclones may be expected. A few very severe cyclones such as Andrew, Mitch and Floyd have occurred over the last 15 years.
Since 1970, tropical cyclone activity has increased in the North Atlantic (fig 17).Future projections based on theory and high-resolution dynamical models consistently indicate that greenhouse warming will cause the globally averaged intensity of tropical cyclones to shift towards stronger storms, with intensity increases of 2–11% by 2100.

Changes in the frequency and distribution of these storms could be a significant component of future climate conditions. According to new research, hurricanes in the North Atlantic are stronger and larger than ever before.

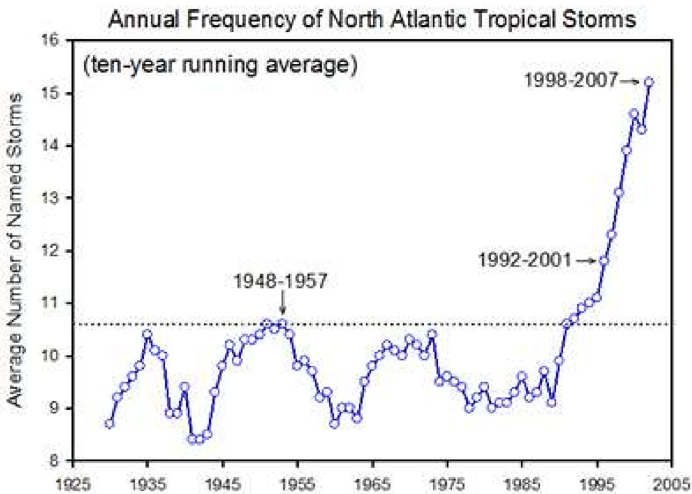

Fig 17: Annual frequency of North Atlantic Tropical Storm) (*climate.org*)

Ozone climatic interactions

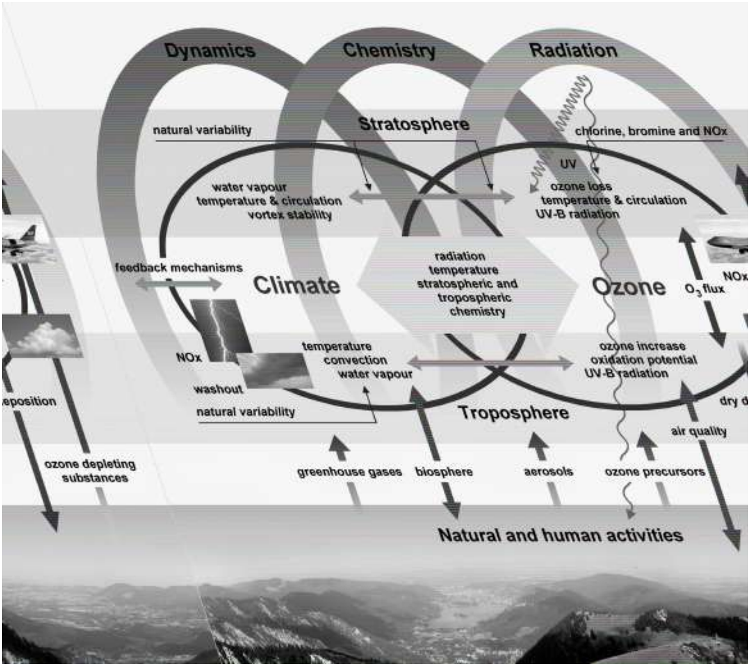

Fig 18: Interactions between human activity, atmospheric composition, chemical and physical processes and climate (atmos.caf.dlr.)

The ozone climate interactions are taking place in both directions. Ozone changes affect climate and climate changes affect ozone. Ozone formation is influenced by the atmospheric constituents and the presence of ozone in turn affects temperature, humidity, wind and the presence of chemicals in the atmosphere (Fig.18).

Ozone interacts with both long wave and shortwave radiation while changes in temperature and circulation affect distribution of ozone.

Absorption of solar radiation and absorption of outgoing infrared radiation by stratospheric ozone cause to warm the stratosphere. Therefore ozone is primarily responsible for making changes in temperature, because it absorb both at short wave and long wave region of the electro magnetic spectrum.

Climate and weather are thought to be a product of the lower atmosphere. Ozone destruction is a separate process taking place in the stratosphere. But there are several links between stratospheric Ozone depletion and troposphere greenhouse gases accumulation.

The scientists are investigating ozone-climate interactions for present and future conditions in the troposphere and the stratosphere through integrated model studies. Success in limiting ozone depleting substances is also helping to mitigate climate change. Protection of the ozone layer has brought important climate benefits because many ozone depleting substances are also potent greenhouse gases (Table 1).

Table 1: Most ozone depleting substances are also potent Greenhouse gases.

Substance	**Ozone depleting potential**	**Global warming potential**
Chlorofluorocarbons(CFC)	0.6- 1.0	4,680 -10,720
Halons	3 -10	1,620 – 7,030
Carbon tetrachloride	1.1	1,380
Methyl bromide	0.6	5
Hydrochlorofluorocarbons	0.01 -0.5	76 -2,270

The success of future research on ozone climatic interactions depends on an integrated strategy, with more interactions between scientists' observations and mathematical models.

Stratospheric cooling and troposphere warming

Less ozone leads to less absorption of ultra-violet radiation form the sun at the stratosphere. So ozone depletion reduces heating as consequence of reduced absorption of UV radiation which make stratosphere cool. Because greenhouse gases traps heat in the troposphere, less heat reaches the stratosphere which makes it colder. It has been found that ozone depletion get severe when the stratosphere becomes colder.

Polar stratospheric clouds (PSCs) are the medium on which reservoir chlorine compounds are converted into ozone-destroying chlorine radicals.

Some of the more popular scenarios of global warming predict cooler stratospheric temperatures, leading to formation of more polar stratospheric clouds and more active chlorine in the area of the Antarctic ozone hole. So global warming can make ozone depletion much worse and may delay its recovery (Fig: 19).

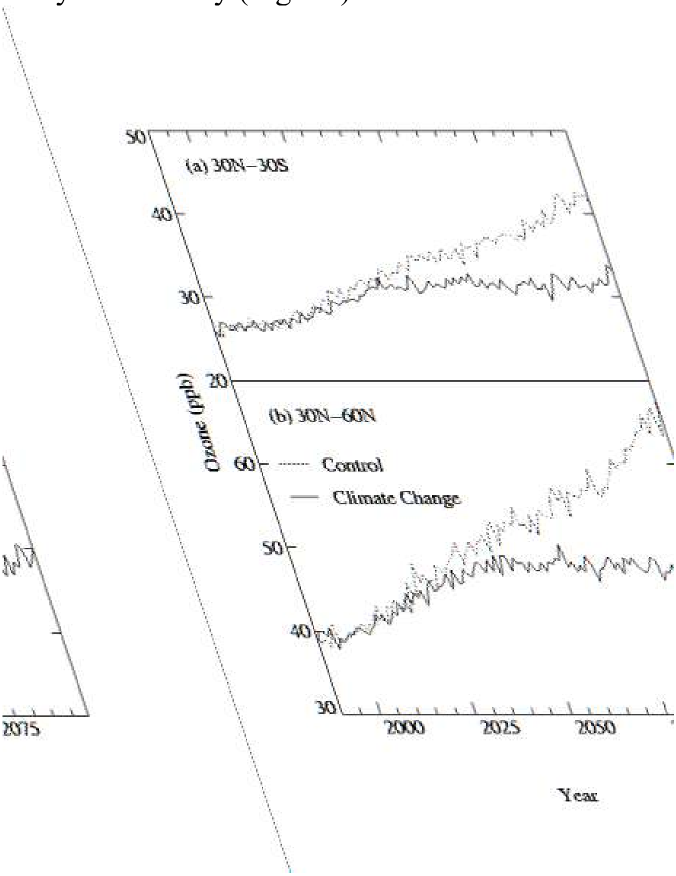

Figure 19. *Abundances of ozone calculated for equatorial region (panel a) and extra tropics (panel b) from the STOCHEM model.*
(*atmosp.physics.utoronto.ca*)

Effects of elevated CO_2, temperature and UV radiation
Changes at the ecosystem level can be complex and can act in both directions through changes in radiation shielding (for example, by forest canopies, water, ice, snow, or clouds) and surface reflectivity (from ice and snow).

Complex interactions between UV and air quality may also be influenced by climate change, through changes in temperature and humidity.Very high fluxes of UV-B radiation detrimentally affect photosynthesis and foliage development of plants. Both higher temperatures and UV-B radiation increased fruit fall, especially in combination. High temperature and UV- B radiation both have reduced fruit production in many species.

Effects on aquatic systems
Both marine and freshwater ecosystems are key components of the earth's biosphere as primary producers of aquatic food chains, producing more than 50% of the global biomass. UV radiation penetrates to aquatic systems can affect from major biomass producers (Phytoplankton) to higher consumers in the food web.
A number of new studies addressing that UV-B have a significant influence on community structure of various aquatic systems. Early life stages of aquatic organisms, particularly eggs and larvae are vulnerable to solar UV-B radiation.

Effects on air quality

Air quality has a significant effect on both environment and human health. Interaction between ozone depletion and climate change may causes alterations in atmospheric chemistry and circulation patterns.

Solar UV B provides energy for many chemical reactions take place in the atmosphere. Therefore changes in the amount of UV B due to stratospheric ozone depletion may have significant impact on the atmospheric chemistry.

Analysis of surface level ozone observations in Antarctica suggests that there has been a significant change in the chemistry of the boundary layer of the atmosphere in this region as a result of stratospheric ozone depletion (UNEP, 2006).

Stratospheric ozone depletion has increased the rate of ozone production near the ground (troposphere ozone) which is considered as a key indicator of air quality.