Questions and Answers about the Environmental Effects of the Ozone Layer Depletion and Climate Change: 2010 Update

Environmental Effects Assessment Panel: 2010

United Nations Environmental Programme

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This document provides some answers to commonly asked questions about the environmental effects of ozone depletion

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Introduction

In the mid-1970s it was discovered that some man-made products destroy ozone molecules in the stratosphere. This destruction leads to higher ultraviolet (UV) radiation levels at the surface of the Earth and can cause damage to ecosystems and to materials such as plastics. It may cause an increase in human diseases such as skin cancers and cataracts.

The discovery of the role of the synthetic ozone-depleting chemicals, such as the chlorofluorocarbons (CFCs), stimulated increased research and monitoring in this field. Computer models predicted a disaster if nothing was done to protect the ozone layer. Based on this scientific information, the nations of the world took action in 1985 with the Vienna Convention for the Protection of the Ozone Layer, followed by the Montreal Protocol on Substances that deplete the Ozone Layer in 1987. The Convention and Protocol have been amended and adjusted several times since 1987 as new knowledge has become available.

The Meetings of the Parties to the Montreal Protocol appointed three Assessment Panels to regularly review research findings and progress. These panels are the Scientific Assessment Panel, the Technological and Economic Assessment Panel and the Environmental Effects Assessment Panel. Each panel covers a designated area with a natural degree of overlap. The main reports of the Panels are published every four years, as required by the Meeting of the Parties. All three reports have an executive summary that is distributed more widely than the entire reports. It has become customary to add a set of questions and answers – mainly for non-expert readers – to these executive summaries.

This document contains the questions and answers prepared by the experts of the Environmental Effects Assessment Panel. They refer mainly to the environmental effects of ozone depletion and its interactions with climate change, based on the 2010 report of this Panel, but also on information from previous assessments and from the report of the Scientific Assessment Panel. Readers who need further details on any question should consult the full reports for a more complete scientific discussion. All these reports can be found on the UNEP website: (http://ozone.unep.org).

The update of this component of the Assessment was discussed by the 24 scientists who attended the Panel Review Meeting for the 2010 Environmental Effects Assessment (Lancaster, England, 29 Augustus – 7 September 2010). In addition, subsequent contributions, reviews or comments were provided by the following individuals: Alkiviadis F Bais, Lars Olof Björn, Anthony P. Cullen, David J. Erickson, Donat-P. Häder, Walter Helbling, Robyn Lucas, Richard L. McKenzie, Mary Norval, Sharon Robinson, Keith R. Solomon.

I .Ozone and UV

Q1. How is ozone produced and destroyed

The ozone molecule (O_3) contains three atoms of oxygen and is mainly formed by the action of the UV rays of the sun on oxygen molecules (diatomic oxygen, O_2) in the upper part of Earth's atmosphere (called the stratosphere). Ozone is also produced locally near Earth's surface from the action of UV radiation on some air pollutants.

About 90% of all ozone molecules are found in the stratosphere, a region that begins about 10-16 kilometres above Earth's surface and extends up to about 50 kilometres. Most of this ozone is found in the lower stratosphere in what is commonly known as the "ozone layer." The stratospheric ozone layer protects life on Earth by absorbing most of the harmful UV radiation from the sun. The remaining 10% of ozone is in the troposphere, which is the lowest region of the atmosphere, between Earth's surface and the stratosphere.

Ozone is a very tiny fraction of the air, which consists mainly of nitrogen (N_2) and oxygen (O_2) molecules. In the stratosphere, near the peak of the ozone layer, there are up to 12 ozone molecules for every million air molecules. In the troposphere near Earth's surface, ozone is even less abundant, with a typical range of 0.02 to 0.1 ozone molecules for each million air molecules.

Ozone is destroyed naturally in the upper stratosphere by the UV radiation from the sun. These reactions are most important in the stratosphere of tropical and middle latitudes, where this radiation is most intense. For each ozone molecule that is destroyed an oxygen atom and an oxygen molecule are formed. Some of these recombine to produce ozone again. These naturally occurring reactions of destruction and production of ozone are balanced so that the ozone amount in the stratosphere remains constant.

Other, non-natural, mechanisms for the destruction of ozone involve halogen atoms. Emissions from human activities and natural processes include large sources of chlorine (Cl), bromine (Br) and fluorine (F) containing gases that eventually reach the stratosphere. When exposed to UV radiation from the Sun, these halogen-containing gases are converted to more reactive gases, also containing chlorine and bromine, for example, chlorine monoxide (ClO) and bromine monoxide (BrO). These reactive gases participate in "catalytic" reaction cycles that efficiently destroy ozone in the stratosphere.

Atomic oxygen (O) is formed when UV radiation in sunlight interacts with ozone and oxygen molecules. The destruction of ozone involves two separate chemical reactions. The net or overall reaction is that of atomic oxygen (O) with ozone (O_3), forming two oxygen molecules (O_2). The cycle can be considered to begin with either ClO or Cl. Cl reacts with (and thereby destroys) ozone and reforms ClO. The cycle then is repeated with another reaction of ClO with O. Because Cl or ClO is reformed each time an ozone molecule is destroyed, chlorine is considered a catalyst for ozone destruction (Figure 1). Similar reactions occur with bromine derivates. The relative potency of the different halogens depends a great deal on the stability of the compounds. Hydrogen fluoride (HF) is so very stable that fluorocarbons have relatively no known impact on ozone. The atmospheric lifetimes of the iodine compounds are extremely short and they do not play an important role in the ozone destruction processes.

Volcanoes can emit some chlorine-containing gases, but these gases are dissolved in rainwater and ice and are usually "washed out" of the atmosphere before they can reach the stratosphere.

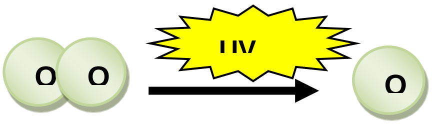

__Figure 1a:__ Formation of atomic oxygen

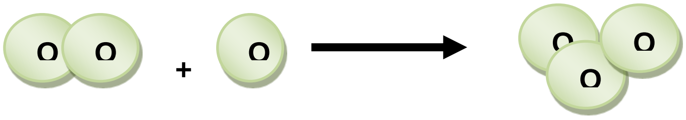

__Figure 1b:__ Production of ozone

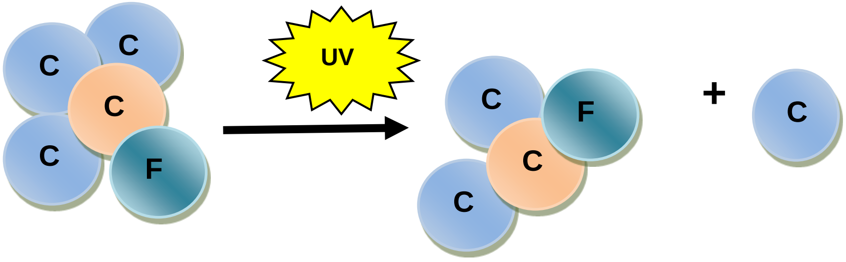

__Figure 1c:__ Formation of atomic chlorine

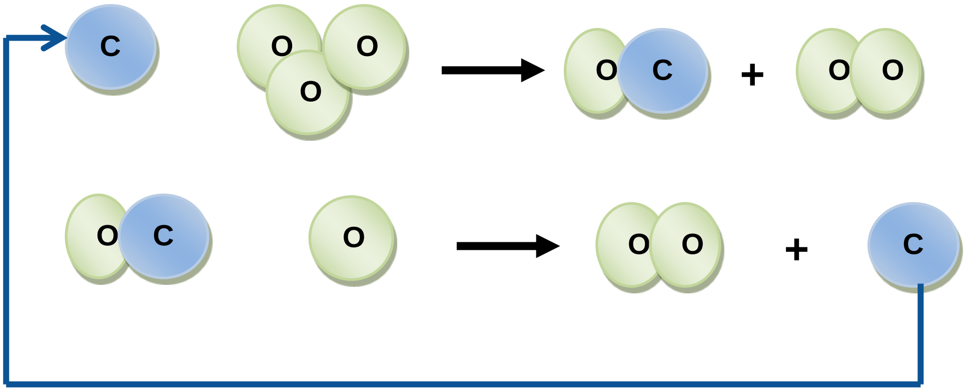

__Figure 1d:__ Destruction of Ozone – The last two reactions are repeated many times. Figure 1 presents only one of the chemical processes responsible for the destruction of Ozone in the Stratosphere. In the example CFC 11 (CCl_3F) is used. (Figure provided by Dr P J Aucamp, Ptersa)

Q2. What is the relationship between ozone and solar ultraviolet radiation?

There is an inverse relationship between the concentration of ozone and the amount of harmful UV radiation transmitted through the atmosphere since ozone absorbs some of the UV radiation.

A small fraction of the radiation emitted by the Sun resides in the ultraviolet range. This range extends from 100 to 400 nm and is divided into three bands: UV-A (315 – 400 nm), UV-B (280 – 315 nm) and UV-C (100 – 280 nm). As the Sun's radiation passes vertically through the atmosphere, all the UV-C and approximately 90% of the UV-B is absorbed by ozone and oxygen molecules in the stratosphere. UV-A radiation is less affected by the atmosphere. Therefore, the UV radiation reaching Earth's surface is composed mainly of UV-A with a small UV-B component. The amount and variability of the UV-B component depends on the solar elevation angle which defines the path-length through the atmosphere and also on the amount of ozone (Figure 2 - also Figure 5). A decrease in the concentration of ozone in the atmosphere results in increased UV-B radiation at the surface of the Earth. UV-B radiation is biologically much more active than UV-A radiation and can have either beneficial or detrimental effects on living organisms. Changes in the amount of UV-B radiation (for example due to stratospheric ozone depletion) are very important for humans.

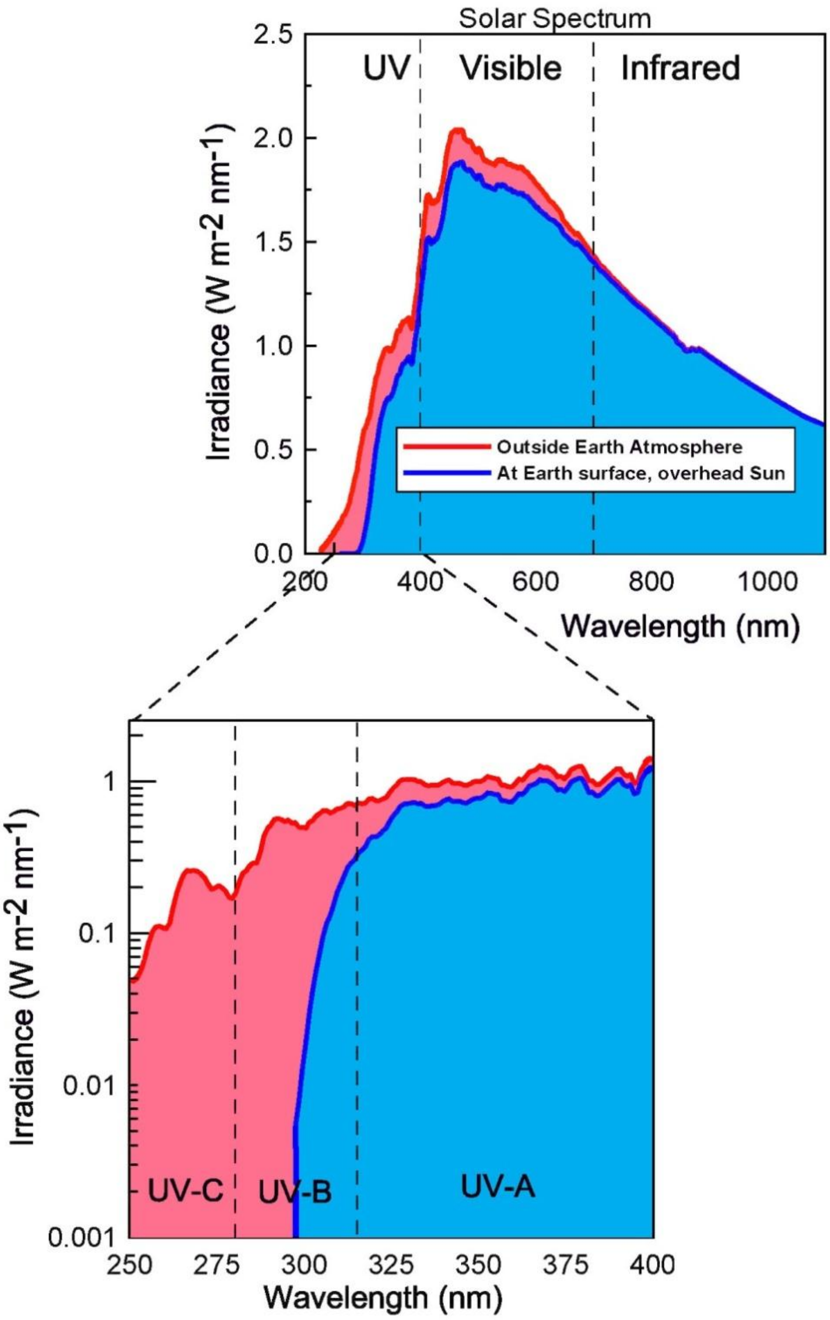

Figure 2: *The spectrum of UV radiation as part of the solar spectrum. Note the log scale on the y-axis in the bottom panel. The blue curve shows that ozone absorption increases rapidly at shorter wavelengths so that at wavelengths less than 300 nm, less than 1% of the radiation is transmitted. Figure provided by Dr R L McKenzie, NIWA.*

Q3. How and why has the situation regarding the ozone layer changed over the past 30 years?

Stratospheric ozone has decreased over the globe since the 1980s. Averaged over the globe, ozone in the period 1996-2009 is about 4% lower than before 1980. Much larger depletion, up to 40%, occurs over the high latitudes of the Southern Hemisphere in October.

The increase in reactive halogen gases in the stratosphere is considered to be the primary cause of the average ozone depletion. The lowest ozone values in recent years occurred after the eruption of Mt. Pinatubo volcano in 1991, which increased the number of sulphur-containing particles in the stratosphere. These particles remained in the stratosphere for several years and increased the effectiveness of reactive halogen gases in destroying ozone. Observed ozone depletion varies significantly with latitude on the globe. The largest losses occur at the highest southern latitudes as a result of the severe ozone loss over Antarctica that occurs every year during winter and early spring. The next largest ozone losses are observed in the high latitudes of the Northern Hemisphere, caused in part by late winter/early spring losses over the Arctic. Ozone-depleted air over both Polar regions is dispersed away from the poles during and after each winter/spring period. Ozone depletion also occurs directly at latitudes between the Equator and Polar regions but is much smaller. Figure 3 shows the average measured and predicted amounts of equivalent effective stratospheric chlorine (EESC) concentration based on the findings of the latest Scientific Assessment Report. EESC is used as an indicator of the amount of ozone depleting substances in the atmosphere. This figure shows that the amounts of these substances in the stratosphere have already reached a maximum and now are decreasing. The concentration of the ozone is inversely proportional to the concentration of the EESC.

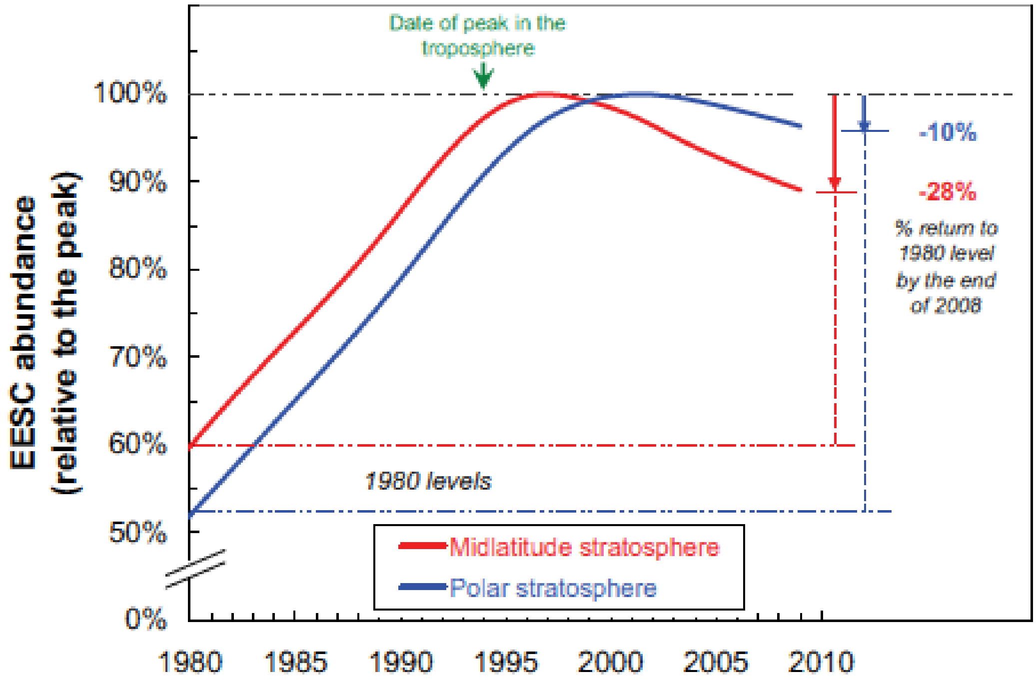

Figure 3: *Stratospheric EESC derived for the mid latitude and polar stratospheric regions relative to peak abundances, plotted as a function of time. (Reproduced from Figure ESA-1 in the executive summary of the Scientific Assessment 2010*

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Q4. What determines the level of solar UV-B radiation at a specific place?

The Sun is the source of the UV radiation reaching Earth. UV radiation is partly absorbed by the components of Earth's atmosphere. The amount of UV radiation that is absorbed depends mainly on the length of the path of the sunlight through the atmosphere.

The UV-B levels at Earth's surface vary with the time of day, geographic location and season. UV radiation is highest in the tropics, because the sun is higher in the sky, and decreases towards the poles where the Sun is lower. The height of the Sun above the horizon (the solar elevation angle) has an influence on the UV radiation, since the steeper angles mean longer pathways and more opportunity for the radiation to be absorbed. For the same reason, UV radiation is most intense near noon hours and least near sunrise or sunset, and is more in the summer and less in the winter. Clouds, particulate matter, aerosols and air pollutants absorb and scatter some of the UV radiation and thereby reduce the amount reaching Earth's surface.

Locations at higher altitudes (Figure 4) have thinner atmosphere overhead, therefore the radiation from the Sun is less attenuated. This increase in UV radiation varies between 5% and 20% for each kilometre of height, depending on the specific wavelength, solar angle, atmospheric pollution and other local conditions. Frequently, other factors cause even larger differences in UV radiation between different altitudes. Surface reflections, especially from snow, ice and sand, increase the UV radiation levels at a particular location, because the reflected radiation is redirected towards the surface through scattering by particles and molecules in the atmosphere. Snow reflects as much as 90% and dry beach sand and sea foam about 25% of UV radiation. Clouds also reflect an appreciable amount of radiation towards the surface, Thus while areas that are not shaded by clouds usually receive more radiation, under certain cloud conditions levels of UV radiation at Earth's surface can actually be higher under these conditions than under clear-sky conditions.

Figure 4: *The quantity of solar UV-B received by an object is affected by the surroundings. UV radiation is both absorbed and reflected from clouds and water, and is reflected by snow and shiny surfaces in town. (Photo provided by Dr P J Aucamp, Ptersa).*

Q5. What is the solar UV Index?

The solar UV Index (UVI) describes the level of solar UV radiation relevant to human sunburn (erythema).

The UVI was originally used in Canada. The maximum value in the South of the country is 10 at midday in the summer, and about 1 at midday in the winter. In other locations and under different conditions the UVI can be higher or lower. In the tropics at sea level the UVI can exceed 16 and peak terrestrial values of 25 can occur at high altitudes. The higher the UVI, the greater the potential for damage, and the less exposure time it takes for harm to occur. For fair-skinned individuals a UVI of more than 10 can cause skin damage (erythema) from an exposure of about 15 minutes. Outside the protective layer of Earth’s atmosphere (altitude > 50 km), the UVI can exceed 300.

Information about UV intensities is provided to the public in terms of the internationally adopted UVI colour-scale, along with appropriate health warnings, as shown in Table 5. The colours corresponding to the various ranges are standardised throughout the world.

The UVI can be measured directly with instruments designed specifically to measure sun burning UV radiation. For clear sky conditions, the UVI can be calculated approximately from knowledge of the ozone and the solar elevation angle (Figure 5). However, the UVI at a specific location and time depends strongly on the cloud cover and on the amount of aerosols. Other influential factors include the seasonally varying Sun-Earth separation, the altitude, atmospheric pollution, and surface reflection. When the surface is snow-covered, the UVI can be up to 90% greater than for snow-free surfaces. Several countries provide forecasts of UVI that take predicted changes in ozone and cloud cover into account. Further details about the UVI can be found at www.unep.org/PDF/Solar_Index_Guide.pdf

Table 5: Colours used in the UV Index

Exposure Category	Colour	UVI Range
Low	🟩	**< 2**
Moderate	🟨	**3 - 5**
High	🟧	**6 - 7**
Very High	🟥	**8 – 10**
Extreme	🟪	**11+**

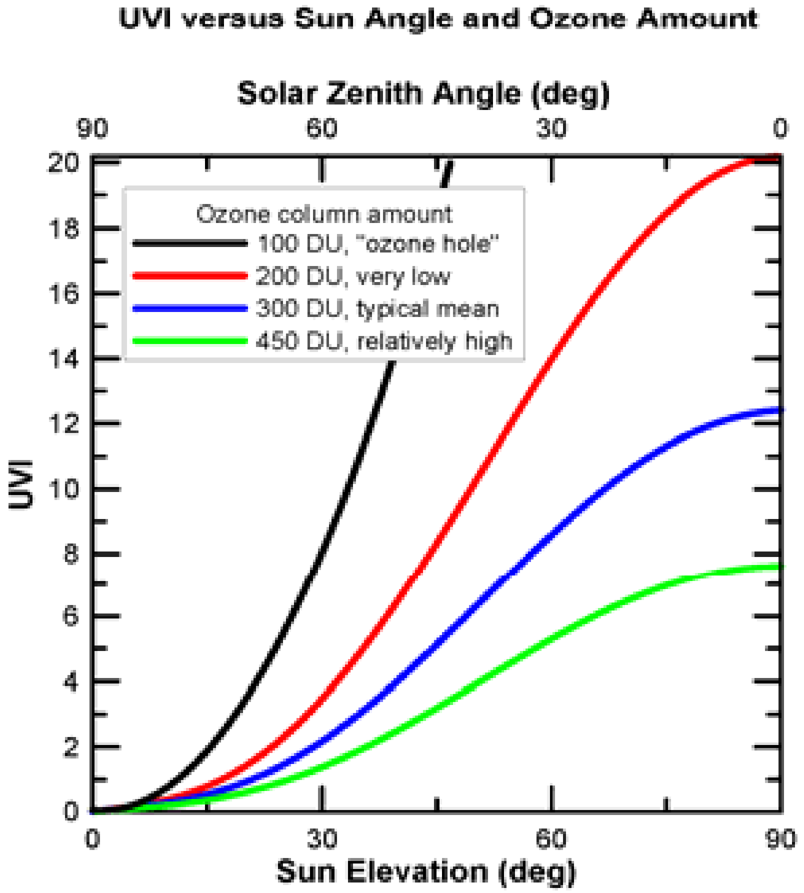

Figure 5: *A figure indicating the variation of the UVI with the solar elevation. The coloured lines represent different Ozone concentrations measured in Dobson Units (DU), Figure provided by Dr R L McKenzie, NIWA.*

Q6. How does the UV index vary with location and time?

The combination of total ozone, aerosols, clouds, air-pollution, altitude, surface reflectivity and solar zenith angle (that is determined by the geographical position, season and time of the day) are the main factors resulting in variation in the UV Index.

A global picture of the UVI can be derived from measurements with instruments on satellites. UVI varies with latitude and time of year, as can be seen from the example for 3 September 2010 presented in Figure 6. UV levels increase with altitude, and therefore the UVI is higher at mountainous locations (as seen, for example, in the Andes and Tibet).

The presence of "patchy clouds" or snow-covered ground can result in larger UV Index values. A combination of small solar zenith angle near noon, high altitude, a naturally low total ozone column and a very clean atmosphere can lead to exceptionally high values of the UVI. A good example is the high altitude desert *Puna de Atacama* in Argentina, where a UV index of 18 is common in January and December, with a maximum of 20 and even more on occasional days.

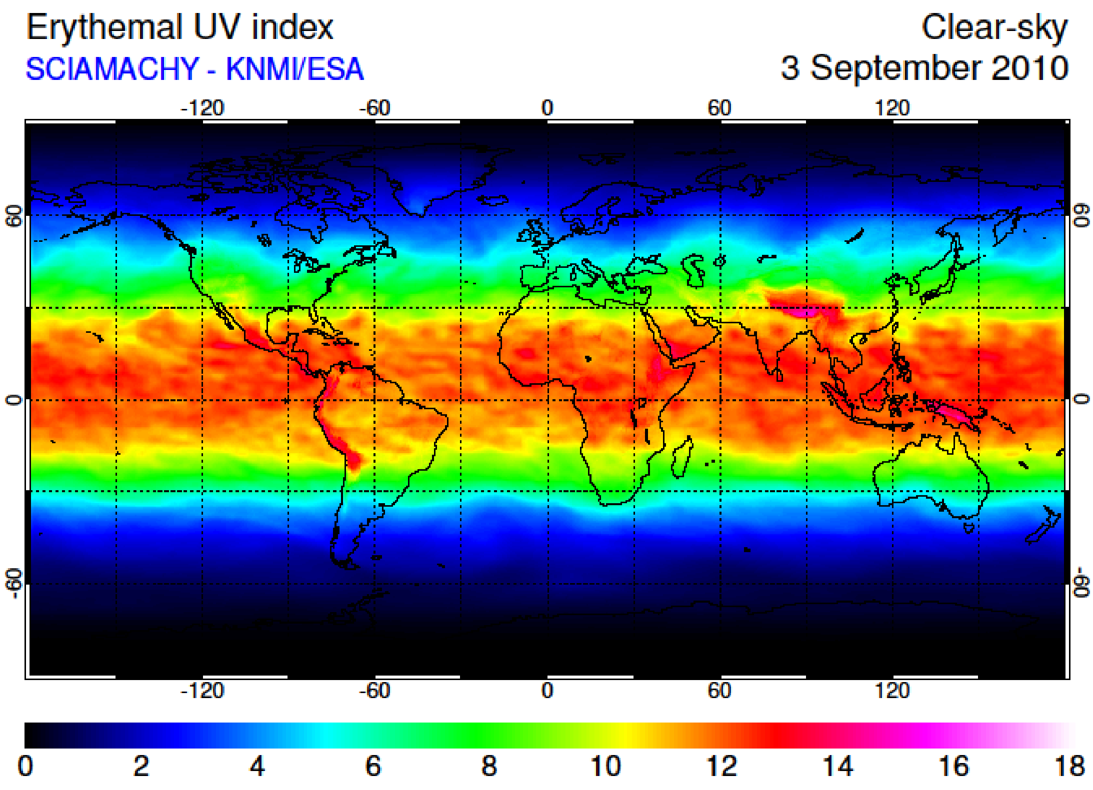

Figure 6: *UV Index for 3 September 2010 derived from Sciamachy instrument on Envisat satellite.*

Q7. What is the effect of the interaction between UV-B radiation, climate change, and human activity on air pollution?

Pollutants emitted by human activities can reduce UV-B radiation near the surface, while particles may lead to enhancement by scattering. These processes decrease some exposures to UV while enhancing others. Interactions between UV radiation and pollutants resulting from changes in climate and burning of fossil and plant fuels will worsen the effects of ozone on humans and plants in the lower atmosphere.

While most of the atmospheric ozone is formed in the stratosphere, ozone is also produced in the lower atmosphere (troposphere) by the chemical reactions between pollutants such as nitrogen oxides and hydrocarbons and UV radiation. This ground-level ozone is a significant component of photochemical smog found in many polluted areas and has important adverse effects on human health and the environment.

Some estimates indicate that increases of this type of air pollution will result in more human deaths than other effects of climate change, such as increased intensity of storms and flooding.

Climate change will likely increase circulation of gases in the atmosphere but cause only small increases in ozone in the lower atmosphere in areas where there is little pollution. These increases will be less significant for the health of humans than those caused by tropospheric ozone in polluted areas.

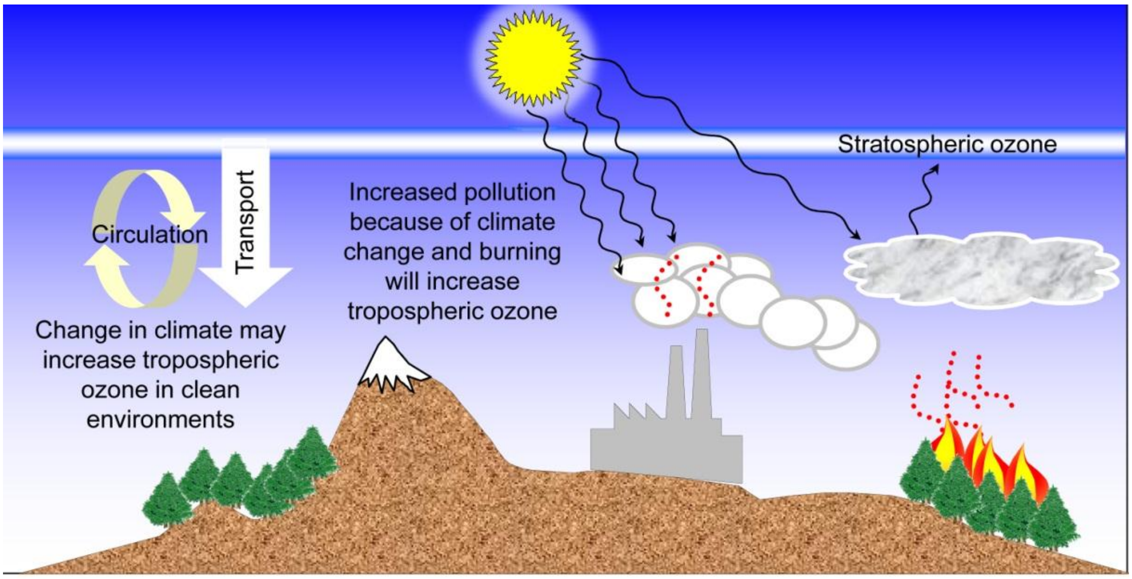

Figure 7: *Concentration of ozone at different altitudes in the atmosphere. Figure provided by Prof K Solomon, Guelph University.*

II. Effect on humans and on the environment

Q8. Can human activities have any effects on worldwide phenomena such as depletion of the ozone layer and climate change?

There is overwhelming evidence that human activities are influencing global phenomena.

Natural environmental cycles often span thousands of years but most scientific measurements are only available for the past one to three centuries. It is not easy to accurately determine the influence of humans on any natural activity. In the case of the ozone layer, the depletion of the ozone over Antarctica cannot be explained by natural cycles alone but is caused by the increase of man-made chemicals in the stratosphere. The relationship between these chemicals (e.g. chlorofluorocarbons, also known as CFCs) and ozone depletion has been shown by experiments in laboratories, numerical modelling studies and by direct measurements in the atmosphere (see Figure 8a).

By absorbing the infrared radiation emitted by Earth, some substances influence the natural energy flows through the atmosphere. The greenhouse gases, such as carbon dioxide, although only a tiny fraction of the atmosphere, play an important role in this process. Carbon dioxide (CO_2) is produced when fossil fuels are used to generate energy and when forests are burned. Measurements show that its concentration has increased by almost 30% over the past 250 years. In the mid-20th century, the concentration of CO_2 was 280 ppmv, and it is currently 390 ppmv, and increasing at about 3% per decade. Methane and nitrous oxide emitted from agricultural activities, changes in land use, and other sources are also important (see Figure 8b).

The increase in greenhouse gases contributes to climate change in the form of increased temperatures (about 0.6°C near Earth’s surface over the past 150 years) and a rise in sea level. Models of the climate change induced by emission of greenhouse gases predict that the global temperature will rise between 2 and 6°C in the next century. If this happens, the change would be much larger than any temperature change experienced over at least the last 10,000 years.

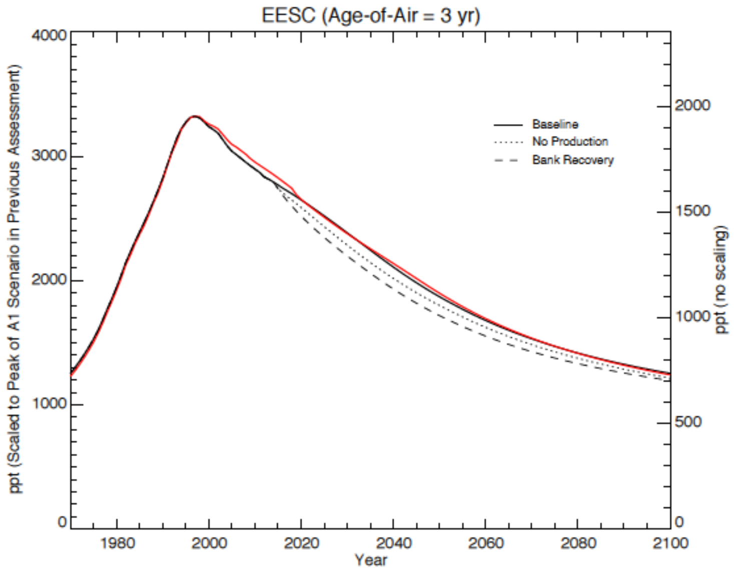

Figure 8a: *Changes in EESC values and prediction of future values (Reproduction of Fig. 5.2 in the Scientific Assessment of Ozone Depletion: 2010 http://us-cdn.creamermedia.co.za/assets/articles/attachments/29653_898_executivesummary_emb.pdf)*

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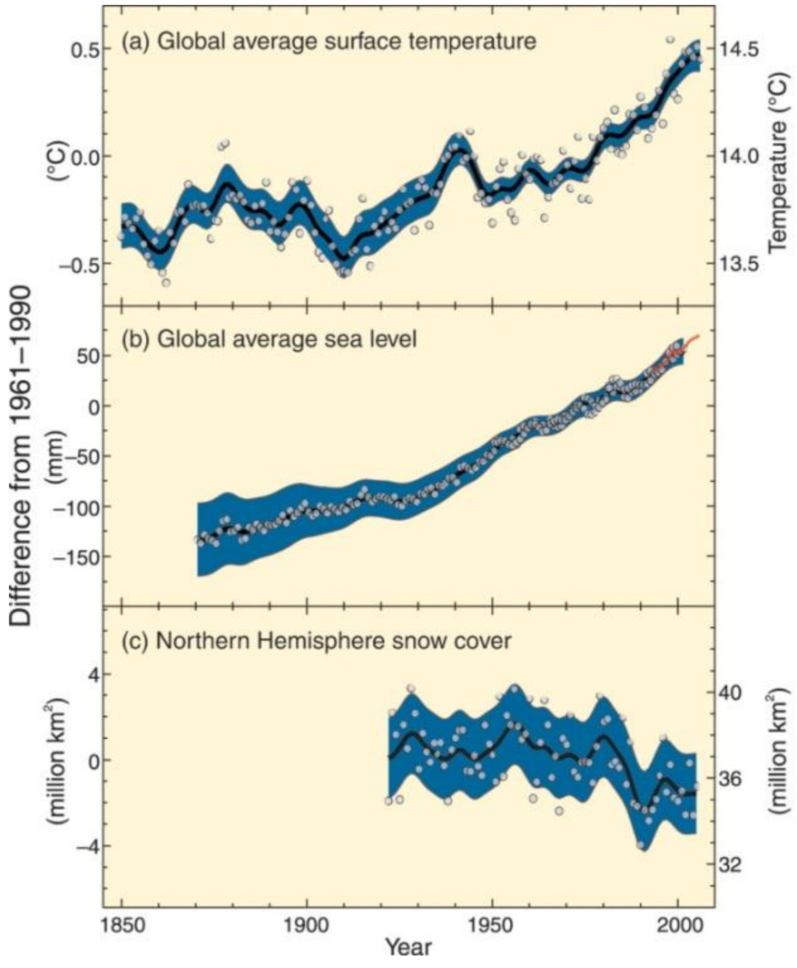

Figure 8b: *Effects of climate change on average surface temperature, sea level and snow cover over time (From the IPCC 2007 report).*

Q9. Effects on Human Health

a. What are the effects of exposure to solar UV radiation on the human eye and how can the eye be protected?

The effects of UV radiation on the eye can be almost immediate (acute) occurring several hours after a short, intense exposure. They can also be long-term (chronic), following exposure of the eye to levels of UV radiation below those required for the acute effects but occurring repeatedly over a long period of time. The commonest acute effect, photokeratitis (snow blindness), leaves few or no permanent effects, whereas cataract due to chronic exposure is irreversible and ultimately leads to severe loss of vision requiring surgery.

Avoidance of the sun is an effective but impractical means of avoiding exposure of the eyes to UV radiation. Although the eyes rarely receive direct sunlight, protection is frequently needed under conditions of high ambient UV radiation and/or where there are reflective surfaces.

Appropriate glass and plastic lenses absorb all UV-B and much of the UV-A radiation. Even clear spectacle lenses provide protection from UV-B. However, in the case of non-wrap-around sunglasses, there is potential for ambient UV radiation to enter the eye from the side. This effect can be exacerbated by tinted sunglass lenses which encourage a wider opening of the eyelids. UV radiation-blocking soft contact lenses (Figure 9a), that cover the entire cornea, effectively shield the cornea and ocular lens against UV radiation incident from all angles. They offer a UV protection alternative in those situations where the wearing of sunglasses is not practical or convenient.

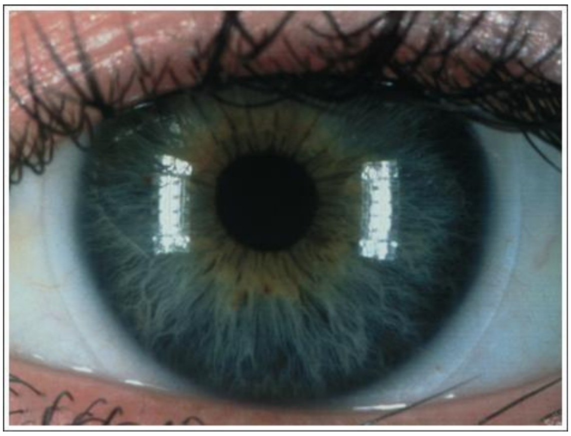

Figure 9a. *Soft UV radiation-absorbing contact lens covering the entire cornea. Photograph provided by Dr A. Cullen (University of Waterloo, Canada).*

b. What are the adverse effects of exposure to solar UV-B on human skin?

Acute overexposure of the skin to solar UV radiation causes sunburn; chronic sunlight exposure can lead to the development of skin cancers.

Sunburn is the major acute outcome in the skin of overexposure to sunlight. The dose of solar UV-B radiation required to induce sunburn varies considerably from one individual to another, largely depending on the pigment in their skin. People are frequently divided into 6 categories of skin type (Table 9b).

The major harmful effect of chronic exposure to sunlight, and/or intermittent episodes of sunburning, is the induction of skin cancers. Such tumours are divided into melanomas and the non-melanoma skin cancers, i.e., basal cell carcinoma and squamous cell carcinoma (Figure 9b). Basal cell carcinomas are most common, followed by squamous cell carcinomas and both are found at highest frequency in fair-skinned individuals living in sunny climates. They can be readily treated and are rarely fatal. Cutaneous melanoma, on the other hand, is rarer but much more dangerous and the number of new cases has increased significantly each year in many countries over the past 40 years or so. The number of cases of melanoma in dark-skinned individuals is fewer than in fair-skinned individuals and it is also uncommon in people under the age of 20.

Table 9b: Skin types.

Phototype/Ethnicity	**UV-sensitivity**	**Sunburn/tan**
I/White Caucasian	Extremely sensitive	Always burns, never tans
II/White Caucasian	Very sensitive	Burns readily, tans slowly and with difficulty
III/White Caucasian	Moderately sensitive	Can burn after high exposure, tans slowly
IV/White Caucasian, often south Mediterranean	Relatively tolerant	Burns rarely, tans easily
V/Brown, Asian/Middle Eastern	Variable	Can burn easily, difficult to assess as pigment is already present
VI/Black, Afro-Caribbean	Relatively insensitive	Rarely burns

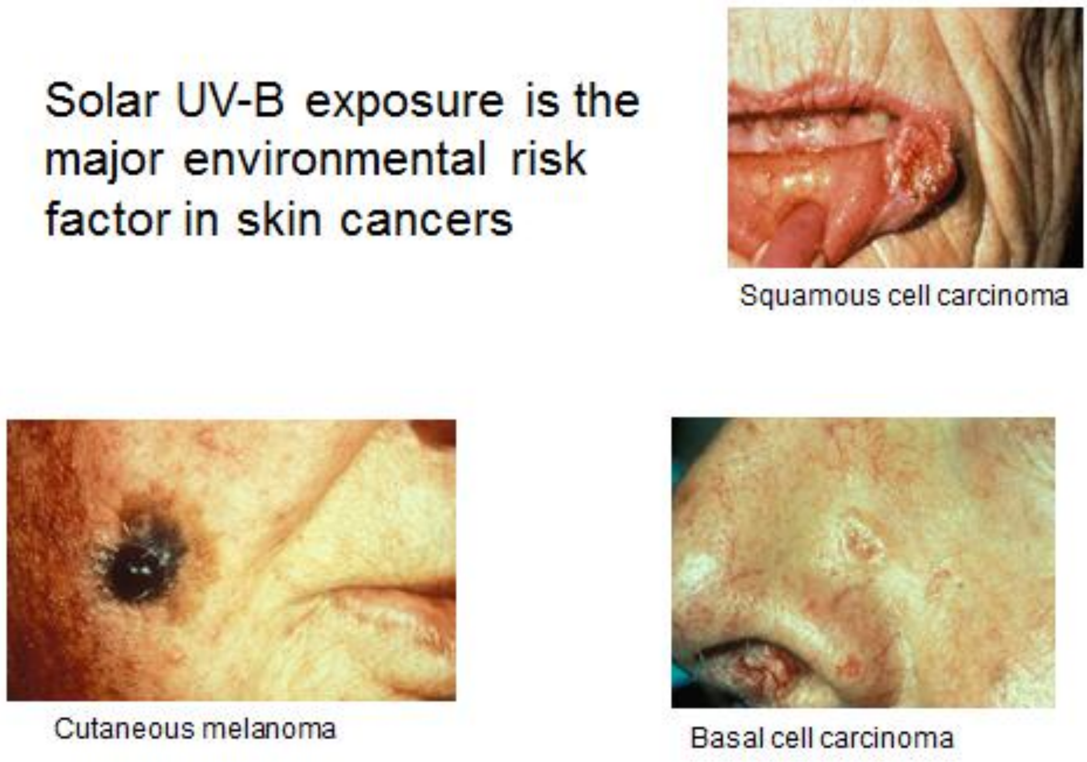

Figure 9b. *Examples of the 3 major types of skin cancer. Photograph supplied by Professor M. Norval (University of Edinburgh, Scotland).*

c. How does UV-B radiation affect the immune system?

The immune system can be suppressed by exposure of the skin and eyes to *UV-B radiation leading to reduced immune responses to infectious agents and skin cancers, but a potentially beneficial effect for some autoimmune diseases.*

UV radiation is absorbed by specific molecules called chromophores in the skin. These initiate a cascade of events affecting the immune system: decreasing the ability of specialised cells to recognise foreign challenges such as invading microorganisms or tumour proteins, altering the production of a range of immune mediators, and inducing the generation of particular lymphocytes called T regulatory cells. All of these changes lead to suppression of immune responses following the exposure.

Numerous animal models of infection have demonstrated that exposure to UV radiation at a critical time during infection can increase the severity of symptoms and duration of the disease. In addition, UV radiation before (and possibly immediately after) immunisation can reduce the immune response generated and therefore the effectiveness of the vaccination. How these observations relate to human diseases is currently not clear and remains a subject of intense interest and research. The results from a limited range of studies in humans indicate that exposure to UV radiation around the time of vaccination can decrease the immune response generated, at least in some groups of individuals.

Some examples in humans where UV exposure before or during infection suppresses immunity are recognised. In the case of cold sores caused by herpes simplex virus (Figure 9c), solar UV radiation is a common trigger for the reactivation of latent virus and the reappearance of the vesicles in the skin. Some immunological effects of UV radiation are also involved in the interaction between certain human papillomavirus types (these viruses typically cause warts) and the many viruses that promote formation of squamous cell carcinomas. The involvement of T regulatory cells in squamous and basal cell carcinomas indicate that UV-induced immunosuppression is an important factor in their development. In contrast, this down regulation in immunity is of potential benefit in protection against the development of some autoimmune diseases, such as multiple sclerosis, where there is an over-activity of T cells directed against specific elements of the body's own tissues.

Figure 9c. *Cold sores caused by reactivation of latent herpes simplex virus following exposure to solar UV-B radiation. Photograph supplied by Professor M. Norval (University of Edinburgh, Scotland).*

d. Are there any beneficial health effects of solar UV-B radiation?

A major benefit to human health of exposure to UV-B radiation is the production of vitamin D.

Although the diet of humans contains some items rich in vitamin D, such as oily fish and eggs, more than 90% of the vitamin D in most people is produced by exposure of the skin to solar UV radiation (Figure 9d). Vitamin D is synthesised most effectively when the sun is at its height in the summer months and little or none is synthesised in the winter at mid to high latitudes. Individuals with dark skin require more sun exposure than those with fair skin to make the same amount of vitamin D, and the production is less efficient in older subjects. It is important for many aspects of human health to maintain a sufficient level of vitamin D in the body. An assessment of this can be made by measuring the concentration of a vitamin D metabolite (25-hydroxyvitamin D) in the blood: a minimal cut-off value is recommended for optimal health benefits, below which some adverse effects could occur.

Vitamin D is required for the growth, development and maintenance of bone. Those individuals deficient in vitamin D can develop bone defects, resulting in an increased risk of osteoporosis and fractures in adults, and of rickets in children. Vitamin D has also been implicated in protection against a range of non-skeletal disorders. These include some internal cancers such as colorectal cancer, autoimmune diseases such as multiple sclerosis and insulin-dependent diabetes, infections such as tuberculosis and influenza, and cardiovascular diseases such as hypertension. The most convincing evidence to date for these protective roles has come from clinical trials involving dietary vitamin D supplementation, and it has yet to be confirmed that increased solar UV-B exposure, affecting vitamin D status, can modulate the risk of the disease.

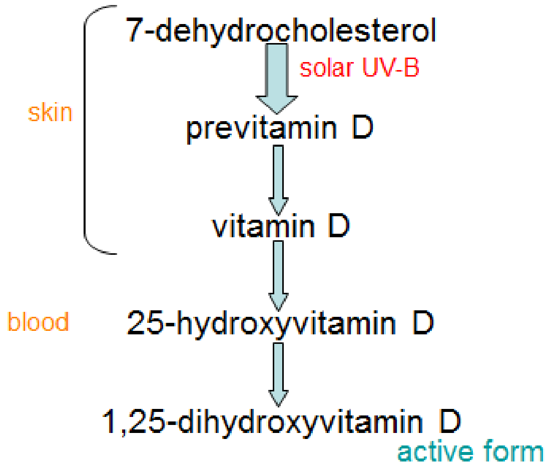

Figure 9d. *Simplified metabolic pathway leading to the active form of vitamin D (1,25-dihydroxyvitamin D).*

e. What risks do the breakdown products of HFCs and HCFCs present to humans and the environment?

The main breakdown product, trifluoroacetic acid (TFA) and other related short-chain fluorinated acids are presently judged to present a negligible risk to human health or the environment.

The hydrofluorocarbons (HFCs) and hydrochlorofluorocarbons (HCFCs) are replacements for the chlorofluorocarbons (CFCs) as they have a smaller effect on the ozone layer. The HFCs and HCFCs are largely degraded before reaching the stratosphere (Figure 9e).

HFCs and HCFCs break down relatively rapidly into several products including persistent substances such as trifluoroacetic acid (TFA) and chlorodifluoroacetic acid (CDFA). The compounds are soluble and are washed from the atmosphere by precipitation and reach surface waters, along with other chemicals washed from the soil. Microbiological degradation slowly removes these substances from the water. In locations where there is little or no outflow and high evaporation (seasonal wetlands and salt lakes), these products are expected to increase in concentration over time.

The effects of increased concentrations of naturally occurring mineral salts (from natural sources such as undersea vents and volcanic activity) and other materials would be greater and more biologically significant than those of breakdown products of the HFCs and HCFCs. TFA is very resistant to breakdown, and amounts deposited in flowing surface water will ultimately accumulate in the oceans. However, based on estimates of current and future use of HFCs and HCFCs, additional inputs to the ocean will add only fractionally (less than 0.1%) to amounts already present.

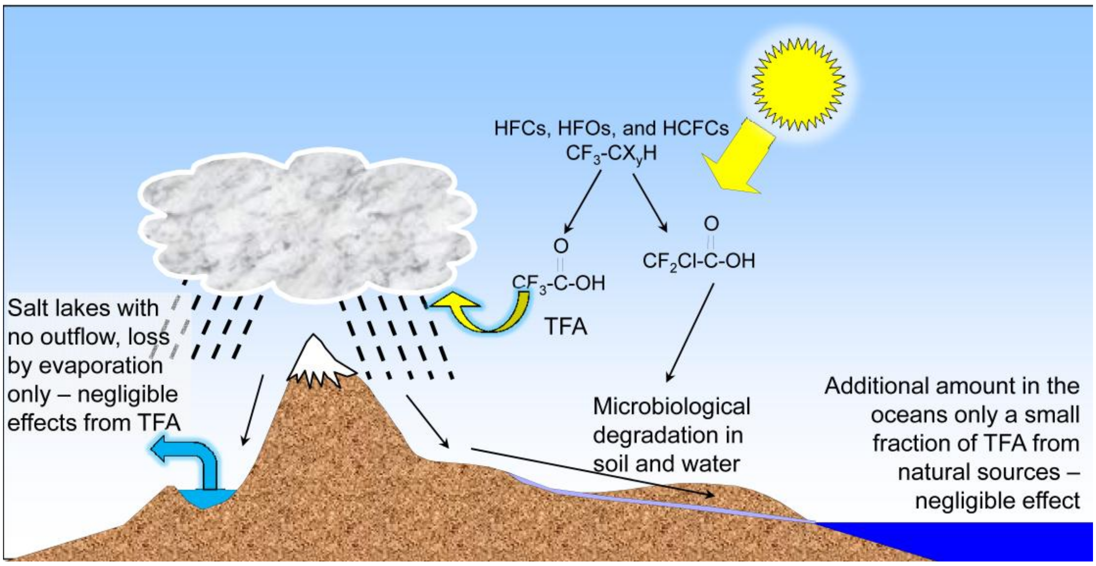

Figure 9e: *The breakdown of CFC replacements into TFA. (Figure provided by Prof K Solomon.)*

f. How can I protect myself from the adverse effects of solar UV-B radiation on the skin?

Many protective strategies against excessive exposure to sunlight have been developed, particularly to avoid sunburn.

The intensity of UV-B radiation from the sun is usually highest during the central hours of the day (about 10 am until 2 pm) or later in periods of daylight savings). Many news outlets and government websites report the daily UV Index, and issue alerts when high values are predicted (see question 5).

If you are outside, it is most important to avoid sunburn. The time taken to reach this point depends on many variables including your ability to tan in response to sunlight. The popular advice “to slip (on a shirt), slap (on a hat), slop (on some sunscreen)” and wrap (add wrap-around sunglasses), is useful (Figure 9f). Hats with brims more than 10 cm wide are recommended for head and neck protection, and can reduce exposure of the eyes by up to 50%. The hood of a jacket and headwear with side-flaps can provide protection from side UV-B irradiation. Wrap-around sunglasses are better at protecting the entire eye than conventional sunglasses with open sides.

Protection of the body with suitable clothing is recommended when outside during the central hours. Some textiles are highly effective in this regard while others are less so. Sunscreens are also effective and ones with a sun protection factor of 30 are generally recommended. They need to be applied at the stated concentration and to be frequently re-applied, especially when swimming. It is particularly important to protect children from sunburn, episodes of which could lead to an increased risk of skin cancer development in adulthood. The use of sun protection is recommended when the UV Index is forecast to be 3 or greater.

Note the wide brimmed hat, wrap-around glasses and textile clothes. The face and exposed arms should be protected by the use of the correct sunscreen.

Figure 9f: *Wearing the correct clothing and the use of sunscreen can protect against UV radiation. (Photograph supplied by Dr A. Cullen, University of Waterloo, Canada.*

g. How much time should I spend in the sun in order to produce sufficient vitamin D but avoiding sunburn and minimising the risk of skin cancer?

There is no short and simple answer to this question but some guidance is given below.

The time will depend on the latitude, season, time of day, weather conditions, the amount of skin exposed and whether your skin is accustomed to exposure. You should also know your skin type (see question 9b) and recognise how readily you burn or tan as a result of sun exposure. Most importantly, sunburn should be avoided, particularly in children. One useful guide is to find out the daily forecast for the noon UV Index (see question 5) for your location. In many countries the UV Index is reported in weather forecasts on the radio and TV and in newspapers, and can also be found on various websites. The UV Index at times other than noon is lower unless there is a big change in cloudiness.

Estimates of the daily variations in sunburning UV radiation and in the UV radiation needed to make vitamin D at mid-latitudes are shown in Table 9g.

Some calculations have been made giving an indication of the number of minutes in the sun required to cause sunburn, and the number required for adequate vitamin D production for various UV Indices at various latitudes in the summer and winter. The values below should be taken as a rough guide only, and are for times around noon and for (previously unexposed) skin type II. They should be multiplied by 2 for skin type IV and by 5 for skin type VI.

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Table 9g: Estimates of daily variations in sunburning UV radiation and in the UV radiation needed to make vitamin D at mid-latitudes.

	Minutes to sunburn	**Minutes for sufficient vitamin D, full body exposure**	**Minutes for sufficient vitamin D, 10% body exposure**
Mid-latitude, summer UV Index 12	15	1	10
Mid-latitude, winter UV Index 1	180	20	200
Tropics UV Index 16	10	<1	7

h. Will global climate change alter the effects of UV radiation on human health?

While there are clear concerns about the health effects of global climate change through, for example, increasing temperatures and changes in the distribution of some vector-borne diseases, it is not possible at the present time to predict whether climate change will affect UV-related health issues.

In trying to assess possible interactions between climate change and solar UV radiation, the major uncertainty for human health is whether people will spend more or less time outdoors in sunlight as temperatures rise, but humidity, storms, floods and droughts also increase. One animal study suggests that the risk of skin cancer is greater for the same level of UV radiation exposure if the ambient temperature increases; there is some support for a similar finding in human populations living in different regions (Figure 9h). Exposure to UV radiation in sunlight can be important for disinfection of waterborne pathogens, which may grow and survive better in warmer conditions.

If warmer temperatures encourage people to spend more time outside, it will be important to ensure adequate sun protection. In contrast, if more time is spent indoors, vitamin D may need to be provided as a dietary supplement.

Climate change may alter the effects of UV radiation on terrestrial and aquatic ecosystems to change the availability or quality of human food supplies, with resulting effects on human health. In addition, climate-induced changes in air pollution have potential health effects, but these remain highly uncertain.

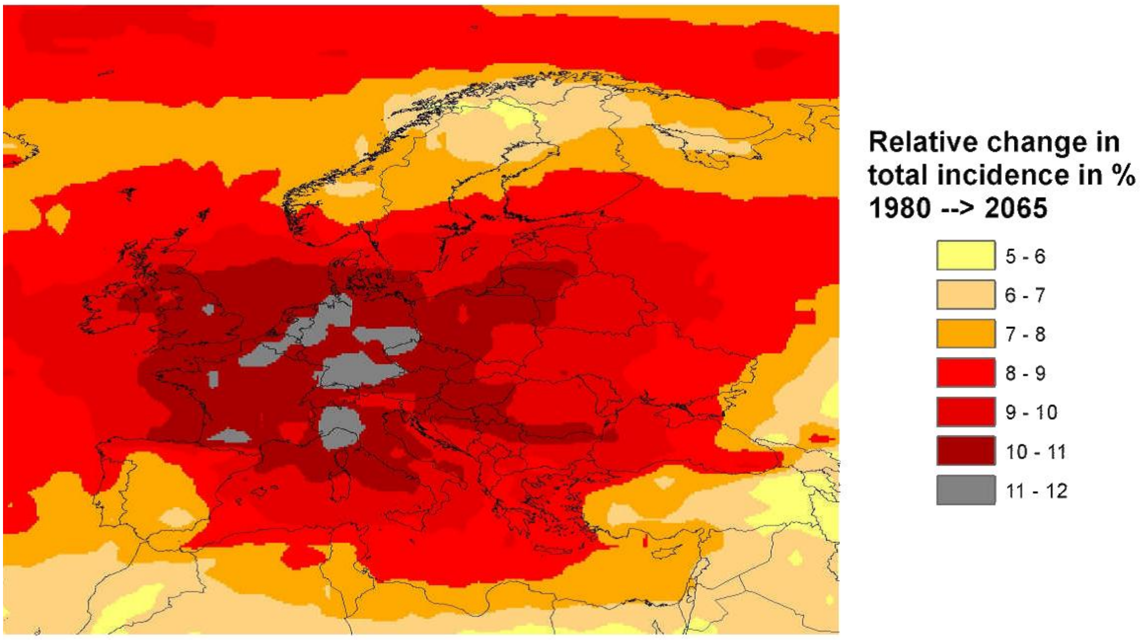

Figure 9h: *The predicted relative change in total skin cancer incidence from 1980 to 2065 in Europe. (From: Figure 5.16. Relative change in total skin cancer incidence from 1980 to 2065 for the A1 scenario, based on the AMOUR2.0 assessment model, RIVM in http://www.rivm.nl/bibliotheek/rapporten/610002001.html).*

Q10. Effects on the Environment

a. What are the major impacts of UV-B radiation on natural terrestrial ecosystems, crops and forests?

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i) *UV-B radiation causes a wide range of responses in terrestrial ecosystems. Animals can move to avoid UV-B radiation but plants cannot. However, most plants (including crop and forest species) have mechanisms that provide some UV shielding.*

Vital biomolecules, including DNA, proteins, and lipids, are potentially vulnerable to UV-B radiation. However, only a small portion of the UV-B radiation striking a leaf penetrates into the inner tissues. In the majority of plant species tested, UV-B radiation induces the synthesis of compounds that act as sunscreens and prevent UV-B radiation from reaching sensitive biological components within the leaves. Other adaptations include increased thickness of leaves, thereby reducing the proportion of inner tissues exposed to UV-B radiation, and changes in the protective waxy layer of the leaves. Plants also have several mechanisms for repairing damage to DNA.

Some protective molecules produced by plants, in response to natural UV-B radiation, are important in our food, enhancing colours, flavours, antioxidant activity and fibre production (see Figure 10a-1). Some of the changes in plant biochemistry induced by UV-B radiation influence the interactions between crop plants and herbivorous insects. The change in biochemical composition can make the leaves less attractive as food for herbivores (including for insect pests) and alter the speed with which leaf litter is broken down in the soil. At an ecosystem level, these effects on palatability and decomposition can be substantial, since they have an impact on the food supply of animals and the recycling of nutrients in the soil.

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ii) *UV radiation has impacts that go beyond the individual plant and can affect ecosystem processes. Changes to plant composition, induced by UV-B radiation, can flow through to the animals and microbes (bacteria and fungi) that rely on plant matter for food.*

The negative effect of UV-B radiation on the food supply of plant-eating insects can be substantial. Some of the reduced consumption is due to direct effects of UV-B radiation on insects and some due to changes in plant tissues induced by the UV-B radiation. Under enhanced UV-B radiation, sunscreen compounds both protect the plant from the UV-B radiation directly and deter insects from eating the plant (herbivory). This means that if UV-B radiation is higher, insects generally eat less plant material. By contrast, higher atmospheric CO_2 leads to increased herbivory, so future levels of UV-B irradiance and CO_2 will be important in controlling both plant production and the food supply for insects.

The changes that occur at the plant level can influence underground decomposition. Decomposition of dead plant material (leaf litter) is a vital process, since it recycles carbon and nutrients making them available to growing plants. UV radiation affects decomposition indirectly via changes to leaf biochemistry and microbial diversity and directly through light-induced breakdown (photodegradation).

Sunscreen compounds and structural alterations, which allow leaves to withstand UV-B radiation while attached to the plant, can make leaves tougher to break down once they form leaf litter. UV-B radiation changes the composition of the microbes in the soil and this can also influence how easily leaf litter is broken down. When plant litter is directly exposed to sunlight, it is degraded photochemically (photodegradation). Changes to both microbial and photodegradation breakdown processes have important consequences for future carbon sequestration and nutrient cycling.

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iii) Some types of crops and wild plants may show detrimental effects from increased UV-B radiation.

It is possible to breed and genetically engineer UV-B tolerant crops. While many forest tree species appear to be UV-B tolerant, there is some evidence that detrimental UV-B effects accumulate slowly from year to year in certain species.

The present rate of global change is so rapid that evolution may not keep up with it, particularly in high latitudes where temperature and UV-B radiation have increased dramatically over recent decades. In Antarctica and the southern tip of South America, plants adapted to environments with relatively low levels of UV-B radiation have been affected by the increased levels of UV-B radiation due to ozone depletion (see Figure 10a-2). Although the negative impact of UV-B radiation on plant growth is usually relatively small (about 6%), some species are more affected than others. Over time, these differences between species may lead to changes in terrestrial ecosystems, especially in regions like Antarctica where UV-B radiation is likely to remain elevated for many more decades.

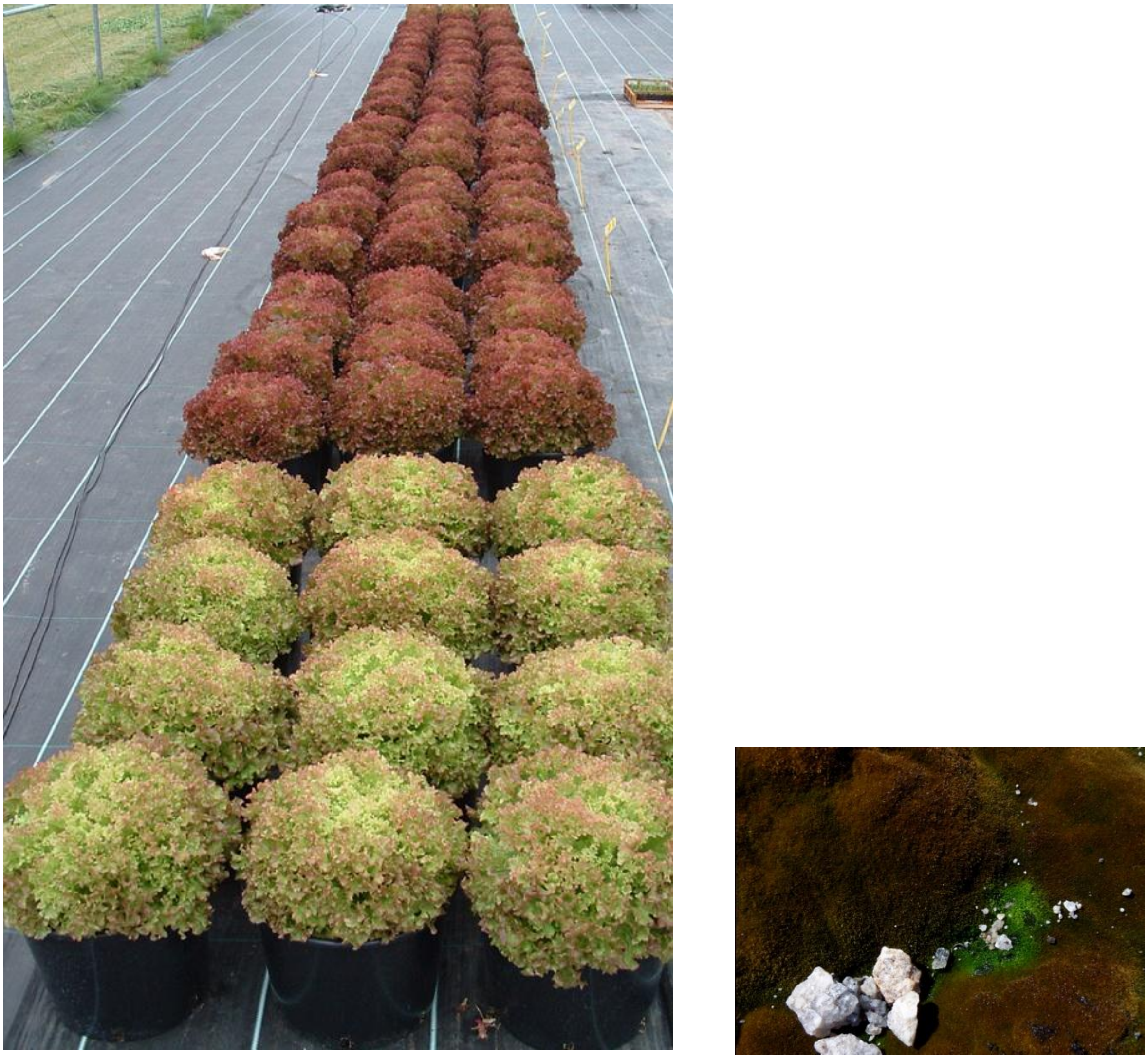


Figure 10a-1: *Other examples of protective molecules produced by plants, in response to UV radiation include the red pigments seen in lettuces (left panel), while those shielded from UV are mostly green. Similarly, Antarctic mosses (right panel) shielded by small stones are green (centre), while the plants around them produce protective red pigments. These protective compounds can be important components of our foods. (Photograph of lettuce from Prof. N. Paul, University of Lancaster, UK, others Prof. S. Robinson, University of Wollongong, Australia).*

Figure 10a-2: *Impacts of UV-B radiation on terrestrial ecosystems. Ozone depletion has led to higher UV fluxes over Antarctica with negative effects on some species of Antarctic plants, such as the mosses seen growing along this icy stream. (Photograph from Prof. S. Robinson, University of Wollongong, Australia)*

b. Does exposure to UV-B radiation affect aquatic life?

UV-B radiation can penetrate to ecologically significant depths in the clearest natural waters and have an effect on the aquatic life.

In clear ocean and lake waters, UV-B radiation can penetrate to tens of metres. In turbid rivers and wetlands, however, UV-B radiation may be completely absorbed within the top few centimetres. In aquatic ecosystems, most organisms, such as phytoplankton, live in the illuminated upper layer of a body of water that allows the penetration of enough light (and UV-B radiation) to support photosynthetic, or green, plants. In particular, UV-B radiation may damage those organisms that live at the surface of the water during their early life stages.

Detrimental effects of UV-B radiation have been shown for phytoplankton, fish eggs and larvae, zooplankton and other primary and secondary consumers. Most adult fish are well protected from excessive solar UV radiation, since they inhabit deep waters. Some shallow-water fish can develop skin cancer and other UV-related diseases.

UV-B radiation reaches different depths in ocean water depending on water chemistry, the density of phytoplankton, and the presence of dissolved and particulate matter. Figure 10b shows the average depth that UV-B radiation penetrates into ocean water. At the depth indicated, only 10 per cent of the UV-B radiation that was present at the water's surface remains. The rest was absorbed or scattered back towards the ocean surface.

In the Gulf of Maine, UV radiation penetrates to considerable depth where the embryos and larvae of the Atlantic cod develop. Exposure to UV radiation equivalent to that present at 10 m depth results in a significant mortality of developing embryos and a significant decrease in the length of the larvae. Such radiation levels occur at many temperate latitudes where these ecologically and commercially important fish spawn. In freshwater lakes and ponds, amphibian embryos are protected from UV-B radiation by the enzyme photolyase, melanin pigmentation of eggs, jelly surrounding the eggs, the water depth and dissolved organic matter in the water. Larvae can seek shelter from sunlight by swimming into shaded areas and vegetation in ponds. In contrast, lobster larvae seem to be tolerant to UV radiation even though they develop in the surface layers of the water column.

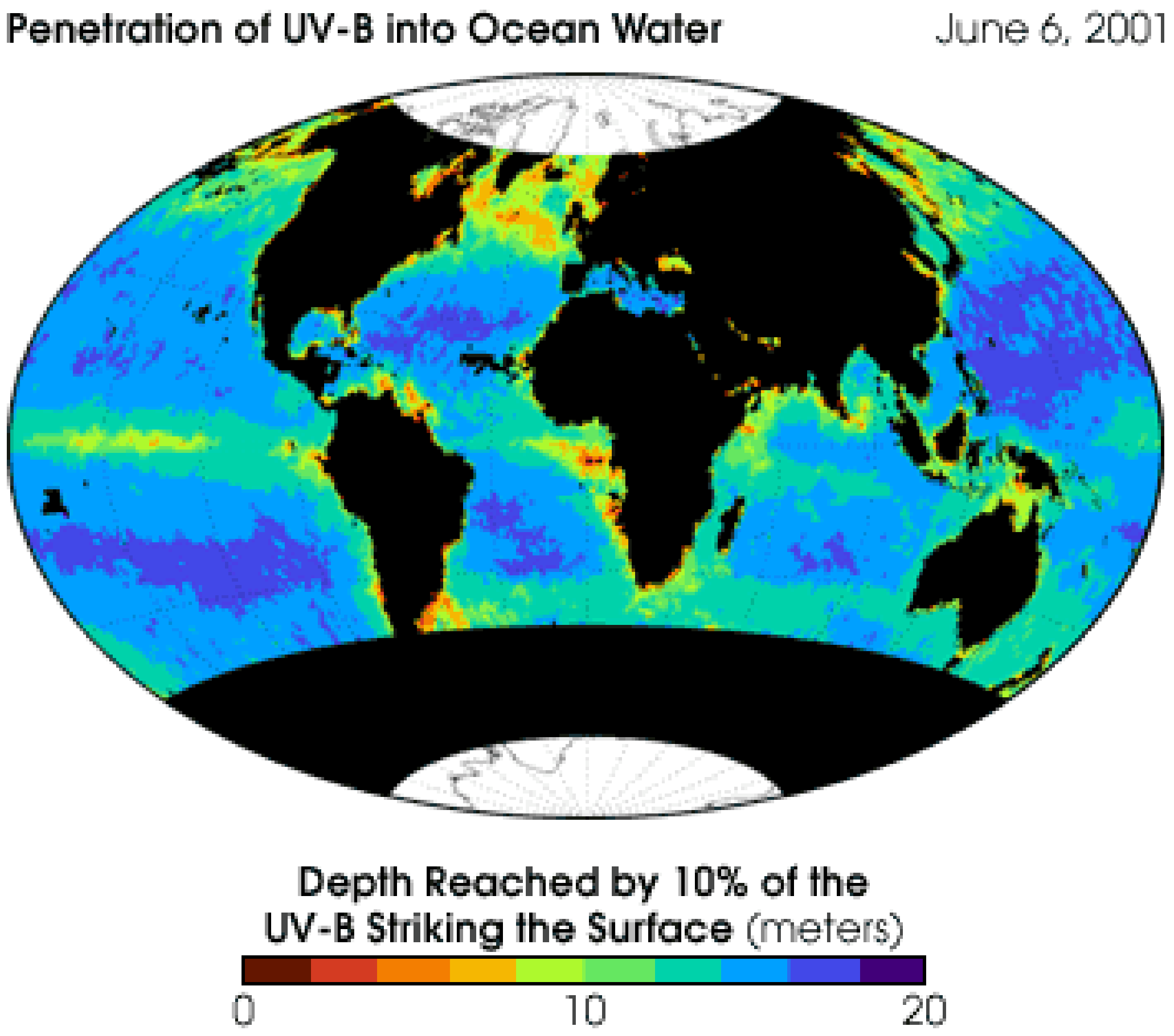


Figure 10b: *The penetration of UV-B radiation into the global oceans by indicating the depth to which 10% of surface irradiance penetrates. (Image courtesy of Vasilkov et al. J. Geophys. Res. Oceans, 2001106, 205-227).*

c. Does climate change alter the effect of UV radiation on aquatic ecosystems?

Climate change will influence various aspects of how UV-B radiation affects aquatic ecosystems, such as through changes in temperature and sea-level, shifts in the timing and extent of sea-ice cover, changes in the wave climate, ocean circulation and salinity and alterations in the stratification of the water column.

These complex changes are likely to have significant effects on ecosystems, including biological production as well as changes in the global hydrological cycle, vertical mixing and efficiency of carbon dioxide uptake by the ocean (Figure 10c). Such effects will vary over time and between different locations. Changes in temperature and the intensity and frequency of rainfall may alter the input of terrestrially-derived coloured dissolved organic matter (CDOM) to inland and coastal aquatic ecosystems. For example, decreased rainfall and increased temperature cause reductions in CDOM inputs and consequent increases in the depth to which UV radiation penetrates. In addition, the dissolved and suspended material in the water column changes the ratio of UV-A to UV-B to photosynthetically active radiation (PAR) in the penetrating UV radiation. These changing ratios, in turn, have various influences on decomposers, producers and consumers.

Climate change influences the amount of ice and snow cover in polar and sub polar areas. Ice and snow strongly attenuate the penetration of solar radiation into the water column. Any substantial decrease in ice and snow cover will alter the exposure of aquatic ecosystems to solar UV radiation.

Shifts in atmospheric circulation will change wind fields, influencing mixing and the depth of the upper mixed layer of the ocean. Such changes, and increases in temperature, affect the stratification of the surface layer of the ocean and the potential impact of UV-B radiation on near-surface organisms. Changing winds will also influence coastal upwelling systems and the potential for possible influence of these systems on UV radiation Additionally, many physiological responses are dependent on temperature, providing another route whereby climate change may interact with the effects of UV radiation.

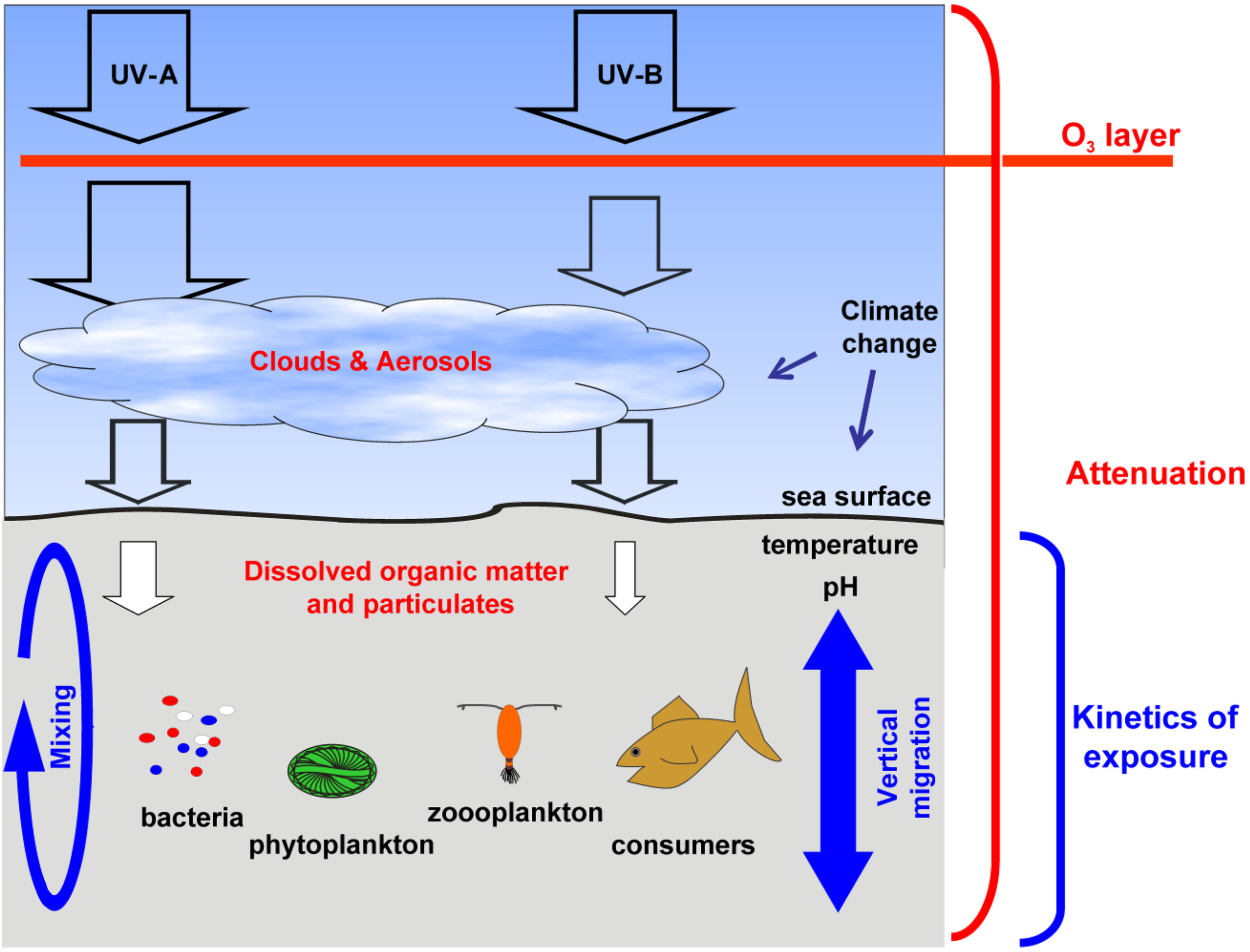


***Figure 10c:** Main factors affecting the quantity and quality of UV radiation received by aquatic organisms (Diagram modified from Gonçalves et al. Ecología Austral., 2010, 20, 129-153).*

d. Do increasing atmospheric CO_2 concentrations influence the sensitivity of aquatic organisms to solar UV-B radiation?

Several marine organisms protect themselves from solar UV-B radiation by producing a calcified outer layer; the increasing acidification of lakes and marine habitats impairs the calcification process.

Acidification of lakes and oceans is a major stress factor closely related to climate change and solar UV-B radiation. Increasing acidification of marine waters due to increased atmospheric CO_2 concentrations hampers carbonate incorporation in many calcified marine organisms and makes them more vulnerable to solar UV-B radiation. Before industrialization, the concentration of CO_2 in the atmosphere was about 280 ppmv (parts per million by volume). This corresponded to an average pH in the oceans of about 8.2. The current level of 390 ppmv CO_2 has lowered the pH of the water by about 0.1 units, which corresponds to 26% increase in acidity. A further pH decrease of 0.3 – 0.4 units is expected by the year 2100. This acidification is expected to adversely affect the uptake and incorporation of calcium carbonate in molluscs, phytoplankton and some seaweeds. Encrustations of calcium carbonate efficiently absorb UV radiation. At lower pH values, increased UV transmission will expose the vulnerable organisms to higher levels of solar UV-B radiation. Experiments have shown that UV radiation significantly inhibits growth, photosynthetic oxygen evolution and calcification rates in the seaweed *Corallina* at high CO_2 concentrations (1000 ppmv as compared to 390 ppmv). In one of the major biomass producers in the ocean (the coccolithophore, *Emiliania huxleyi,* Figure 10d), calcification rates are diminished by increased acidity, resulting in thinner protective scales (coccoliths) on the surface. The transmission of UV radiation is significantly higher because of the acidification (by 0.1 pH units).

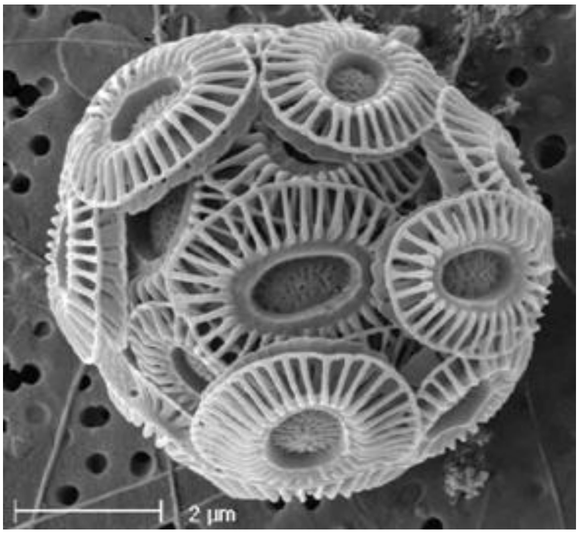


Figure 10d: *Scanning electron micrograph of the phytoplankton coccolithophore Emiliania huxleyi covered with coccoliths. Courtesy of Kunshan Gao, Xiamen, China.*

e. What effects does the depletion of ozone have on environmental processes and cycles?

Changes in UV-B radiation cause complex alterations to atmospheric chemistry, and thus affects the entire biosphere, with consequences for all organisms on Earth, including humans.

UV radiation influences the biological productivity of oceans, including the production of gases at their surfaces and their subsequent transfer to the atmosphere. Once in the atmosphere, gases such as carbon dioxide (CO_2) interact with the physical climate system resulting in alterations to climate and feedbacks in the global biogeochemical system (Figure 10e). Since atmospheric CO_2 plays a central role in the distribution of heat in the atmosphere, its increasing concentrations may affect many components of the physical climate system, such as wind, precipitation and the exchange of heat and energy between the air and the oceans.

There are also similarly complex interactions between biogeochemical cycles on land and the integrated climate system that may have important implications for organisms on Earth. At this stage, it is not possible to predict the overall environmental effects of these complex interactions between changes in climate and UV radiation.

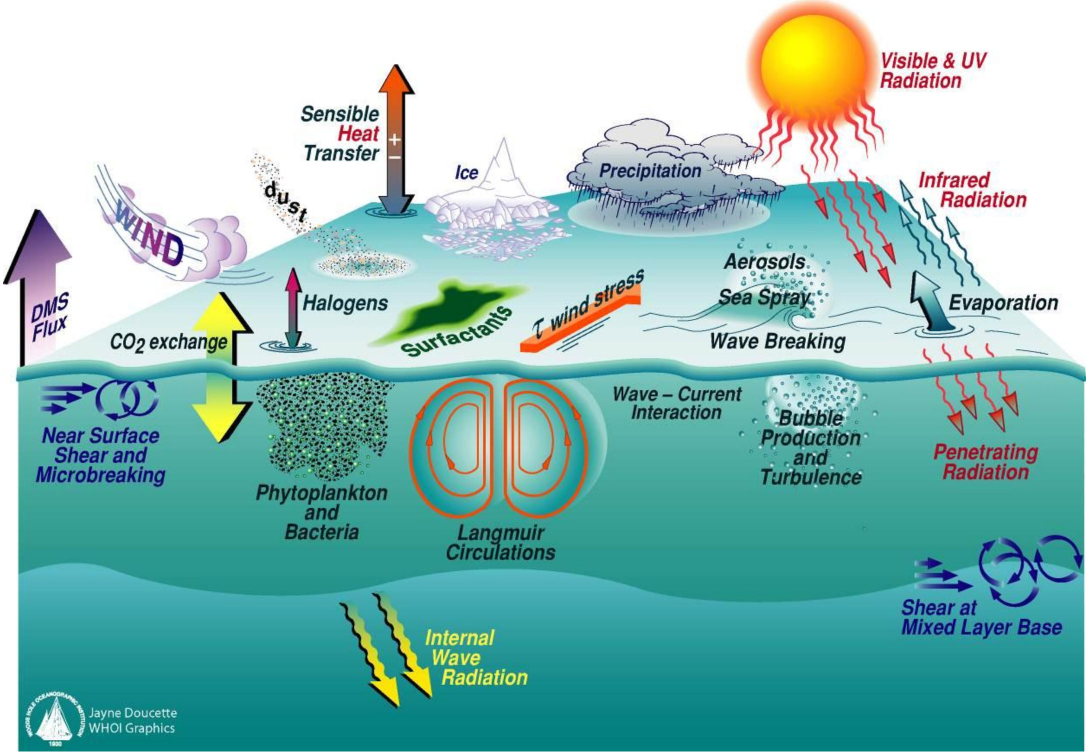


Figure 10e: *Interactions between environmental processes and cycles. (Figure provided by the US Surface Ocean Lower Atmosphere Study (SOLAS) and the WHOI).*

Q11. Can the increased temperature due to global warming increase the deleterious effects of UV-B radiation on plastics and wood products used outdoors?

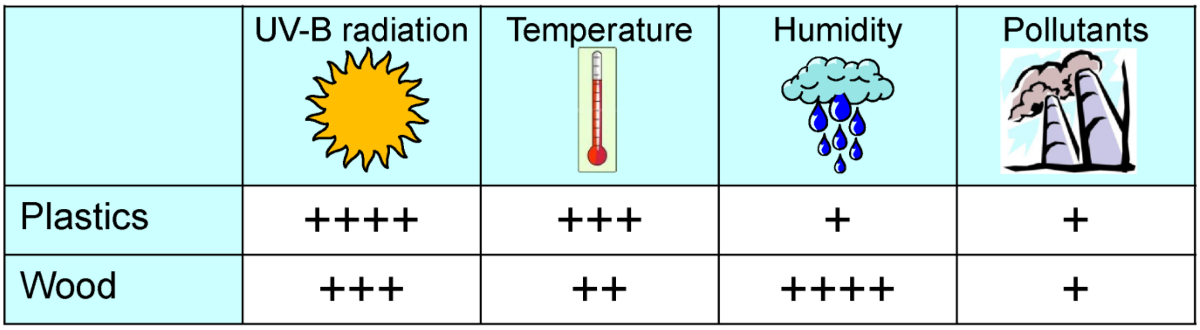
Yes, climate change can have a detrimental effect on plastics and wood products used outdoors.

Useful lifetimes of plastic and wood products are determined to a large extent by degradation due to the action of solar UV radiation (Table 11). A partial depletion of the stratospheric ozone layer results in increased terrestrial UV-B flux, affecting organic materials used in construction. Plastics materials undergo oxidation and chemical breakdown when exposed to UV-B radiation in the atmosphere. This is well known to result in discolouration, surface cracking and loss of strength or stiffness in the product, limiting its useful lifetime. Additives called light stabilizers are used to partly mitigate the deleterious effects of UV-B radiation in plastics used outdoors. Similar degradation and breakdown occurs in wood products, although here biodegradation also contributes to the deterioration very significantly. The action of UV-B radiation on the surface of wood also renders it hydrophilic; rainwater is better absorbed by the surface, leading to the growth of wood-rot fungi that biodegrade the wood. Photodamage by UV-B radiation facilitating fungal biodegradation is seen in wood-plastic composites (or plastic lumber) that are essentially plastics mixed with large amounts of wood flour.

Climate models suggest that near-surface air temperatures will rise anywhere from 2°C to 6°C during the 21st century due to accumulation of greenhouse gases. The rates of chemical reactions that cause the UV-initiated oxidative degradation of plastics or wood are increased at higher temperatures. Thus the useful lifetimes of these materials outdoors will shorten as the ambient air temperature increases. The extent to which this happens depends on the temperature sensitivity of the reaction and varies from material to material. The change can be significant for plastics exposed in geographic locations with already high UV-B radiation that experience higher ambient temperatures.

The change of a few degrees in temperature is already found in seasonal variations. Plastics with a deeper colour exposed to sunlight reach bulk temperatures higher than those of light-coloured products of the same plastic. While the oxidative breakdown will indeed be faster, the available light-stabilizer technologies are likely to control this, thus maintaining the useful lifetimes at the present levels. Because of the need to use higher levels of conventional stabilizers or coatings, the cost of preservation may be higher in some locations.

Table 11: Several environmental factors affect the outdoor degradation of materials



	UV-B radiation	Temperature	Humidity	Pollutants
Plastics	++++	+++	+	+
Wood	+++	++	++++	+

++++ Very susceptible, +++ Moderately Susceptible, ++ Susceptible, + Likely to be susceptible (illustration from Dr. A. Andrady).

Q12. Ozone and Climate

a. Do ozone depleting gases and their substitutes have an effect on climate"?

Stratospheric ozone depletion has an influence on climate change since both ozone and the compounds responsible for its depletion are active greenhouse gases.

Ozone depleting substances (ODSs) such as the CFCs have contributed to increases in global average surface temperature. On the other hand, ozone depletion itself has a cooling effect. Warming due to ODSs and cooling associated with ozone depletion are two distinct climate forcing mechanisms that do not simply offset one another. Bromine-containing gases currently contribute much less to warming than to cooling, whereas CFCs and HCFCs contribute more to warming than to cooling. HFCs and PFCs contribute only to warming.

Actions taken under the Montreal Protocol have led to the replacement of CFCs with HCFCs, HFCs, and other substances. Because replacement species (with the exception of HFCs) generally have lower global warming potentials (GWPs) and because total halocarbon emissions have decreased, their contribution to climate change has been reduced (Figure 12a). Ammonia and hydrocarbons used as halocarbon substitutes will have a negligible effect on global climate. The relative future warming and cooling effects of emissions of CFCs, HCFCs, HFCs, PFCs and halons vary. The indirect cooling effect of ODSs is projected to cease upon ozone layer recovery, so that GWPs associated with the indirect cooling effect depend on the year of emission, compliance with the Montreal Protocol and gas lifetimes.

Substitution for ODSs in air conditioning, refrigeration, and foam blowing by HFCs, PFCs, and other gases such as hydrocarbons are not expected to have a significant effect on global tropospheric chemistry.

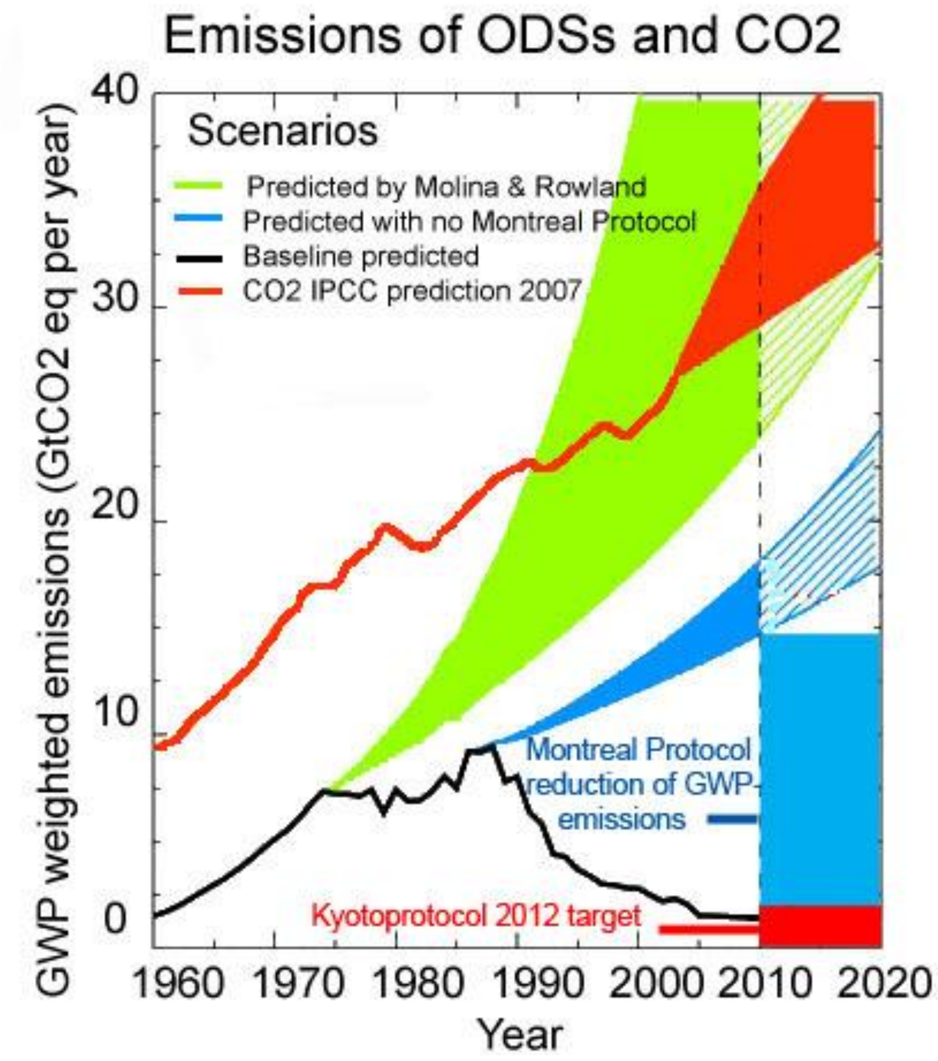


Figure 12a: *An illustration of the reduction in global warming by the Montreal Protocol compared with what was expected by the Kyoto Protocol on Climate Change (Based on a figure provided by Dr Mack McFarland based on Velders, et al. Proc. Nat. Acad. Sci. USA., 2007, 104, 4814–4819).*

b. Is ozone depletion affected by climate change?

Climate change affects ozone depletion through changes in atmospheric conditions that affect the chemical production and loss of stratospheric ozone. The interactions are complex (see Figure 11b). Climate change is expected to decrease temperatures and water vapour abundances in the stratosphere. This will tend to speed up ozone recovery outside Polar Regions, but slow down the recovery in Polar Regions

Ozone, the CFCs and their substitutes are minor greenhouse gases with a relatively small (± 13%) contribution to climate change. Several other gases involved in the chemistry of ozone depletion are also active greenhouse gases. They include water vapour, methane, and nitrous oxide. Increases in those will ultimately lead to increases in stratospheric gases that destroy ozone. Changes in solar output and future volcanic eruptions will influence both climate change and ozone depletion.

While current ozone depletion compared with periods prior to the 1980s is dominated by chlorine and bromine in the stratosphere, in the longer term (~100 years) the impact of climate change will dominate through the effects of changes in atmospheric circulation and chemistry (Figure 12b). The result is that over the first half of the current century, increases in greenhouse gases may contribute to a colder stratosphere. This will lead to a decrease in the rate of destruction of ozone outside Polar Regions. In Polar Regions, however, the lower temperatures may lead to increased polar stratospheric clouds, thus exacerbating ozone depletion. The temperature changes will also lead to changes in atmospheric circulation. These changes may aid the mixing of long-lived CFCs from the troposphere to the stratosphere, which will increase their rate of photochemical destruction. This will lead to more severe ozone depletion in the short term but will contribute to a faster ultimate recovery of ozone. Changes in polar ozone also can lead to changes in circulation patterns in the lower atmosphere, which in turn affect surface climate. The effects of climate change on UV radiation are twofold: those that influence total ozone directly (and thus indirectly affect UV radiation), and those that depend on changes in other variables (such as clouds, aerosols or snow cover that influence solar UV radiation directly).

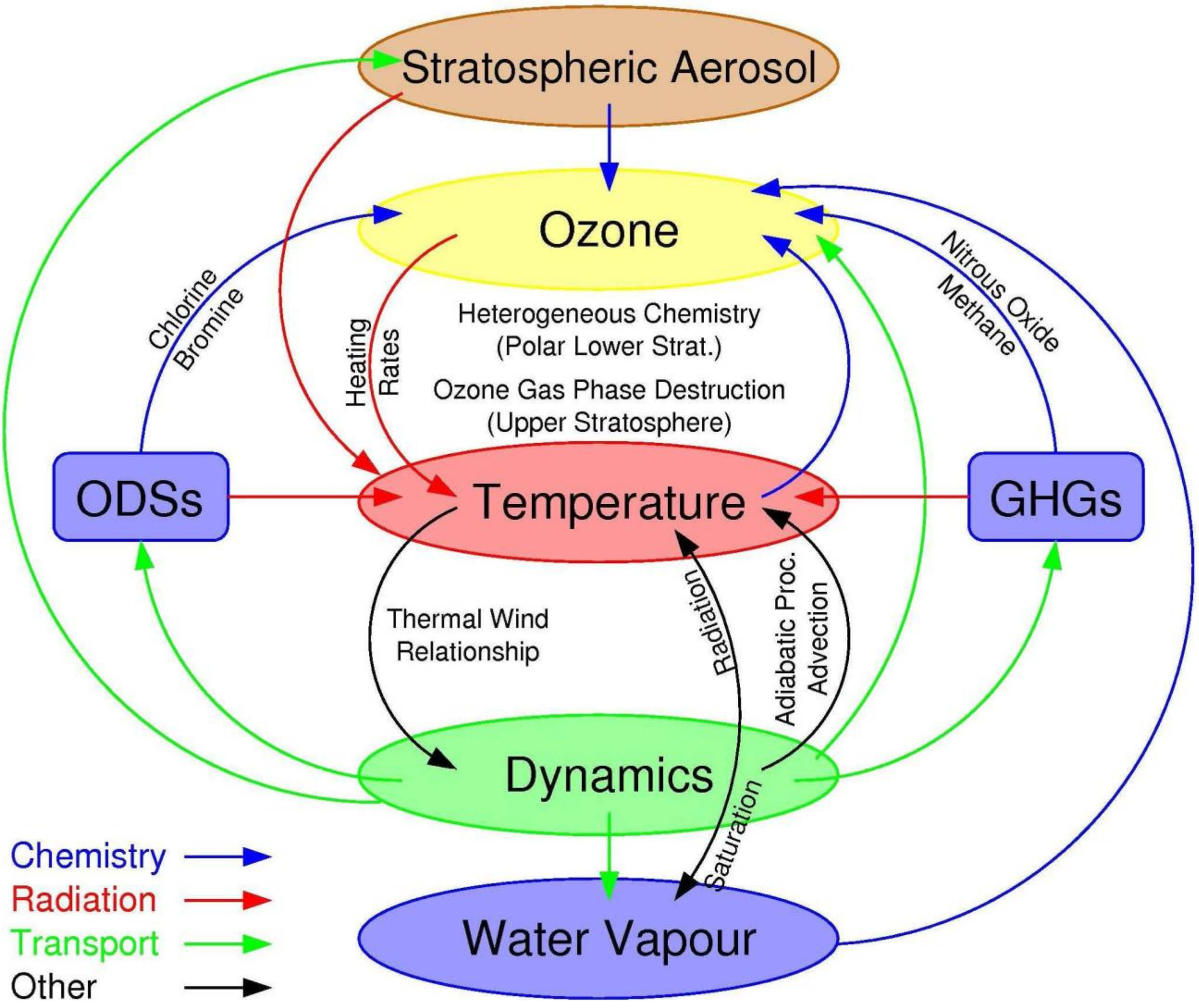


Figure 12b: *Schematic of ozone focused stratospheric chemistry-climate interactions. Links between components of the chemistry-climate system are indicated with arrows representing chemistry (blue), radiation (red), transport (green) and other mechanisms (black). A simple example is ozone depletion in the upper stratosphere leading to lower temperatures. Lower temperatures slow down the gas phase destruction of ozone, thus reducing the amount of ozone depletion. Feedback cycles not originating from ozone, but e.g. dynamics, are possible as well: "Dynamics" moderates the distribution of GHGs (e.g. the meridional gradient of N_2O, nitrous oxide), this changes temperature directly (radiation) and indirectly (chemistry, via a change in ozone) and the changing temperature will alter the dynamics (e.g. via the thermal wind relationship) and ozone (e.g. in a colder upper stratosphere ozone gas phase destruction will slow down leading to increased ozone values). The feedback loops involving volcanic aerosol in the stratosphere are sporadic and currently not important.*

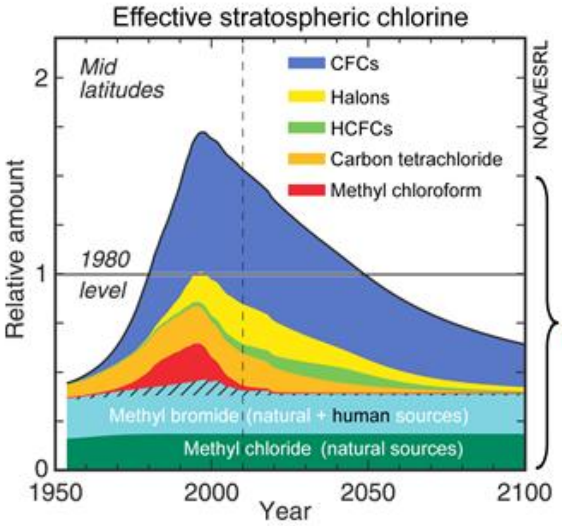
Q13. Are the control measures in the Montreal Protocol working? What is the world we avoided?

a. Phase-out of ODS

Yes the Montreal Protocol has been very successful.

The Montreal Protocol for the Protection of the Ozone Layer is the most successful environmental international agreement to date. It has been ratified by all of the 196 countries of the world. All the CFCs have been phased out since January 2010. The phase-out of the HCFCs is on schedule and has been advanced.

The detail of the phase-out achieved and the predictions of future halocarbon concentrations in the stratosphere can be found in the Scientific Assessment Panel's 2010 report. Stratospheric ozone is no longer decreasing and is predicted to return to pre-1980 values before 2050 at mid-latitudes and a few years later at high latitudes. Concentrations of ozone depleting substances have been decreasing for over ten years, and are expected to continue to decrease in the future (Figure 13a).



The Montreal Protocol has slowed and reversed the accumulation of ozone depleting substances (ODSs) in the stratosphere as measured by effective stratospheric chlorine amounts.

Figure 13a: *The measurement of past and predicted future concentrations of halocarbons in the stratosphere (Reproduction of Fig. 5.1 in the Scientific Assessment of Ozone Depletion: 2010* http://us-cdn.creamermedia.co.za/assets/articles/attachments/29653_898_executivesummary_emb.pdf).

b. UV Radiation changes

The Montreal Protocol had a huge influence on UV B radiation.

The Montreal Protocol for the Protection of the Ozone Layer is the most successful environmental international agreement to date. It has been ratified by all of the 196 countries of the world. All the CFCs have been phased out since January 2010. The phase-out of the HCFCs is on schedule and has been advanced.

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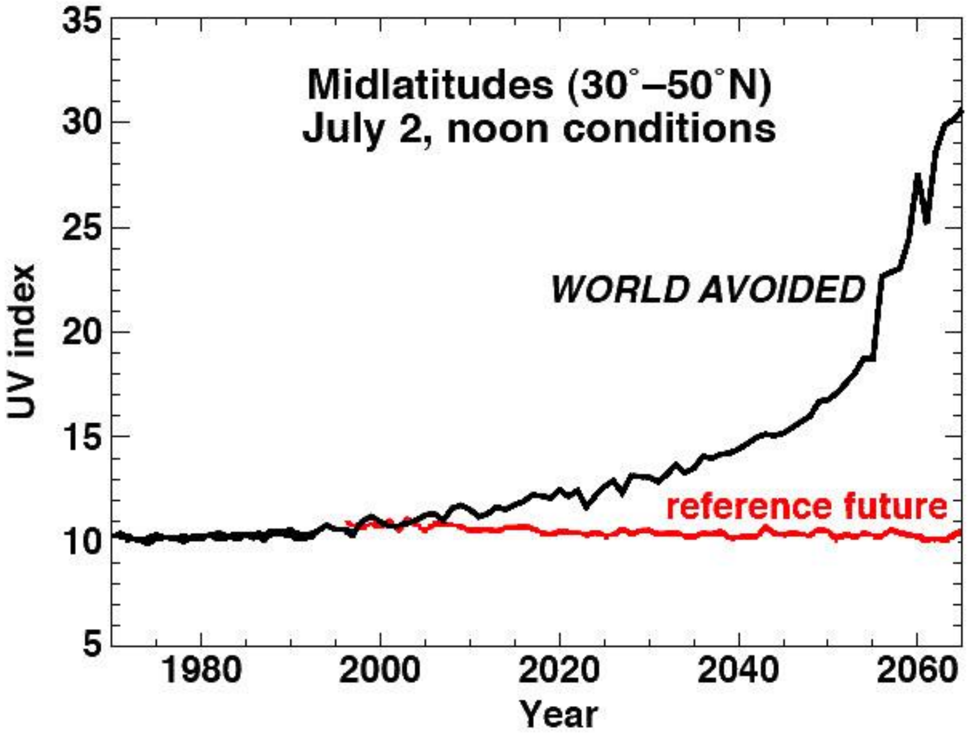

Figure 13b: Prediction of the UV Index indicating what could have happened in the absence of a Montreal Protocol from Figure 5.11 Scientific Assessment of Ozone Depletion: 2010.
http://us-cdn.creamermedia.co.za/assets/articles/attachments/29653_898_executivesummary_emb.pdf)

c. Effect on the climate

As a result of the phase-out schedules of the Montreal Protocol, the global production and use of chlorofluorocarbons (CFCs) and halons has decreased significantly. However, the sustained growth in demand for refrigeration, air-conditioning and insulating foam products in developing countries has led to an increase in the consumption and emissions of hydrofluorocarbons (HFCs). Consequently the use of HCFCs and HFCs as replacements for CFCs and halons has increased. The HCFCs are low-ozone-depletion-potential substitutes for high-ozone-depletion-potential substances, particularly CFCs and halons, and were classified under the Protocol as "transitional substitutes" during the time it took to commercialize new ozone-safe alternatives and replacements. Ultimately, HCFCs will be phased out globally under the Montreal Protocol leaving much of the application demand for refrigeration, air conditioning, heating and thermal-insulating foam production to be met by HFCs. The demand for HCFCs and/or HFCs in many applications is expected to increase. HFCs do not deplete the ozone layer but, along with CFCs and HCFCs, are greenhouse gases that contribute to the radiative forcing of climate. Thus, the transition away from ozone depleting substances (ODSs) has implications for future climate. HFCs are in the "basket of gases" regulated under the 1997 Kyoto Protocol, a global treaty to reduce developed-country emissions of greenhouse gases.

Figure 13c shows the GWP-weighted emissions of CFC, HCFC, HFC, and CO_2 for the period 1960 – 2050 and the corresponding emissions for CFCs from 1987-2020 following a scenario in which there is no Montreal Protocol regulation. The CFC curves include all principal ODSs in the Montreal Protocol except HCFCs. The emissions of individual compounds are multiplied by their respective Global Warming Potentials (GWPs) to obtain aggregate emissions expressed as equivalent $GtCO_2\ yr^{-1}$ (as used in the 2007 IPCC report). The colour-shaded regions show ranges of emissions of CFCs, HCFCs, HFCs, and CO_2 as indicated in the panel legends. The high and low labels identify the upper and lower limits in the global baseline scenarios. Shown for reference are emissions for the range of one of the scenarios (SRES CO_2) from the IPCC 2007 report and the 450- and 550-ppm CO_2 stabilization scenarios. The reduction of CFCs has been very beneficial in mitigating climate change due to increasing CO_2, but if the projected growth rate of the HFC replacement chemicals continues, the rate of warming due to their increase could approach that due to increasing CO_2.

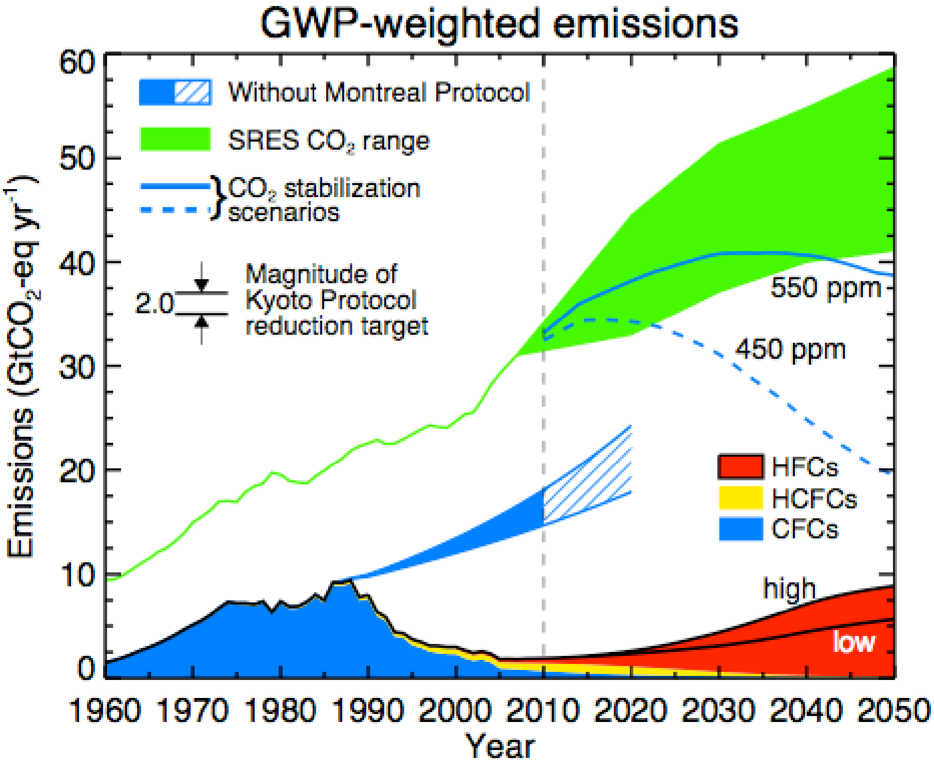

Figure 13c: *Effect of the Montreal Protocol on the climate change (Figure provided by Dr Mack McFarland from Velders, et al., Proc. Nat. Acad. Sci. USA., 2009,* ***106****, 10949-10954). Background: CO_2 –equivalence is the contribution to climate forcing from different greenhouse-gas emissions. It can be compared by scaling the emissions with the associated global warming potentials (GWPs) to form 'CO_2 -equivalent' emissions. Typically, the 100^{-yr} GWP is used. HFC emissions in 2050 will largely offset the climate benefits already achieved by the Montreal Protocol in terms of annual emissions reductions. HFC emissions are projected to reach 5.5–8.8 $GtCO_2$- eq yr^{-1} in 2050. In comparison, ODS emissions peaked at 9.4 $GtCO_2$-eq yr^{-1} in 1988 and could have reached 15–18 $GtCO_2$-eq yr^{-1} in 2010 in the absence of Montreal Protocol regulations.*

Q14. Where can I get more information about the science and effects of ozone depletion?

There are several websites that contain information on ozone, UV radiation, environmental effects and related topics. The sites mentioned below belong to dependable organizations and contain reliable information. Most of these sites contain links to other sources of information.

UNEP	http://www.ozone.unep.org
WMO	http://www.wmo.ch
WHO	http://www.who.int
IPCC	http://www.ipcc.ch
NOAA	http://www.noaa.gov/climate.html
EPA	http://www.epa.gov/ozone.html
NASA	http://ozonewatch.gsfc.nasa.gov
NIWA	http://www.niwascience.co.nz
WOUDC	http://www.woudc.org
Environment Canada	http://www.ec.gc.ca