ENVIRONMENTAL EFFECTS ASSESSMENT PANEL (EEAP)

Environmental Effects of Ozone Depletion: 2010 Assessment
Interactions of Ozone Depletion and Climate Change

Executive Summary

Ozone Depletion and Climate Change

- **There are strong interactions between ozone depletion and changes in climate induced by increasing greenhouse gases (GHGs).** Ozone depletion affects climate, and climate change affects ozone. The successful implementation of the Montreal Protocol has had a marked effect on climate change. Calculations show that the phase-out of chlorofluorocarbons (CFCs) reduced Earth's warming effect (i.e., radiative forcing) far more than the measures taken under the Kyoto protocol for the reduction of GHGs. The amount of stratospheric ozone can be affected by the increases in the concentration of GHGs, which lead to decreased temperatures in the stratosphere and accelerated circulation patterns, which tend to decrease total ozone in the tropics and increase total ozone at mid and high latitudes. Changes in circulation induced by changes in ozone can also affect patterns of surface wind and rainfall.

- **The Montreal Protocol is working, but it will take several decades for ozone to return to 1980 levels.** The concentrations of ozone depleting substances have been decreasing after reaching a peak in the 1990s, and ozone column amounts are no longer decreasing. Mid-latitude ozone is expected to return to 1980 levels before mid-century, which is earlier than predicted previously. However, the recovery rate will be slower at high latitudes. Springtime ozone depletion is expected to continue to occur at polar latitudes, especially in Antarctica in the next few decades.

- **Because of the success of the Montreal Protocol in controlling ozone depletion, increases in UV-B radiation have been small outside regions affected by the Antarctic ozone hole, and have been difficult to detect.** There is a large variability in UV-B radiation due to factors other than ozone, such as clouds and aerosols. There are few long-term measurements available to confirm the increases that would have occurred as a result of ozone depletion. At mid-latitudes, UV-B irradiances are currently up to 5% greater than in 1980, but increases have been substantial at high and polar latitudes where ozone depletion has been larger. Despite the low solar elevations in Antarctica, UV-B radiation doses in late spring during the ozone hole period can be sufficient to induce sunburn, and are about twice as great as those that would have occurred prior to the onset of ozone depletion. Unfortunately, no measurements were available prior to the onset of the ozone hole to confirm this change.

- **Without the Montreal Protocol, peak values of sunburning UV radiation could have tripled by 2065 at mid-northern latitudes.** This would have had serious consequences for the environment and for human health. This contrasts sharply with the current situation, where clear-sky UV is only slightly greater than that prior to the onset of ozone depletion, and is expected to decrease in the decades ahead at mid- to high latitudes.

- **The projected changes in ozone and clouds may lead to large decreases in UV at high latitudes, where UV is already low; and to small increases at low latitudes, where it is already high. This could have important implications for health and ecosystems**. Compared to 1980, UV-B irradiance towards the end of the 21st century is projected to be lower at mid to high latitudes by between 5 and 20%, respectively, and higher by 2-3% in the low latitudes. However, these projections must be treated with caution because they also depend strongly on changes in cloud cover, air pollutants, and aerosols, all of which are influenced by climate change, and their future is uncertain. With these predicted changes in UV radiation it would become more difficult to achieve optimal exposure times for sufficient UV-B-induced vitamin D production at high latitudes, while the risk of skin damage would be increased at low latitudes.

- **Because the future UV climate remains uncertain, continued modelling and measurement efforts are needed.** Strong interactions between ozone depletion and climate change and uncertainties in the measurements and models limit our confidence in predicting future UV irradiance. It is therefore important to improve our understanding of the processes involved, and to continue monitoring ozone and surface UV spectral irradiances, both from the surface and from satellites. This capability will enable us to monitor and respond to unexpected changes in the future.

Human Health

- **Health risks of solar UV-B radiation can be assessed most confidently for cataracts and skin cancers. Although there is concern about an increased risk of infectious diseases, data to guide public health decisions are lacking.** The incidences of cataract and skin cancers continue to rise in many countries, with significant societal impacts and costs to health care systems. In some regions the incidence of melanoma in children and young people is no longer increasing, or increasing incidence is confined to less lethal forms. These changes probably reflect intensive public health information campaigns, based on sound research findings. For infectious diseases, equivalent research findings are not available except from animal studies. Use of replacements for ozone depleting substances may result in risks to health but these have not been quantified.

- **Health benefits of sun exposure are principally derived from vitamin D production in the skin following solar UV-B irradiation.** Optimal vitamin D status supports bone health and may decrease the risk of several internal cancers and autoimmune, infectious and cardiovascular diseases. It is not yet clear whether oral vitamin D supplementation provides all of the benefits of UV-induced vitamin D or whether higher vitamin D status is always beneficial. Appropriate sun exposure to balance risk and benefits depends on personal characteristics such as genetic background (including skin colour and vitamin D receptor types) and external/environmental factors (including diet, season, time of day and latitude). This is an area of active current research, the results of which will provide guidance to the general public to better balance the benefits of sun exposure whilst minimizing risks.

- **Health effects associated with combined changes in solar UV radiation and climate are plausible; directed studies are required to guide health care decisions and future policies regarding health care.** Higher temperatures are likely to lead to more skin cancers for the same exposure to UV radiation. However, this is the most definitive statement that can be made to date about a combined effect, as more studies have not been done. Although higher temperatures may change sun exposure patterns, there is considerable uncertainty in modeling future human behaviour in response to climate change. There is enough information to suspect that combined effects could be serious, but the data to develop robust risk estimates are not available.

Terrestrial Ecosystems

- **In areas where substantial ozone depletion has occurred, results from a wide range of field studies suggest that increased UV-B radiation reduces terrestrial plant productivity by about 6%.** This reduction results from direct damage and increased diversion of plant resources towards protection and acclimation. Long-term effects of reduced plant growth could be important, particularly for potential carbon sequestration (capture).

- **Changes in UV radiation caused by global environmental change can have very important consequences for terrestrial ecosystems.** Region-specific **c**hanges in cloud cover and vegetative cover (in response to increased aridity or deforestation) predicted for the coming decades are likely to have large impacts on the levels of UV radiation received by terrestrial organisms. These variations in UV radiation (both UV-B ad UV-A) will affect a large range of ecosystems.

- **Predicted changes in climate may modify plant and ecosystem responses to UV radiation.** For example, while moderate drought can decrease UV sensitivity in plants, further decreases in precipitation and increasing temperatures due to climate change are likely to restrict plant growth and compromise plants to re-distribute resources for protection from UV radiation and other climate factors. Thus even limited climate change could have consequences for survival, especially in harsh environments.

- **UV radiation promotes the breakdown of dead plant material and consequently carbon loss to the atmosphere.** Exposure of vegetation and soils to UV radiation may increase in the future at low to mid-latitudes due to reduced cloud cover or more intensive land use. The breakdown of dead plant material through the action of sunlight (photodegradation) is a very important ecosystem process in many environments, especially for those components that decay only very slowly by microbial action.

- **Variations in UV-B radiation caused by climate change and ozone depletion can have large effects on plant interactions with pests, with important implications for food security and food quality.** Plant consumption by herbivores (e.g. insects) usually decreases under elevated UV-B radiation. Over the coming decades, rising atmospheric carbon dioxide and increased planting density may counteract this beneficial effect of UV-B radiation.

- **UV-B radiation may improve the quality of food, for example, through increased antioxidant activity, flavour and fibre content.** Knowledge gained in this area could be used in the design of agricultural systems that take advantage of these natural plant products to increase nutritional value.

- **Solar UV-B radiation changes microbial biodiversity with consequences for soil fertility and plant disease.** Changes in the composition of microbial communities on dead plant material can alter rates of decay (an important ecosystem process that contributes to soil fertility). On living plants, changes in species composition of microbes by UV-B radiation can affect susceptibility to fungal infections.

Aquatic Ecosystems

- **Detrimental effects of solar UV-B radiation have been demonstrated for many aquatic organisms.** In contrast, relatively little information is available regarding consequences on biodiversity and species composition, or on the interactions between trophic levels within natural ecosystems.

- **For several aquatic organisms, UV-B-induced negative effects are worsened by environmental pollution.** UV-B radiation has a greater impact on aquatic organisms in sites polluted by crude oil and heavy metals such as cadmium, selenium or copper.

- **Climate change will alter the exposure of aquatic organisms to solar UV radiation by influencing their depth distribution as well as the transparency of the water.** Increased temperature due to climate change tends to decrease the depth of the upper mixed layer, thus exposing organisms to higher irradiances. Dissolved organic matter (DOM) is the major factor influencing UV transparency in most inland waters and coastal areas. In some regions, DOM concentrations have nearly doubled in the past 20 years. Since some waterborne human pathogens are sensitive to solar UV radiation, changes in DOM may alter their exposure and inactivation.

- **Enhanced solar UV-B radiation in conjunction with rising global temperatures may negatively affect seaweeds that have ecologic and economic importance.** The vertical distribution of seaweeds in their ecosystem is strongly determined by solar UV radiation. Early developmental stages of brown and red algae are impaired by these environmental factors.

- **Climate-driven changes in environmental conditions may exceed the capacity of protective strategies of aquatic organisms to adapt to solar UV radiation.** Different species use different combinations of avoidance strategies, photoprotection and photorepair, which determine the limits of their ability to adapt to high solar UV radiation. While many cyanobacteria, which are major biomass producers in both marine and inland ecosystems, are sensitive to solar UV radiation, others can survive in habitats with extreme UV-B irradiances, frequent desiccation and extreme temperatures by using a combination of adaptive strategies.

- **The rise in atmospheric CO_2 concentrations increases the acidity of the water, making calcified organisms more vulnerable to solar UV-B radiation.** The continued acidification of marine waters impairs carbonate incorporation in calcified organisms, such as phytoplankton, seaweeds and corals.

Biogeochemical Cycles

- **There are interactions between the effects of solar UV radiation and climate change on the processes that drive the carbon cycle.** These interactions could accelerate the rate of atmospheric CO_2 increase and subsequent global warming beyond current predictions.

- **Projected shifts to warmer and drier conditions, such as in the Mediterranean and in western North America, will increase UV-induced carbon loss to the atmosphere.** UV-induced breakdown of dead plant material is likely to become a much more significant pathway for CO_2 emissions to the atmosphere.

- **In mid- and high-latitude oceanic areas, the capacity to take up atmospheric CO_2 is decreasing.** This decrease is mainly due to negative effects of climate change and solar UV radiation on photosynthesis and related CO_2 uptake processes in oceans.

- **Predicted climate-related increases in runoff from the Arctic and alpine regions to aquatic ecosystems will accelerate the UV-induced breakdown of soil organic carbon into atmospheric CO_2.** The runoff also reduces water clarity and thus UV exposure in freshwaters and the coastal ocean.

- **Feedbacks involving greenhouse gases other than CO_2 are increasing due to interactive effects of UV radiation and climate change.** For example, increases in oxygen-deficient regions of the ocean caused by climate change enhance emissions of nitrous oxide, an important greenhouse and ozone-depleting gas.

- **Further reductions in solar UV-B irradiance reaching the Earth's surface caused by recovery of the ozone layer may retard photochemical reactions of organic and inorganic pollutants.** This effect may increase the persistence and exposure concentrations of organic pollutants. On the other hand, in the case of metals, this may be beneficial, since UV-induced transformations of metals often increases their toxicity.

Air Quality

- **The impacts of air pollution on human health and the environment will be directly influenced by future changes in climate, emissions of pollutants, and stratospheric ozone.** Ultraviolet radiation is one of the controlling factors for the formation of photochemical smog which includes tropospheric ozone and aerosols; it also initiates the production of hydroxyl radicals, which control the amount of many climate- and ozone-relevant gases in the atmosphere. Uncertainties still exist in quantifying the chemical processes and wind-driven transport of pollutants. The net effects of future changes in UV radiation, meteorological conditions, and anthropogenic emissions may be large but will depend on local conditions, posing challenges for prediction and management of air quality.

- **Numerical models predict that future changes in UV radiation and climate will modify the trends and geographic distribution of hydroxyl radicals, thus affecting urban and regional photochemical smog formation, as well as the abundance of several greenhouse gases.** Concentrations of hydroxyl radicals are predicted to decrease globally by an average of 20% by 2100, with local concentrations varying by as much as a factor of two above and below current values. However, significant differences between modelled and measured values in a limited number of case studies show that we do not fully understand the chemistry of hydroxyl radicals in the atmosphere. Therefore, the consequences for human health and the environment are uncertain.

- **Photochemically produced tropospheric ozone is projected to increase over the next 20-40 years in certain regions of low and middle latitudes because of interactions of emissions, chemical processes, and climate change.** If emissions of anthropogenic air pollutants from combustion of fossil fuels, burning of biomass, and agricultural activities continue to increase, concentrations of tropospheric ozone will tend to increase. Climate-driven increases in temperature and humidity will also increase tropospheric ozone production in polluted regions, but reduce it in more pristine regions. Higher temperatures of some soils tend to increase emissions of nitrogen oxides (NOx) and biogenic volatile organic compounds (VOCs), leading to greater background concentrations of ozone in the troposphere. For the future protection of human health and the environment, more effective controls will need to be considered for emissions of NOx and VOCs related to human activities.

- **Aerosols composed of organic substances have a major role for climate and air quality, and contribute a large uncertainty to the energy budget of the atmosphere.** Aerosols are mostly formed via the UV-initiated oxidation of volatile organic compounds from anthropogenic and biogenic sources, although the details of the chemistry are still poorly known and current models under-predict their abundance. A better understanding of their formation, chemical composition, and optical properties is required to assess their significance for air quality and to better quantify their direct and indirect radiative forcing of climate.

- **The decomposition of substitutes for ozone-depleting substances can lead to a range of chemical species, however with little relevance expected for human health and the environment.** The hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs) used as substitutes for ozone-depleting CFCs can break down into trifluoroacetic acid (TFA), which is very stable and will accumulate in the oceans, salt lakes, and playas. However, based on historical use and projections of future uses, including new products entering the market such as the fluoro-olefins, increased loadings of TFA and monofluoracetic acid (MFA) in these environmental sinks will be small. Even when added to existing amounts from natural sources, risks from TFA (and the more toxic MFA) to humans and organisms in the aquatic environment are judged to be negligible.

Materials

- **Increased ambient temperature accelerates the UV-induced degradation of plastics and wood, thus shortening their useful outdoor lifetimes**. Natural and man-made materials are widely used in outdoor construction, agriculture and other applications. The increased rate of degradation at the higher temperatures depends on the specific material, the UV radiation environment and the geographic location of exposure.

- **The presently available stabilisation technologies can mitigate the damage to some types of common polymers routinely exposed to solar UV radiation**. State of the art stablisers, surface coatings and material substitution technologies, are likely to control the deleterious effects of environments that have enhanced UV radiation and temperature, but only for some types of common plastics.

- **Plastic nanocomposites and wood-plastic composites that are increasingly used in outdoor applications appear to have relatively higher solar UV radiation stability compared to conventional materials.** The use of nanofillers in composites is increasing as these deliver a superior performance compared to conventional composites. Wood-plastics composites, although also UV-stable compared to the plastic alone, can still suffer reduced lifetimes at high humidity levels.