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ENVIRONMENTAL EFFECTS OF OZONE DEPLETION AND ITS INTERACTIONS WITH CLIMATE CHANGE: 2002 ASSESSMENT

Pursuant to Article 6 of the Montreal Protocol on Substances that Deplete the Ozone Layer under the Auspices of the United Nations Environment Programme (UNEP)

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Introduction

The four earlier assessments on Environmental Effects of Ozone Depletion, between 1989 and 1998, dealt almost exclusively with increasing ultraviolet radiation and its impacts. The present assessment gives an update on these same problems, but with a special emphasis on the interactions with climate change, at the request of the 11th Meeting of the Parties to the Montreal Protocol. Depletion of the stratospheric ozone layer and climate change are dealt with in separate international conventions. Although both processes are aspects of global atmospheric change, the measures needed for phasing out ozone depleting chemicals and for limiting the increasing greenhouse effect are distinctly different. Even if separated in this fashion, it is becoming increasingly clear that the two processes have many interactions. For the time period that these two threats co-exist, there is a strong likelihood that their interactions will have consequences for the environment.

Some of these interactions take place within the atmosphere and influence the UV radiation reaching the earth's surface, resulting in effects on health, ecosystems and materials. In other cases, a particular effect of UV radiation, e.g., on phytoplankton in the oceans, may even play a role in the large-scale interactions between climate change and ozone depletion. In addition, a specific biological system or material may be affected by increased UV radiation in combination with rising temperatures, changing precipitation or other aspects of climate change; these various factors may interact with each other in an additive, antagonistic or synergistic way.

Climate models that simulate future ozone levels have improved but still remain highly uncertain. Several models predict delays in recovery of the ozone layer, ranging from almost zero to a decade or more or even to further ozone depletion late in the century. This calls for an analysis of the consequences of a prolonged period of increased UV-B radiation on health and the environment.

Changes in snow and ice cover arising from global warming can modify the UV radiation received at the Earth's surface. The penetration of UV radiation into the sea and freshwaters is dependent on the concentration of dissolved organic matter in the water, which is modified by both UV radiation and temperature. Oceanic productivity is also influenced by temperature and UV radiation; the changed productivity in turn leads to changes in sulphur emission from the ocean, potentially altering the transmission of sunlight to the surface. The induction of skin cancer by solar UV radiation is likely to increase with global warming. Increasing temperatures are also expected to exacerbate the UV-related problems in air quality, and UV-induced damage to materials.

Research and understanding of most of these complex processes is still in an initial and uncertain phase, but it appears that some of these will have environmental impacts. In the following chapters, new information on the effects of increased UV radiation will be discussed in more detail, with special attention given to the role of interactions between ozone depletion and climate change.

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Ozone and UV Changes

- **Atmospheric ozone remains depleted**. Antarctic ozone losses have remained similar each spring in recent years. In the Arctic, the ozone losses can be substantial, but only during winters when stratospheric temperatures fall below a critical threshold. Outside the Polar regions, ozone losses are less severe. Relative to 1980, the 1997-2000 losses in total ozone are about 6% at southern mid-latitudes on a year-round basis. At northern mid-latitudes the ozone losses are about 4% in winter/spring season, and 2% in summer/autumn. In the tropics, there have been no significant changes in column ozone. Globally, the annual average ozone loss is approximately 3%. These changes are in broad agreement with model calculations.
- **Although the quality, quantity, and availability of ground-based UV measurements continue to improve, a global-scale assessment from them is not yet available.** The complicated spatial and temporal distributions of the predominant variables that affect ultraviolet radiation at the surface (for example, clouds, airborne fine particles, snow cover, sea ice cover, and total ozone) continue to limit the ability to describe fully surface ultraviolet radiation on the global scale, whether through measurements or model-based approaches.
- **Spectral surface ultraviolet data records, which started in the early 1990s, are still too short and too variable to permit the calculation of statistically significant long-term (i.e., multi-decadal) trends.** However, long-term increases in peak UV levels have been observed at a few sites, and the measured increases are in agreement with model calculations. Progress has been made inferring historical levels of UV radiation using measurements of ozone from satellites in conjunction with measurements of total solar radiation obtained from extensive meteorological networks.
- **Long-term effects on UV radiation from changes in cloud and snow cover have been observed.** At two of three sites in Canada the increases in UV-B radiation were as expected from the changes in stratospheric ozone concentrations that have occurred, while at another site the UV-B trend was much larger as a result of additional long-term changes in snow cover and cloud. This indicates potentially complex interactions between climate change and UV-B radiation. Cloud reflectance measured by satellite has shown a long-term increase in some regions (e.g., in Antarctica), which would tend to reduce the UV-B radiation. In other regions (e.g., in the tropics) there have been decreases in cloud cover. These changes in cloud cover are not yet satisfactorily explained by models. Future changes in cloud cover and tropospheric air quality (especially aerosols) may modify significantly the UV exposures experienced at the Earth's surface.
- **Anthropogenic aerosols play a more important role in attenuating UV radiation than has been assumed previously.** Comparisons between UV measured at the Earth's surface and satellite data indicate that satellite estimates are too large in polluted locations, and thus aerosols are more important than previously thought. The effects of pollution originating from urban and industrial areas may extend over wide geographical areas. Episodes of biomass burning, which contribute to

enhanced particulates and gas composition, can decrease UV-B at the Earth's surface and in the troposphere.

- **Future changes in well-mixed greenhouse gases will affect the future evolution of ozone through chemical, radiative, and dynamic processes.** In this highly coupled system, an evaluation of the relative importance of these factors is difficult; studies are ongoing. Stratospheric cooling (due mainly to projected carbon dioxide increases) is predicted to increase ozone amounts in the upper stratosphere. However, a reliable assessment of these effects on total column ozone is limited by uncertainties in lower stratospheric response to these changes.

Health

- **New studies continue to confirm the adverse effects of UV-B radiation on the eyes, skin, and immune system.** Although no new health effects have been discovered, many improvements have been made in understanding the mechanism of action of UV-B, thereby reducing the level of uncertainty in predictions regarding the health consequences of ozone depletion.
- **Studies on the ocular effects of UV radiation strengthen the association between UV-B exposure and the development of age-related cortical cataract.** New epidemiological studies confirm the role of UV radiation in the formation of cortical cataract, and studies in various animal models strongly implicate UV-B radiation as the primary cause of this condition.
- **New animal models for UV-induced cutaneous melanoma and basal cell carcinoma have been developed.** These models are being used to determine how UV radiation causes or contributes to the development of these skin cancers. Interestingly, induction of melanoma in a transgenic mouse model occurred only when animals were exposed to UV radiation early in life. Similar results were obtained in an opossum model. These findings support those from epidemiological studies suggesting that exposure to UV radiation early in life is an important risk factor in the subsequent development of melanoma. In both models, UV-B, rather than UV-A radiation seems to play the more important role in melanoma induction.
- **Specific genes and biochemical pathways in cells that contribute to skin cancer development have been identified.** Such studies improve our understanding of the involvement of UV radiation in skin cancer induction and may eventually allow the identification of persons at greatest risk of developing UV-induced cancers of the skin.
- **New studies indicate that the risk of skin cancer development can be reduced by certain interventions.** Regular use of sunscreens reduced the incidence of squamous cell cancers in adults, and applying DNA repair enzymes to the skin of persons with a genetic susceptibility to skin cancer reduced the development of precancerous lesions.
- **Research on the immunological effects of UV irradiation continues to improve our understanding of the mechanisms by which UV radiation reduces immune function.** However, many questions remain as to the significance of these effects for allergies, autoimmune diseases, vaccinations, and cancers of internal organs.
- **Studies in animal models of infectious diseases provide compelling evidence that UV-B radiation can increase the incidence, severity, and duration of a variety of diseases.** Some of these effects are subtle and thus will be difficult to detect in epidemiological studies of infectious diseases in human populations. Nonetheless, evidence continues to accumulate suggesting

associations between sunlight exposure and reduced efficacy of vaccinations and exacerbation of infectious diseases, particularly those caused by herpes viruses (cold sores, and shingles).

- **Phase-out of the ozone-depleting chemical, methyl bromide, may lead to increased use and numbers of other pesticides**. In locations where these chemicals are well regulated, additional health risks are expected to be small. However, in locations where controls are lax, there is reason to be concerned that increased use may lead to additional health risks.

- **Interactions between global climate change and ozone depletion are likely to influence the risk of adverse effects of UV-B radiation on health**. This influence could be either positive or negative and thus introduces greater uncertainty into the estimates of health effects. For example, increased temperature could increase the incidence of skin cancer, but it might also alter behavior by reducing the hours spent outdoors. Global climate change may also extend the period of ozone depletion, which would further increase the incidence of skin cancer. Changes in the geographic distribution of pesticide use resulting from climate change could introduce adverse health effects in some regions and reduce them in others. Similarly, shifts in the geographic distribution of vectors harboring infectious agents, coupled with impaired immune function, could have a greater impact on infectious diseases than anticipated from ozone depletion alone.

Terrestrial Ecosystems

- **Interaction of ultraviolet radiation with other global climate change factors may affect many ecosystem processes.** Examples of such processes and attributes that may be modified include plant biomass production, plant consumption by herbivores including insects, disease incidence of plants and animals, and changes in species abundance and composition. In these and other studies there is a need for long-term experiments.

- **A meta-analysis, with quantitative and statistical information has been used to assess how well overall research predicts common trends and results from different species of plants from experiments conducted outdoors using UV lamp systems.** This analysis showed that of the physiological and morphological traits, overall significance of elevated UV-B was found for decreased plant height and leaf area, increased phenolic compounds and sometimes reduced shoot mass.

- **Fungi and bacteria exposed to sunlight can be directly damaged by enhanced UV-B.** The species composition and biodiversity of bacteria and fungi growing on plants can be changed by UV-B. Biodiversity can be either increased or decreased. For pathogens, elevated UV-B can either increase or decrease the severity of disease development in plants.