REFERENCE

Ultraviolet Radiation: How it Affects Life on Earth

What Determines How Much Ultraviolet Radiation Reaches the Earth's Surface?

The amount of UV radiation reaching the Earth's surface varies widely around the globe and through time. Several factors account for this variation at any given location. They are discussed below in order of importance, and descriptions of their effects appear in succeeding paragraphs.

"The amount of UV radiation reaching the Earth's surface varies widely around the globe and through time."

The effects of ultraviolet radiation decrease with depth in the water column. (Image courtesy of NOAA)

Cloud Cover

Cloud cover plays a highly influential role in the amount of both UV-A and UV-B radiation reaching the ground. Each water droplet in a cloud scatters some incoming UV radiation back into space, so a thick cover of clouds protects organisms and materials from almost all UV. The larger the percentage of the sky that is covered by clouds, the less UV reaches the ground. The more opaque the cloud, the less UV-B. However, thin or broken cloud cover can be deceiving to people who are sunbathing, and the result can be an unexpected and severe sunburn.

Ozone in the Stratosphere

Ozone is the combination of three oxygen atoms into a single molecule (O_3). It is a gas produced naturally in the stratosphere where it strongly absorbs incoming

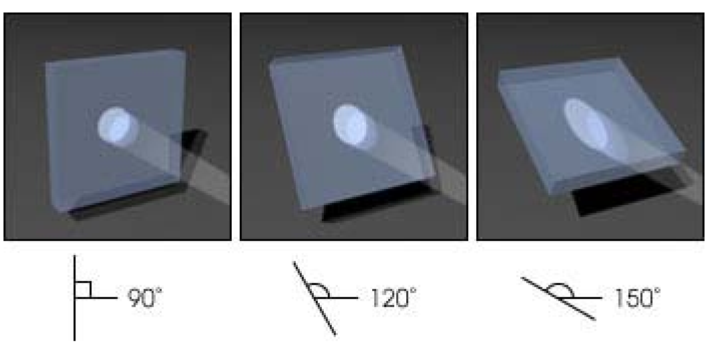
UV radiation. But as stratospheric ozone decreases, UV radiation is allowed to pass through, and exposure at the Earth's surface increases. Exposure to shorter wavelengths increases by a larger percentage than exposure to longer wavelengths. Scientists can accurately estimate the amount of UV-B radiation at the surface using global data from satellites such as NASA's TOMS (Total Ozone Mapping Spectrometer), GOME (Global Ozone Monitoring Experiment) and Aura (will open in a new window), to be launched in 2003, satellites. These satellite measurements are compared to ground-based measurements to ensure that the satellite data are valid. To calculate the reduction of UV-B by ozone, scientists consider the total ozone in a column of air from the stratosphere to the Earth's surface. At mid-latitudes, a decrease of one percent in ozone may result in an increase of between one (310 nm) and three (305 nm) percent of potentially harmful UV-B at the surface during mid-summer when UV-B is highest.

Ozone depletion is greater at higher latitudes, (toward the North and South Poles) and negligible at lower latitudes (between 30 degrees N and 30 degrees S). This means that decreases in ozone over Toronto are likely to be greater than those over Boston, and those over Boston greater than those over Los Angeles, while Miami will typically see the least ozone depletion of the four cities. However, cities at lower latitudes generally receive more sunlight because they are nearer the equator, so UV levels are higher even in the absence of ozone depletion. If ozone were to decrease at lower latitudes, southern cities would experience a greater absolute increase in UV-B than cities in the north for the same amount of ozone depletion.

The U.S. Department of Agriculture maintains an extensive network of radiometers to monitor ultraviolet B (UV-B) radiation across the country. The one pictured above is in Beltsville, Maryland. (Photograph by Jeannie Allen)

Oblique angle of sunlight reaching the surface

At any given time, sunlight strikes most of the Earth at an oblique angle. In this way, the number of UV photons is spread over a wider surface area, lowering the amount of incoming radiation at any given spot, compared to its intensity when the sun is directly overhead. In addition, the amount of atmosphere crossed by sunlight is greater at oblique angles than when the sun is directly overhead. Thus, the light travels through more ozone before reaching the Earth's surface, thereby increasing the amount of UV-B that is absorbed by molecules of ozone and reducing UV-B exposure at the surface.



The three images above illustrate how a change in angle between the sun and the Earth's surface affect the intensity of sunlight (and UV-B) on the surface. When the sun is directly overhead, forming a 90° angle with the surface, sunlight is spread over the minimum area. Also, the light only has to pass through the atmosphere directly above the surface. An increased angle between the sun and the surface—due to latitude, time of day, and season—

spreads the same amount of energy over a wider area, and the sunlight passes through more atmosphere, diffusing the light. Therefore, UV-B radiation is stronger at the equator than the poles, stronger at noon than evening, and stronger in summer than winter. (Illustration by Robert Simmon)

Aerosols

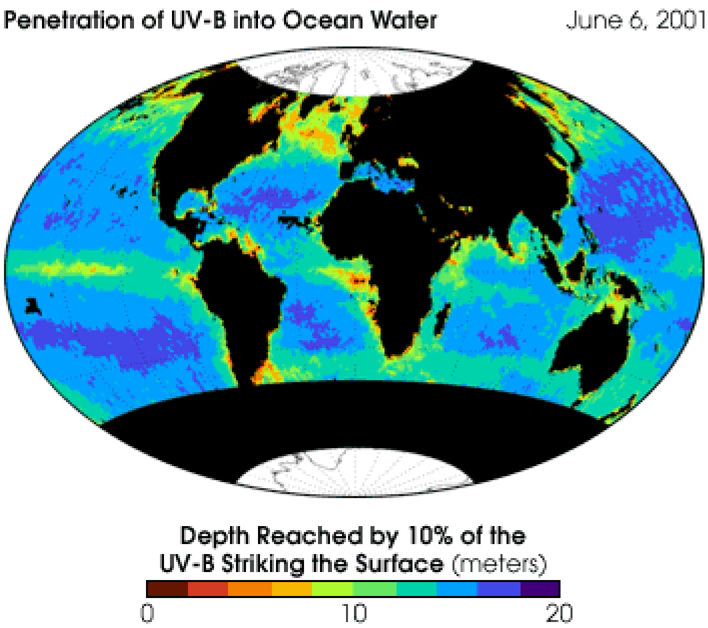
Unlike clouds, aerosols in the troposphere, such as dust and smoke, not only scatter but also absorb UV-B radiation. Usually the UV reduction by aerosols is only a few percent, but in regions of heavy smoke or dust, aerosol particles can absorb more than 50 percent of the radiation.

While the presence of aerosols anywhere in the atmosphere will always scatter some UV radiation back to space, in some circumstances, aerosols can contribute to an increase in UV exposure at the surface. For example, over Antarctica, cold temperatures cause ice particles (Polar Stratospheric Clouds) to form in the stratosphere. The nuclei for these particles are thought to be sulfuric acid aerosol, possibly of volcanic origin. The ice particles provide the surfaces that allow complex chemical reactions to take place in a manner than can deplete stratospheric ozone.

The eruption of Mt. Pinatubo in 1991 injected sulfate aerosols into the stratosphere, significantly though temporarily depleting stratospheric ozone and resulting in an increase of UV-B reaching the Earth's surface. Over millions of years, the biosphere has evolved to deal with temporary increases in UV from reductions in stratospheric ozone by natural causes such as volcanic eruptions, but has not had the time required to adjust to long-term ozone reductions attributed to human activities of the last 30 years. (Photograph courtesy USGS)

Water Depth

UV-B exposure decreases rapidly at increasing depths in the water column. In other words, water and the impurities in it strongly absorb and scatter incoming UV-B radiation. Some substances that are dissolved in water, such as organic carbon from nearby land, will also absorb UV-B radiation and enhance protection of microorganisms, plants, and animals from UV-B. Different masses of water at different locations contain different amounts of such dissolved substances and other particles, making evaluation of UV damage very difficult.



Ultraviolet B (UV-B) radiation reaches different depths in ocean water depending on water chemistry, the density of phytoplankton, and the presence of sediment and other particulates. The map above indicates the average depth UV-B penetrates into ocean water. At the depth indicated, only 10 percent 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. (Image courtesy Vasilkov et al., JGR-Oceans, 2001)

Elevation

Living organisms at high elevations are generally exposed to more solar radiation and with it, more UV-B than organisms at low elevations. This is because at high elevations UV-B radiation travels through less atmosphere before it reaches the ground, and so it has fewer chances of encountering radiation-absorbing aerosols or chemical substances (such as ozone and sulfur dioxide) than it does at lower elevations.

Ecosystems at high altitudes, such as this lake in the Rocky Mountains of Colorado, receive more exposure to ultraviolet radiation than ecosystems at low altitudes. (Photo courtesy Philip Greenspun © 1994)

Reflectivity of the Earth's Surface

As a highly reflective substance, snow dramatically increases UV-B exposure near the Earth's surface as it reflects most of the radiation back into the atmosphere, where it is then scattered back toward the surface by aerosols and air molecules. Fresh snow can reflect much as 94 percent of the incoming UV radiation. In contrast, snow-free lands typically reflect only 2-4 percent of UV and ocean surfaces reflect about 5-8 percent (Herman and Celarier 1997).

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back: Effects on the Biosphere

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