

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 the surface ultraviolet radiation on a 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.

• **Exposure of plants to enhanced UV-B can result in altered disease and herbivory intensity**

UV-B often decreases the intensity of insect herbivory and this likely involves plant tissue chemical changes, such as altered phenolic chemistry. The influence of UV-B on pathogen attack on plants can involve both changes in host plant chemistry and direct effects on pathogens. This can either increase, or decrease pathogen attack in different species of plants.

• **Common higher plant responses to elevated UV-B may be lessened by elevated CO₂**

In cases where enhanced UV-B reduces plant growth (height, leaf area and sometimes shoot mass), elevated CO₂ can often overcome these reductions.

• **Water limitation may decrease the sensitivity of some plants to enhanced UV-B**

Plants, especially those of agricultural use, experiencing drought stress are often less responsive to enhanced UV-B. Plants from some environments, such as Mediterranean scrub vegetation, may be more tolerant to drought stress if exposed to elevated UV-B.

• **The effects of UV-B on plant growth reductions are often accompanied by greater DNA damage**

UV-B can affect several critical macromolecules, such as nucleic acids, proteins and lipids. The mechanisms that mediate growth inhibition by UV-B under natural conditions are still poorly understood. However, correlative evidence suggests that DNA damage may play a significant role.

• **Increasing temperatures can promote repair of UV-B damage to DNA, although combining extreme temperatures and enhanced UV-B can cause unexpected results**

DNA damage is repaired more effectively if not limited by low temperatures. Thus, repair is promoted by warming under certain circumstances, and this may lessen the inhibitory effects of UV-B on plant growth. Some responses to extreme temperatures will be modified in unexpected ways by enhanced UV-B; for example, there is evidence for substantially increased frost sensitivity of some subarctic heath species. There is a need for further research in this area in relation to climatic change trends.

Aquatic ecosystems

• **Recent results continue to confirm the general consensus that solar UV negatively affects aquatic organisms**

Reductions in productivity, impaired reproduction and development and increased mutation rate have been shown for

phytoplankton, fish eggs and larvae, zooplankton and primary and secondary consumers exposed to UV radiation. UV-B related decreases in biomass productivity are relayed through all levels of the food web, possibly resulting in reduced food production for humans, reduced sink capacity for atmospheric carbon dioxide, as well as changes in species composition and ecosystem integrity.

• It is at the ecosystem level where assessments of anthropogenic climate change and UV-related effects are interrelated and where there is the potential for both antagonistic and synergistic effects

Recent studies have shown that these changes may lead to loss of ecosystem resilience. In some aquatic ecosystems the onset of spring phytoplankton blooms and spawning in invertebrates and vertebrates coincides with dramatic ozone depletion as well as shifts in several climate-related parameters.

• Polar ecosystems are particularly sensitive to change, because the freeze–thaw boundary applies critical limits to subsequent environmental responses

These include: air and water temperature; the timing, extent and duration of ice and snow cover; changes in the surface albedo; changes in water column colored dissolved organic matter (CDOM) concentrations; and the level of solar radiation and the extent of its penetration. Such changes, which may be driven by climate variability, may be more important for UV-B exposure levels and spectral balance between UV-B and visible radiation than ozone depletion.

• Solar UV penetrating the top layers of the water column markedly affects zooplankton, as well as larval stages of primary and secondary consumers

The effect of solar UV is strongly modified by other environmental factors, such as variability in cloud cover, water temperature, mutual shading in algal blooms and depth of mixing layer. Although the primary causes for a decline in fish and shellfish populations are predation and poor food supply for larvae, over-fishing of adults coupled with increased water temperature, pollution and disease, and exposure to increased UV-B radiation may contribute to that decline. For amphibians, climate-induced reductions in water depth at sites where eggs are laid have caused a high mortality of embryos due to increased exposure to solar UV-B and subsequent vulnerability to infection.

• In addition to increasing solar UV-B radiation, aquatic ecosystems are confronted with other environmental stress factors including increased nutrient input, pollution, acidification and global climate change

In turn, climate change will result in temperature and sea level change, shifts in the timing and extent of sea ice cover, changes in salinity and altered stratification of the water column, and wave climate and ocean circulation. These effects will be linked by pronounced feedback mechanisms, which are not yet completely understood. The resulting complex changes are likely to have significant impacts that will vary both spatially and temporally.

Biogeochemical cycles

• Global warming and enhanced UV-B radiation interact to affect a range of biogeochemical processes

On land, warming increases microbial activity, nutrient cycling, and greenhouse gas emissions from soils, whereas increased UV-B can retard or accelerate these processes. In aquatic

systems, warming also increases microbial activity. The exposure of organisms to UV is amplified by increased water stratification and changed mixing of surface waters that are related to global climate change.

• Interactions between UV-B radiation and increased ocean temperatures affect sulfur emissions that influence the balance between incoming and outgoing radiation in the marine atmosphere

Enhancements of sulfur transfer from the ocean to the atmosphere are linked to changes in ocean surface layer mixing, induced by global warming, increased UV-B exposure, and UV-B inhibition of bacterial growth. Oceanic sulfur emissions can influence cloud characteristics that in turn affect radiation in the marine atmosphere.

• There is new evidence that UV accelerates decomposition of the colored organic matter that runs off from land into the ocean

Previously, it was believed that land-derived organic matter was mainly lost by biological oxidation and burial in coastal zones where sedimentation is high. Now, it is known that UV plays a central role in the removal of this organic matter.

• The exchange of trace gases between terrestrial systems and the atmosphere is influenced by changes in UV-B

Additional research on UV-induced carbon monoxide production from dead plant matter in terrestrial ecosystems indicates that the global annual carbon monoxide input from this source to the atmosphere is significant. Solar UV-induced nitrogen oxide production has been observed in snowpacks located at diverse sites in Greenland, Antarctica, Canada and the northern United States. The UV-driven emissions of carbon monoxide and nitrogen oxides may change local concentrations of tropospheric ozone.

• Important components of the terrestrial nitrogen cycle are sensitive to enhanced UV-B radiation

In the Northern Arctic, where unavailable nitrogen severely limits plant growth, nitrogen fixation by free-living blue-green algae was retarded by enhanced UV-B. Potential nitrogen fixation by symbiotic algae in a sub-Arctic lichen species was also reduced in the long term. In addition, enhanced UV-B increased nitrogen immobilized by soil bacteria in the Sub-arctic, making nitrogen less available for plant production.

• Enhanced UV-B radiation accelerates the decomposition of colored dissolved organic matter (CDOM) entering the sea via terrestrial runoff

This has important effects on oceanic carbon cycle dynamics. UV-induced changes in visible light absorption by CDOM can affect the accuracy of estimates of coastal oceanic productivity based on remote sensing of ocean color.

• Several important sources of natural ozone depleting halogenated substances have been identified in the terrestrial biosphere and explain deficits in global budgets

Calculations of global atmospheric budgets of methyl bromide and methyl chloride indicate large missing sources. Recent experimental data indicate that natural emissions of these gases from terrestrial ecosystems, particularly salt marshes, account for a significant part of these missing sources. Emissions appear to result from an active process strongly related to diurnal incident light levels. Methyl chloride and methyl bromide participate in ozone-depleting processes.

Air quality

- **The effect of stratospheric ozone depletion on tropospheric ozone trends is significant, but small compared to the anthropogenic emissions in air-polluted areas**

Model and experimental studies suggest that the impacts of stratospheric ozone depletion on tropospheric ozone are different at different altitudes and for different chemical regimes. A measurable effect on concentrations will be expected only in regions where local emissions make minor contributions. The vertical distribution of NO_x, as well as the emission of volatile organic carbons and abundance of water vapour, are important influencing factors.

- **Risks from the effects on humans and the environment of trifluoroacetic acid (TFA) and chlorodifluoroacetic acid (CDFA) produced by atmospheric degradation of HCFCs and HFCs are judged to be minimal**

TFA has been measured in rain, rivers, lakes, and oceans, the ultimate sink for these and related compounds. Anthropogenic sources of TFA other than degradation of HCFCs and HFCs have been identified.

- **Interactions between ozone depletion and climate change will have an impact on tropospheric hydroxyl (OH) radical concentration, the “cleaning” agent of the troposphere**

Stratospheric ozone depletion leads to an increase in concentration of the OH radical in the troposphere. Increases in the concentration of gases such as volatile organic compounds will act as a sink for OH in the troposphere. Aerosols can also act to reduce UV-B in some circumstances and hence reduce OH. Changes in cloudiness and temperature will also have an effect. All of these can be influenced by climate change. The net change in air quality and chemical composition in the troposphere will depend on the balance between these effects.

- **Changes in the aerosol content of the atmosphere resulting from global warming may affect ozone photolysis rates and hence reduce tropospheric ozone concentrations**

Model and field studies show that a reduction in the ozone photolysis rate and ozone production in the troposphere is to be expected in the presence of increased absorbing aerosols in the troposphere.

Materials

- **Climate change is likely to modify the rates of UV-induced degradation of natural and synthetic materials**

In regions of the world with high UV-B levels, increase in the ambient temperature will have a marked influence in increasing the rate of light-induced degradation of materials. This is particularly true of plastics and wood used in building construction. Increased humidity can also have a similar effect on some materials when coupled with high UV, especially at the high ambient temperatures.

- **New varieties of commodity plastics with improved properties are emerging and these too can be stabilized effectively with existing light stabilizers**

Recent improvements in catalysts have led to the discovery of metallocene plastics (polyethylenes and polypropylenes) that have improved properties including slightly better UV resistance compared to the conventional varieties. Commonly used conventional light stabilizers were found to be effective in stabilizing these varieties of thermoplastics as well.

- **Recent data suggest synergistic improvement in light-stabilizer effectiveness when mixtures of conventional HALS stabilizers are used in plastics**

Hindered amine light stabilizers (HALS) are commonly used as a light stabilizer with common plastics. Mixtures of two or more of these were recently reported to perform even better as light stabilizers of plastics. Increasing the light stabilizer effectiveness is important for minimizing the cost of stabilization of plastics formulations against the damage caused by UV radiation and climate change.