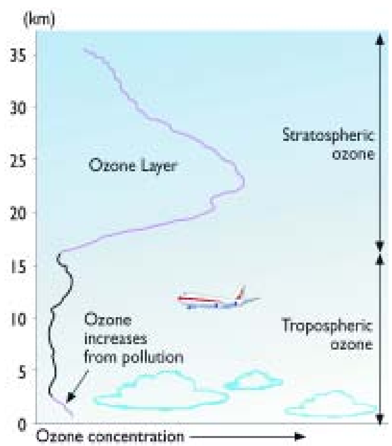
9 Elevated ultraviolet radiation levels will affect people, plants, and animals.

The ozone layer absorbs UV from the sun, protecting life on earth from exposure to excessive levels of UV. Ozone depletion may thus lead to increases in UV levels at the earth's surface.

Ozone in the Atmosphere



Most ozone resides in the stratosphere, relatively high above the earth's surface, where it protects life on earth from excess UV radiation. Increases in ozone levels occur near earth's surface as a result of pollution. This ground-level ozone, also known as smog, causes respiratory problems in humans and other negative impacts. The discussion in this report concerns stratospheric ozone, not ground-level ozone.

Ultraviolet radiation (UV) reaching the earth's surface is a growing concern in the Arctic, largely due to depletion of stratospheric ozone caused by emissions of chlorofluorocarbons (CFCs) and other manmade chemicals over the last 50 years. Ozone depletion over the Arctic has been severe and is greatest in the spring when living things are most vulnerable.

While the international treaty known as the Montreal Protocol (and subsequent amendments that strengthened it) has phased out the production of most of these ozone-destroying chemicals, many have long atmospheric lifetimes and so those previously released will continue to destroy ozone for decades to come. Ozone depletion in the Arctic is highly sensitive to changes in temperature, meaning that ozone levels are likely to be strongly influenced by climate change, even though the fundamental depletion processes involve ozone-destroying chemicals produced by human activities.

Although the uncertainty in future ozone projections is high, the long timeframe for ozone recovery suggests that the Arctic is very likely to be subject to elevated levels of UV for several decades. Increased UV levels are likely to affect many living things in the Arctic. In humans, excess levels are known to cause skin cancer, sunburn, cataracts, cornea damage, and immune system suppression. Ultraviolet radiation is also known to cause or accelerate damage to a number of materials used in the region's infrastructure. There are also likely to be wide-ranging impacts on natural ecosystems.

Many people confuse the issues of ozone depletion and climate change. While the two are related in a number of ways, they are driven by two distinct mechanisms. Human-induced climate change results from the build up of carbon dioxide, methane, and other greenhouse gases that trap heat in the lower atmosphere (called the troposphere), causing global warming. Ozone depletion results from the human-induced build-up of chlorinated chemicals such as byproducts of CFCs and halons that break apart ozone molecules through chemical reactions that take place in the stratosphere.

The United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO) have undertaken periodic assessments of changes in stratospheric ozone and ultraviolet radiation. The most recent UNEP/WMO Scientific Assessment of Ozone Depletion was completed in 2002. The ACIA has built upon and extended the findings of that assessment.

Arctic Ozone Depletion

The ozone layer absorbs UV from the sun, protecting life on earth from exposure to excessive levels of UV. Ozone depletion may thus lead to increases in UV levels at the earth's surface. The most severe depletion has taken place in the polar regions, causing the so-called Antarctic "ozone hole," and a similar, though less severe, seasonal depletion over the Arctic. Varying degrees of depletion extend around the globe, generally becoming less severe with increasing distance from the poles.

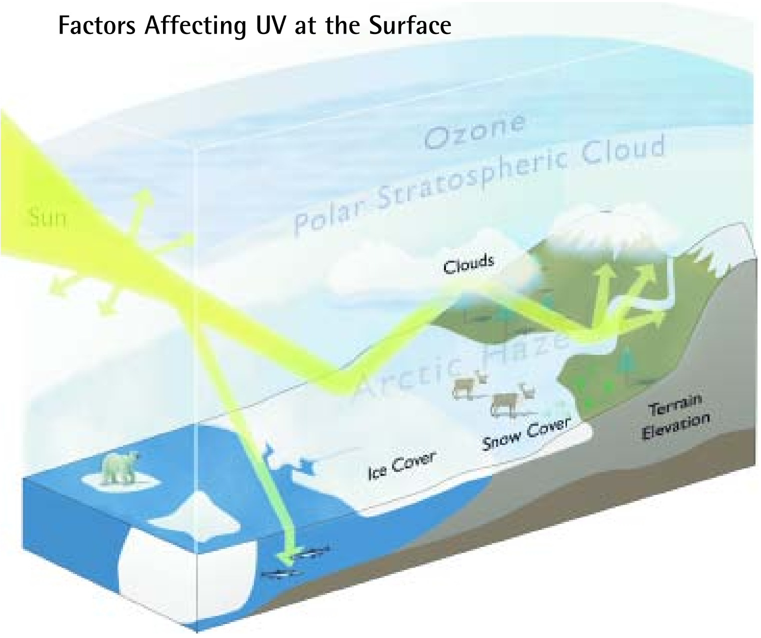
The accumulated annually averaged loss of ozone over the Arctic has been about 7% since 1979. But this obscures much larger losses at particular times of the year and on particular days, and it is these losses that have the potential for significant biological impacts. The largest ozone reductions have occurred in spring, with average springtime losses of 10-15% since 1979. The largest monthly deviations, 30-35% below normal, were in March 1996 and 1997. Daily ozone values were 40-45% below normal in March-April 1997. Major ozone losses (defined as greater than 25% depletion) lasting several weeks have been observed during seven of the past nine springs in the Arctic.

Factors Determining UV at the Surface

Ozone levels directly influence the amount of UV reaching the earth's surface. Surface UV levels are also strongly affected by clouds, the angle of the sun's rays, altitude, the presence of tiny particles in the atmosphere (which scientists refer to as aerosols), and the reflectivity of the surface (determined largely by the extent of snow cover, which is highly reflective). These factors change from day to day, season to season, and year to year, and can increase or decrease the amount of UV that reaches living things at the surface. The highest doses of UV in the Arctic are observed in the spring and summer, due primarily to the relatively high angle of the sun. The low sun angle during autumn and winter creates a great deal of diffuse UV scattered from the atmosphere and reflected off snow and ice. Reflectance off snow can increase the dose received by living things at the surface by over 50%.

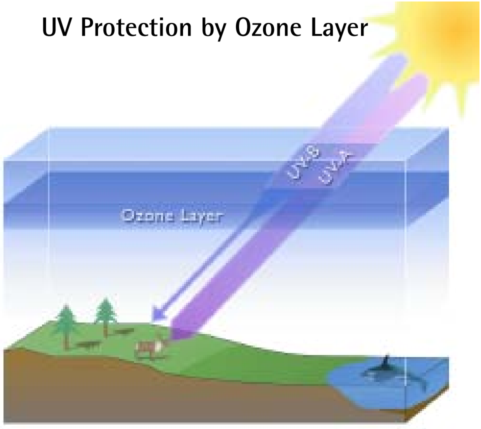
The various factors affecting UV doses can have multi-faceted effects, some of which are likely to be influenced by climate change. For example, snow and ice reflect solar radiation upward, so plants and animals on top of the ice are likely to receive lower doses as snow and ice recede due to warming. On the other hand, plants and animals below the snow and ice, which were previously protected by that cover, will receive more UV as snow and ice recede. The projected reduction in snow and ice cover on the surface of rivers, lakes, and oceans is thus likely to increase the exposure of many living things in these water bodies to damaging levels of UV. In addition, the projected earlier spring melting of snow and ice cover comes at the time of year when UV radiation is most likely to be elevated due to ozone loss.

Factors Affecting UV at the Surface



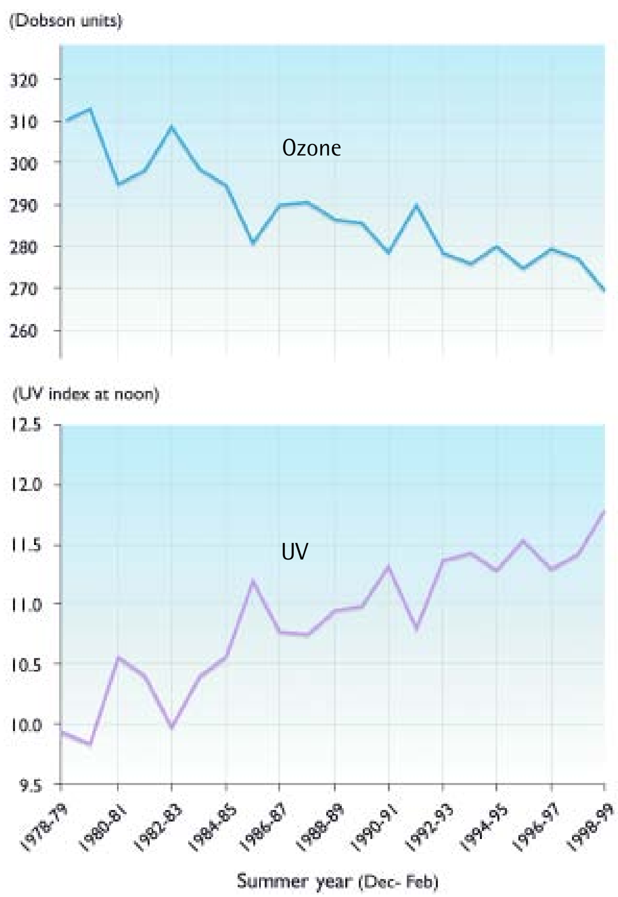
Ozone levels, clouds, the angle of the sun's rays, altitude, tiny particles in the atmosphere (which scientists refer to as aerosols), and the reflectivity of the surface (determined largely by the extent of snow cover, which is highly reflective), all influence the amount of UV reaching the surface.

UV Protection by Ozone Layer



The stratospheric ozone layer absorbs some of the ultraviolet radiation from the sun. UV-B radiation is most strongly absorbed by ozone, greatly reducing the amount that reaches the earth. UV-A and other types of solar radiation are not strongly absorbed by ozone. Human exposure to UV increases the risk of skin cancer, cataracts, and a suppressed immune system. UV exposure can also damage plant and animal life on land, in the oceans, and in rivers and lakes.

As Ozone Declines, UV Rises



This graph demonstrates the well-established fact that all other factors being equal, less stratospheric ozone results in more UV radiation at the surface. Other factors also affect UV levels, including clouds, snow, and ice, and any of these can alter this simple relationship.

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Variations Over Time and Space

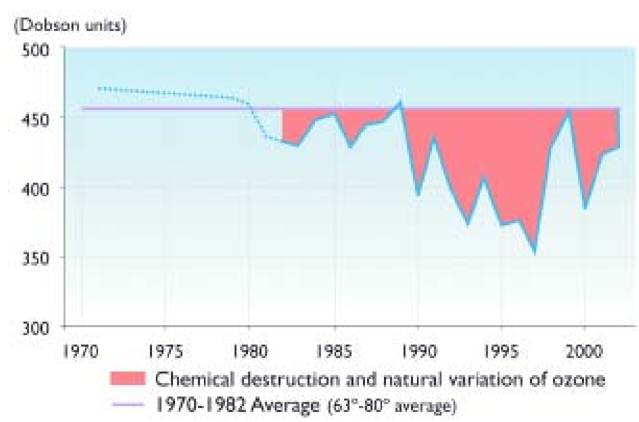
The ozone depletion and resulting increase in UV levels at the surface in the Arctic have not been symmetrical around the pole. Depletion is also not consistent over time; some years show strong depletion while others do not, due to variations in the dynamics and temperature of the stratosphere. There is a great deal of natural variability in ozone levels, and along with the long-term changes due to human activities, natural variations continue to occur. Transport of ozone can result in days of very high or very low UV levels. Because of the nature of ozone depletion, elevated UV is generally observed in spring, when biological systems are most sensitive. Increased UV doses, especially when combined with other environmental stresses, pose a threat to some arctic species and ecosystems.

Because ozone depletion is expected to persist over the Arctic for several more decades, model results anticipate up to a 90% increase in spring UV doses for 2010-2020, relative to those in 1972-1992.

Arctic Ozone Recovery Delayed by Climate Change

No significant improvement in stratospheric ozone levels over the Arctic is projected for the next few decades. One reason is that increasing levels of greenhouse gases, while warming the troposphere, actually cool the stratosphere. This can worsen ozone depletion over the poles because lower temperatures strengthen the swirl of winds known as the polar vortex and encourage the formation of polar stratospheric clouds. The icy particles of these clouds are sites on which ozone-destroying chemical reactions occur. And the vortex isolates the stratosphere over the Arctic and prevents ozone from outside the region from replenishing the depleted ozone over the Arctic. Thus, for the next few decades, ozone depletion and elevated UV levels are projected to persist over the Arctic. At the same time, a reduction in springtime snow and ice cover due to warming is likely to expose vulnerable young plant and animal life to elevated UV levels.

Arctic Ozone in March

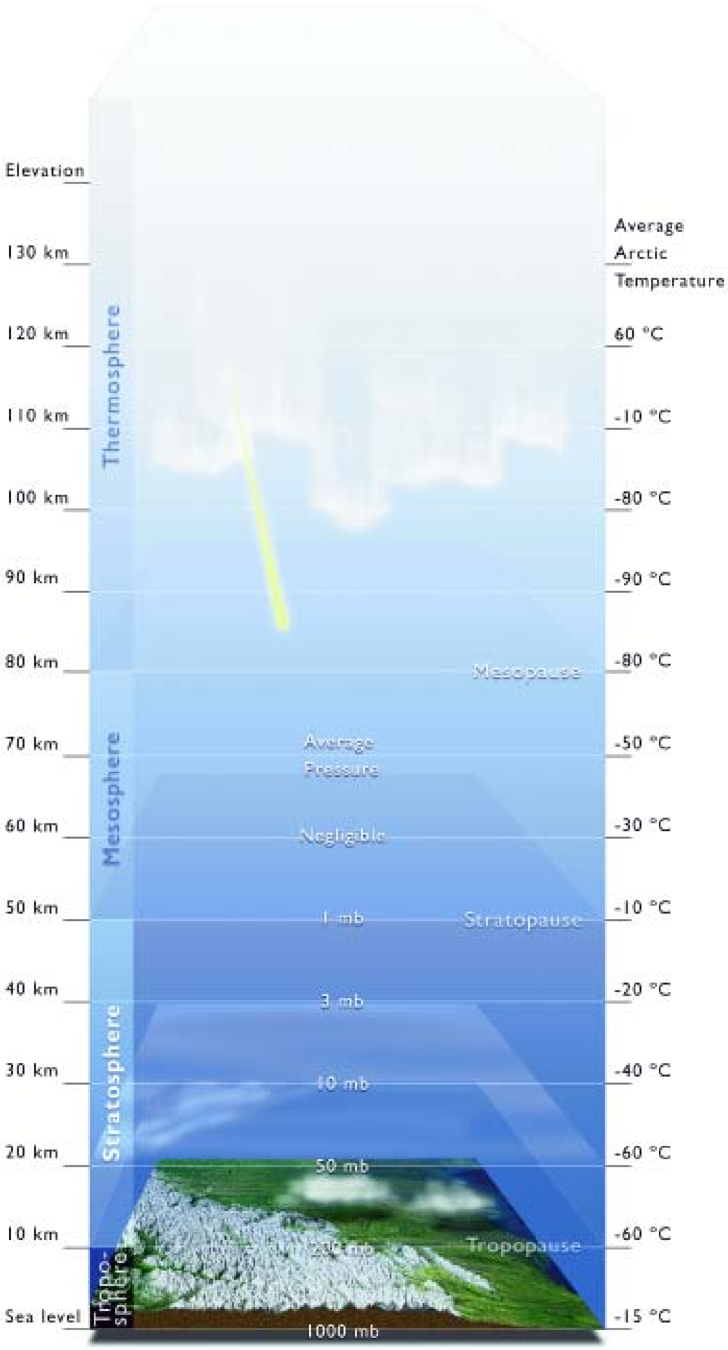


Ozone levels vary significantly from year to year. There is also a strong downward trend in ozone that is especially pronounced at the poles. This graph shows a pre-depletion average (solid red line) compared to ozone levels in more recent years. Natural variations in meteorological conditions influence the year-to-year changes, especially in the Arctic where depletion is highly sensitive to temperature. The blue line represents a monthly average in March in the Arctic. After 1982, significant depletion is found in most years.

Because ozone depletion is expected to persist over the Arctic for several more decades, episodes of very low spring ozone levels are likely to continue. Model results anticipate up to a 90% increase in springtime UV doses for 2010-2020 relative to those in 1972-1992. Because the models used to make these projections assume full compliance with the Montreal Protocol and its amendments, ozone recovery is likely to be slower and UV levels higher than projected if the phase-out of ozone-depleting chemicals is not achieved as outlined by the Protocol and its amendments.

Polar stratospheric clouds.

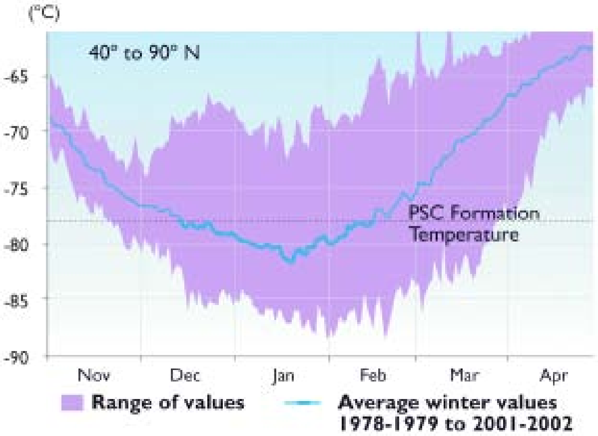
Layers of the Atmosphere



No significant improvement in stratospheric ozone levels over the Arctic is projected for the next few decades.

Key Finding #9

Temperatures in the Polar Lower Stratosphere



Over the Arctic, minimum air temperatures in the lower stratosphere are near -80˚C in January and February. Polar stratospheric clouds (PSCs) form when temperatures fall below -78˚C. The icy particles of these clouds are sites upon which ozone-destroying chemical reactions take place. Increasing concentrations of greenhouse gases, while warming the air near the earth's surface, act to cool the stratosphere, causing these clouds to form for a longer period of time, worsening ozone depletion.

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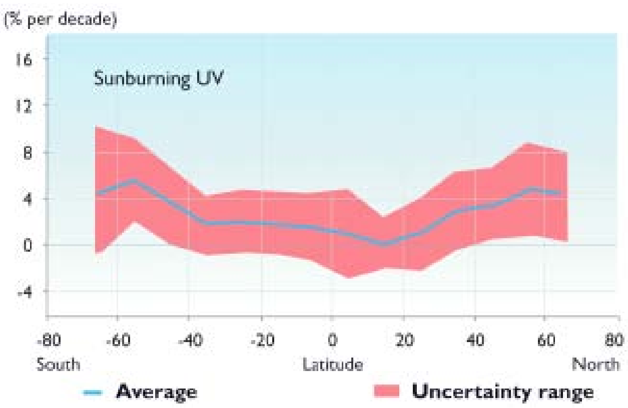
Impacts of UV on People

Human beings receive about half their lifetime UV dose by the time they are 18 years old. Current elevated UV levels in the Arctic indicate that the present generation of young people is likely to receive about a 30% greater lifetime UV dose than any prior generation. Such increases in UV doses are important to people of the Arctic because UV can induce or accelerate incidence of skin cancer, cornea damage, cataracts, immune system suppression, viral infections, aging of the skin, sunburn, and other skin disorders. Skin pigmentation, while protecting to some extent against skin cancer, is not an efficient protector against UV-induced immune system suppression. The immunosuppressive effects of UV play an important role in UV-induced skin cancer by preventing the destruction of skin cancers by the immune system. Some evidence suggests a connection between exposure to sunlight and non-Hodgkin's lymphoma and autoimmune diseases such as multiple sclerosis, with the relationship suggested to be via the immunosuppressive effects of UV. Because UV is known to activate viruses such as the herpes simplex virus through immune suppression, increased UV could increase the incidence of viral diseases among arctic populations, particularly as climate warming may introduce virus-carrying insect species to the Arctic.

Eye damage is of particular concern in the Arctic. UV has traditionally been measured on a flat, horizontal surface, but this does not represent the way a person receives a UV dose. People, who are generally vertical when outside, receive a higher dose than a horizontal surface, largely due to reflection from snow. Measurements incorporating this fact indicate that springtime ozone depletion could contribute greatly to UV effects on the eyes due to the significance of snow reflection. Observations show that UV doses to vertical surfaces such as the eyes are higher at the end of April than at any other time of the year. These high doses suggest that the amount of UV received when looking toward the horizon can be equivalent or greater than the amount received when looking directly upward. People can reduce the risks of UV-induced health effects by limiting their exposure through the use of sunscreens, sunglasses, protective clothing, and other preventative measures.

Changes in Surface UV Radiation



Sunburning UV has increased worldwide since 1980. The graph shows this UV at the surface, estimated from observed decreases in ozone and the relationship between ozone and UV established at various locations. The UV increases are largest near the poles because the reduction in ozone has been largest there.

In addition to the impacts on human health, UV radiation is known to adversely affect many materials used in construction and other outdoor applications. Exposure to UV can alter plastics, synthetic polymers used in paint, and natural polymers present in wood. Increased UV exposure due to ozone depletion is therefore likely to decrease the useful life of these materials and add costs for more frequent painting and other maintenance. High surface reflectivity due to snow cover and long hours of sunlight in spring and summer along with springtime ozone losses can combine to deliver a high cumulative UV dose to vertical surfaces such as the walls of buildings, leading to degradation of susceptible materials. The high winds and repeated freezing and thawing that occur in the Arctic may exacerbate materials problems that can develop as a result of UV damage. The costs of early replacement imply rising infrastructure costs that are likely to be paid for by individuals.

Impacts of UV on Ecosystems

Ecosystems on Land

Plants and animals show a variety of effects from increased UV radiation, though these effects vary widely by species. In the short term, a few species are projected to benefit, while many more would be adversely affected. Long-term effects are largely unknown. In addition to direct effects, animals will be indirectly affected by changes in plants. For example, pigments that are needed to protect plants against UV also make them less digestible for the animals that depend upon them. So while some plants can adapt to higher UV levels by increasing their pigmentation, there are often wider implications of this adaptation for dependent animals and ecosystem processes. Increased UV also has long-term impacts on ecosystem processes that reduce nutrient cycling and can decrease productivity.

Springtime in the Arctic is a critical time for the birth and growth of animals and plants. Historically, ozone had been at its highest levels in the spring, offering living things the heightened UV protection they needed during this sensitive time. Since ozone depletion due to manmade chemicals became a problem several decades ago, spring is now the time of year with the largest losses of stratospheric ozone. Longer daylight hours in springtime also add to UV exposure. Increases in UV also interact with climate change, such as the warming-related decrease in springtime snow cover, creating the potential for increased impacts on plants, animals, and ecosystems.

Birch Forests at Risk from Impacts of UV and Warming on the Autumn Moth

One example of a documented impact of increased UV that also has interactions with climate warming involves the autumn moth, an insect that eats the leaves of birch trees, causing tremendous damage to forests. Increased UV modifies the chemical structure of the birch leaves, greatly reducing their nutritional value. The moth caterpillars thus eat up to three times more than normal to compensate. Increased UV also appears to improve the immune system of the autumn moth. In addition, UV destroys the polyhydrosis virus that is an important controller of the survival of moth caterpillars. Increased UV is thus expected to lead to increased caterpillar populations that would in turn lead to more birch forest defoliation. At the same time, winter temperatures below -36˚C have previously limited the survival of autumn moth eggs, controlling moth populations. When winter temperatures rise above that threshold, caterpillar survival increases. Thus, observed and projected winter warming is expected to further increase moth populations, thus increasing damage to birch forests. The damaging impacts of climate change are likely to exceed the impacts of UV on birch forests.

Birch forest destroyed by autumn moths in Abisco, Sweden, 2004. Above is a close up of caterpillars eating birch foliage.

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Freshwater Ecosystems

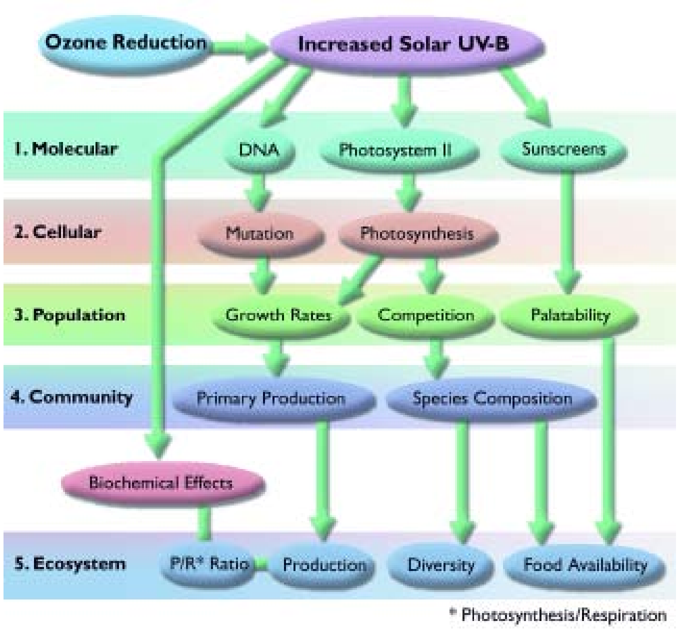
Some freshwater species, such as amphibians, are known to be highly sensitive to UV radiation, though the vulnerability of northern species has been little examined. Climate-related changes are projected in three important factors that control the levels of UV that reach living things in freshwater systems: stratospheric ozone, snow and ice cover, and materials dissolved in water that act as natural sunscreens against UV. Reduced stratospheric ozone is expected to persist for several decades, allowing increased UV levels to reach the surface, particularly in spring.

Climate warming is expected to increase levels of dissolved matter in many arctic freshwater systems as warming increases vegetation growth.

More significantly for aquatic life, the warming-induced reduction in springtime snow and ice cover will decrease protection for plants and animals normally shielded by that cover, leading to major increases in underwater UV exposure. White ice and snow form significant barriers to UV penetration; just two centimeters of snow can reduce the below-ice exposure to UV by about a factor of three. This is especially important in freshwater systems that contain low levels of dissolved matter that would shield against UV.

Lakes and ponds in northern areas of the Arctic generally contain much less dissolved material than those in the southern part of the region, due mainly to the greater vegetation that surrounds water bodies in the south. Arctic waters also contain little aquatic vegetation. In addition to the low levels of dissolved matter and resulting deep penetration of UV in arctic lakes and ponds, many of these freshwater systems are quite shallow. For example, the average depth of more than 900 lakes in northern Finland and about 80 lakes in arctic Canada is less than 5 meters. As a consequence, all living things, even those at the bottom of the lakes, are exposed to UV radiation.

Effects of Increased UV In Freshwater Ecosystems



UV is the most reactive waveband in the solar spectrum and has a wide range of effects, from the molecular level to the level of the whole ecosystem.

Some of the first impacts of warming will be associated with the loss of permanent ice cover in far northern lakes; these impacts are already taking place in the Canadian High Arctic. As the length of the ice-free season increases, these effects will be amplified. However, climate warming is expected to increase levels of dissolved matter in many arctic freshwater systems as warming increases vegetation growth. In addition, thawing permafrost could increase the amount of sediment stirred up in the water, adding protection against UV. These changes could partially offset the increases in UV due to reduced snow and ice cover and to decreased ozone levels.

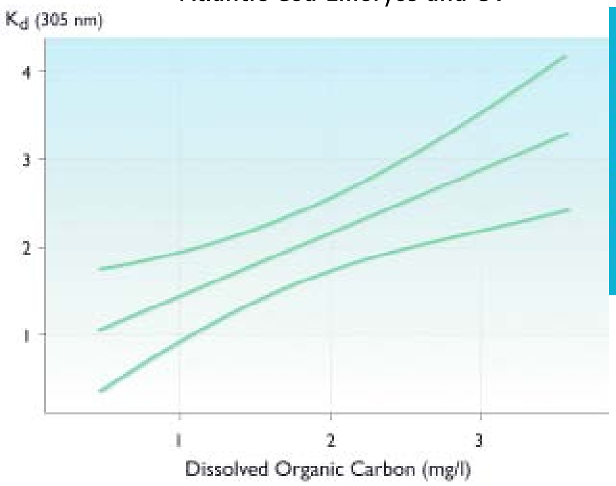
Marine Ecosystems

Phytoplankton, the tiny plants that are the primary producers of marine food chains, can be negatively impacted by exposure to UV radiation. Severe UV exposure can decrease productivity at the base of the food chain, perhaps by 20-30%. Current levels of UV negatively affect some secondary producers of marine food chains; UV-induced deaths in early life stages and reduced survival and ability to reproduce have been observed. Damage to the DNA of some species in samples collected from depths of up to 20 meters has been detected. Some species suffer strong negative impacts while others are resistant, depending on season and location of spawning, presence of UV screening substances, ability to repair UV-induced damage, and other factors.

There is clear evidence of detrimental effects of UV on early life stages of some marine fish species. For example, in one experiment, exposure to surface levels of UV killed many northern anchovy and Pacific mackerel embryos and larvae; significant sub-lethal effects were also reported. Under extreme conditions, this experiment suggested that 13% of the annual production of northern anchovy larvae could be lost. Atlantic cod eggs in shallow water (50 centimeters deep) also show negative effects due to UV exposure.

UV-induced changes in food chain interactions are likely to be more significant than direct effects on any one species. For example, UV exposure, even at low doses, reduces the content of important fatty acids in algae, decreasing the levels of these essential nutrients available to be taken up by fish larvae. Since fish larvae and the chain of predators through the food web require these essential fatty acids for proper development and growth, such a reduction in the nutritional quality of the food base has potentially widespread and significant implications for the overall health and productivity of the marine ecosystem. Exposure to UV radiation has many harmful effects on the health of fish and other marine animals, notably the suppression of the immune system. Even a single UV exposure decreases a fish's immune response, and the reduction is still visible 14 days after the exposure. This could cause increased susceptibility to disease by whole populations. The immune systems of young fish are likely to be even more vulnerable to UV as they are in critical stages of development, resulting in compromised immune defenses later in life.

Atlantic Cod Embryos and UV

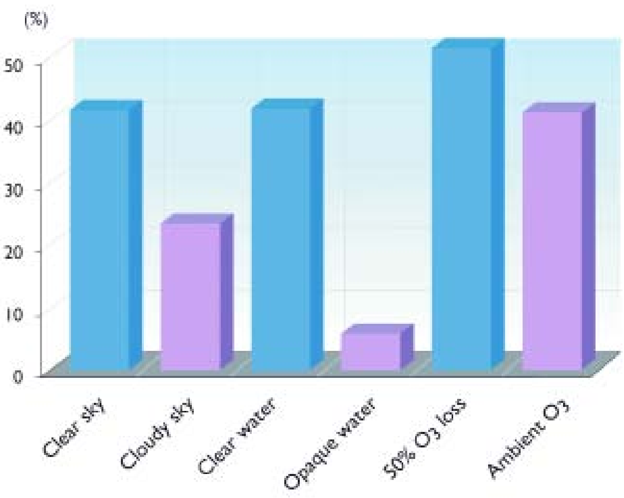


Atlantic cod embryos are sensitive to UV radiation. If protected from UV exposure, whether by stratospheric ozone, clouds, or dissolved organic carbon, their survival improves sharply. This graphic illustrates the level of protection provided by the organic matter content of the water column, with survival improving with increasing levels of dissolved organic matter. Climate change could affect levels of dissolved matter in water.

Key Finding #9

Recent studies estimate that a 50% seasonal reduction in stratospheric ozone could reduce primary production in marine systems by up to 8.5%. However, as with freshwater systems, cloud cover, ice cover, and the clarity or opaqueness of the water will also be important factors in determining UV exposure.

Zooplankton Embryos and UV



Model simulations of the relative effects of selected variables on UV-induced death in *Calanus finmarchicus*. The graph illustrates that clouds, water opacity, and ozone all reduce embryo deaths due to UV, but that the opacity of the water column has the strongest protective effect of the three variables. Zooplankton are an essential part of the marine food chain.

A species of marine zooplankton called *Calanus finmarchicus*.