Q16

Does depletion of the ozone layer increase ground-level ultraviolet radiation?

Yes, ultraviolet radiation at Earth's surface increases as the amount of overhead total ozone decreases because ozone absorbs ultraviolet radiation from the Sun. Measurements by ground-based instruments and estimates made using satellite data provide evidence that surface ultraviolet radiation has increased in large geographic regions in response to ozone depletion.

Depletion of stratospheric ozone leads to an increase in solar ultraviolet radiation at Earth's surface. The increase occurs primarily in the ultraviolet-B (UV-B) component of the Sun's radiation. UV-B is defined as radiation in the wavelength range of 280 to 315 nanometers, which is invisible to the human eye. Long-term changes in UV-B radiation reaching the surface have been measured directly and can be estimated from changes in total ozone (see Q3).

Exposure to UV-B radiation can harm humans, other life forms, and materials (see Q2). Most of the effects of sunlight on the human body are caused by UV-B radiation. A principal effect is sunburn, which first appears as reddening of the skin, also called erythema. Excess exposure to UV-B radiation can lead to skin cancer. Erythemal radiation is regularly reported to the public in many countries in the form of the UV Index (UVI), which is proportional to the erythemally weighted UV radiation at Earth's surface. The UVI ranges from zero at night to more than 20 at noon for high elevations in the tropics.

Surface UV-B radiation. The amount of UV-B radiation reaching Earth's surface at a particular location depends in large part on total column ozone (see Q3) in the atmosphere at that location. Ozone molecules in the stratosphere and in the troposphere absorb UV-B radiation, thereby significantly reducing the amount that reaches Earth's surface (see Q2). If conditions occur that reduce the abundance of ozone molecules somewhere in the troposphere or stratosphere, total ozone is reduced and the amount of UV-B radiation reaching Earth's surface is increased proportionately.

Additional causes of UV changes. The actual amount of UV-B radiation reaching Earth's surface at a specific location and time depends on a number of other factors, in addition to the amount of total ozone. The primary additional factor is the elevation of the Sun in the sky, which changes at any location with daily and seasonal cycles. Other factors include the altitude of the location, local cloudiness, the amount of ice or snow cover, and the amounts of atmospheric particles (aerosols) in the atmosphere above the location. Changes in clouds and aerosols are partially related to air pollution and greenhouse gas emissions from human activities. The seasonal change in the Earth–Sun distance is also a significant factor affecting the amount of UV-B radiation reaching the surface.

Measurements indicate that both increases and decreases in UV radiation at certain locations have resulted from variations in one or more of these factors. Estimating the impact of changes in these factors is complex. For example, an increase in cloud cover usually results in a reduction of UV radiation below the clouds and at the same time could increase UV radiation at a location in the mountains above the clouds. Conversely, if clouds don't sufficiently block the direct beam from the Sun, reflections from cloud particles can result in an increase in the amount of UV-B reaching the surface.

Biologically-weighted UV and the UV Index (UVI). The effect of ozone on the amount of biologically relevant UV that arrives at the Earth's surface is governed by the wavelength dependence of the biological action involved, which typically — as in the case for skin damage — increases towards shorter (higher energy) UV-B wavelengths. Effects are commonly reported in terms of the UVI. All else being equal, the UVI rises as the abundance of total ozone declines. This inverse relationship between total ozone and the UVI measured at surface locations at stations throughout the world is shown in **Figure Q16-1**. The observations show that a 50% decline in total ozone is associated with a factor of two increase in the UVI.

The UVI is used internationally to increase public awareness about the detrimental effects of UV on human health and to guide the need for personal protective measures. Largest values of the UVI occur in the tropics, where the midday Sun has the highest elevation throughout the year and total ozone values tend to be low (see Figure Q3-1). At all latitudes, the UVI is larger in mountainous areas (due to less overhead air to scatter or absorb the radiation) and over snow- or ice-covered regions (due to increased surface reflectivity). Values of the UVI greater than 10 are considered 'extreme': under this circumstance, damage to sensitive fair skin can occur within 15 minutes of exposure.

The expected variation of the UVI with respect to total ozone is shown by the line marked "Model" in Figure Q16-1, which is in excellent agreement with the observations. The sensitivity of UV-B to ozone change is similar to that for the UVI, whereas other biological weightings exhibit different sensitivities. For example, the sensitivity for damage to DNA as a function of total ozone is about twice as large as that for the UVI and UV-B, while the sensitivity for the production of Vitamin D in the skin is intermediate between those for DNA-damage and erythema.

Long-term surface UV changes. Changes in surface UV since

Relationship Between Changes in Total Column Ozone and UV Index

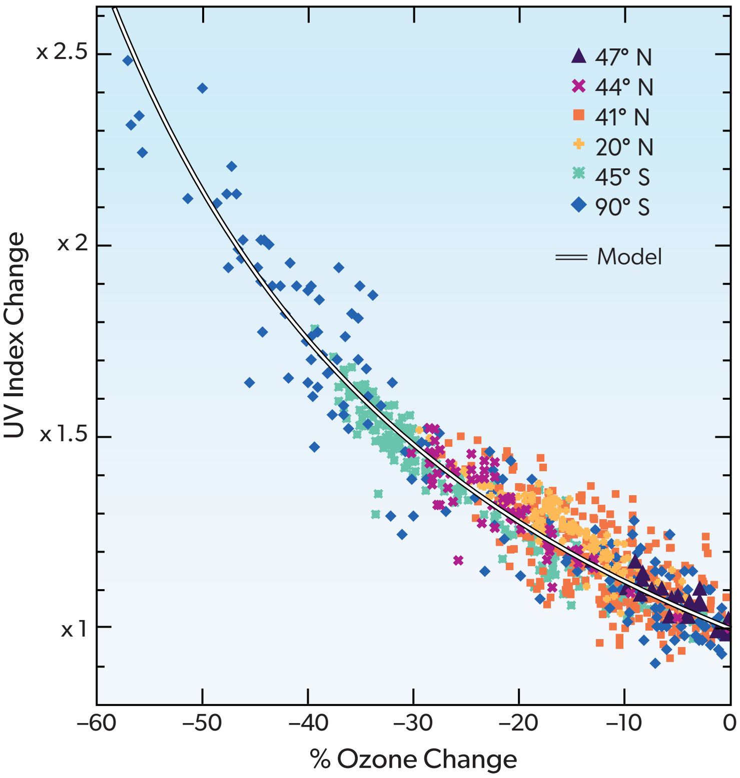

Figure Q16-1. Relationship between changes in total column ozone and the UVI measured at six sites distributed throughout the world. All data are for cloud-free conditions and are acquired at the same solar elevation for each site during the 1990s. The observed variations in ozone are large. For example, at the South Pole the ozone amount is sometimes reduced by more than 50% from its maximum. The corresponding UVI for that lowest ozone amount is a factor of 2.5 larger than for the highest ozone amount. At lower latitudes, ozone changes are smaller, but increases in the UVI can still exceed a factor of 1.5. UVI data for all sites show a similar ozone dependence, which agrees well with the dependence predicted using a model of radiative transfer through the atmosphere, as shown by the smooth curve labeled "Model".

the onset of ozone depletion are not well documented. Estimated changes derived from satellite measurements of ozone are incomplete because the backscattered radiation used by the satellites does not fully penetrate the lowermost portion of the atmosphere. Consequently, effects on UV radiation at Earth's surface due to interactions of sunlight with atmospheric aerosols and clouds must be estimated using computer models. Few ground-based measurements of UV radiation suitable for long term trend analysis were available prior to the early 1990s, during the period of most pronounced ozone depletion (see Q12). The start of the UV instrument record is further complicated by the volcanic eruption of Mount Pinatubo in 1991 (see Q13). Stratospheric aerosols from this eruption contributed to widespread ozone loss and also directly blocked solar radiation, including UV radiation, for more than a year.

The maximum daily UVI varies dramatically with location and season due largely to its strong dependence on solar elevation angle. Ground-based measurements since the early 1990s from the Palmer research station on the Antarctic Peninsula, the city of San Diego in southern California, and at Point Barrow near Utqiaġvik in northern Alaska enable a direct comparison between the UVI at polar and lower latitudes. The data show that the large geographical differences in the historical UVI have been dramatically affected by ozone depletion, especially at the Antarctic site, where the increases exceed historical geographic differences (see **Figure Q16-2**).

For San Diego and Point Barrow, the daily maximum UVI is largest during summer, when the midday Sun is closest to being overhead. For the Antarctic site, the daily maximum UVI now peaks in spring, the season of lowest total ozone due to the ozone hole (see Q10). The daily maximum UVI decreases significantly after mid-December due to the seasonal recovery of total ozone, following the break-up of the ozone hole (see Q10).

Prior to the development of the Antarctic ozone hole, the UVI was always much higher at San Diego (32°N) than at Palmer Station (64°S). Measurements at Palmer Station demonstrate the dramatic effect of Antarctic ozone depletion. There, estimates of the UVI for the years 1970 to 1976, a period before the appearance of the ozone hole, are compared with measurements for the period 1990–2020 when Antarctic ozone depletion increased the UVI throughout spring and into summer (orange shading). The development of the ozone hole led to large enhancements of the UVI that persist for many months, with the greatest increases occurring during spring.

The maximum UVI at Palmer Station is now larger by about a factor of 2.5 compared with the pre-ozone-hole period. The highest UVIs observed in spring now exceed those measured in spring and early summer in San Diego, despite San Diego's much lower latitude. The large levels of UV radiation reaching the surface due to the Antarctic ozone hole have had an adverse effect on the microscopic plants and animals at the base of the food chain in the high-latitude marine environment.

At San Diego, measurements of the UVI since 1992 and UVI values reconstructed based on pre-ozone depletion values are almost indistinguishable. This small change is consistent with the small variation in total ozone observed at subtropical latitudes (see Q12) and with the finding that the maximum daily UVI has remained essentially constant at these latitudes over about the past 20 years. At the Arctic site near Point Barrow, the UVI has increased by approximately 20% since the 1970s.

Modeling UV changes. Despite the short data record, trends in the UVI measured at unpolluted sites since the early 1990s agree well with trends calculated from changes in total ozone. These measurements show that the change in the UVI from 1996 (around the time that stratospheric chlorine peaked, see Figure Q15-1) to 2020 have been small.

Model simulations of ozone in a world without the Montreal Protocol show that large increases in the UVI due to ozone depletion occur during the period 1996 to 2020. In these simulations, at mid-southern latitudes the UVI in summer increases by

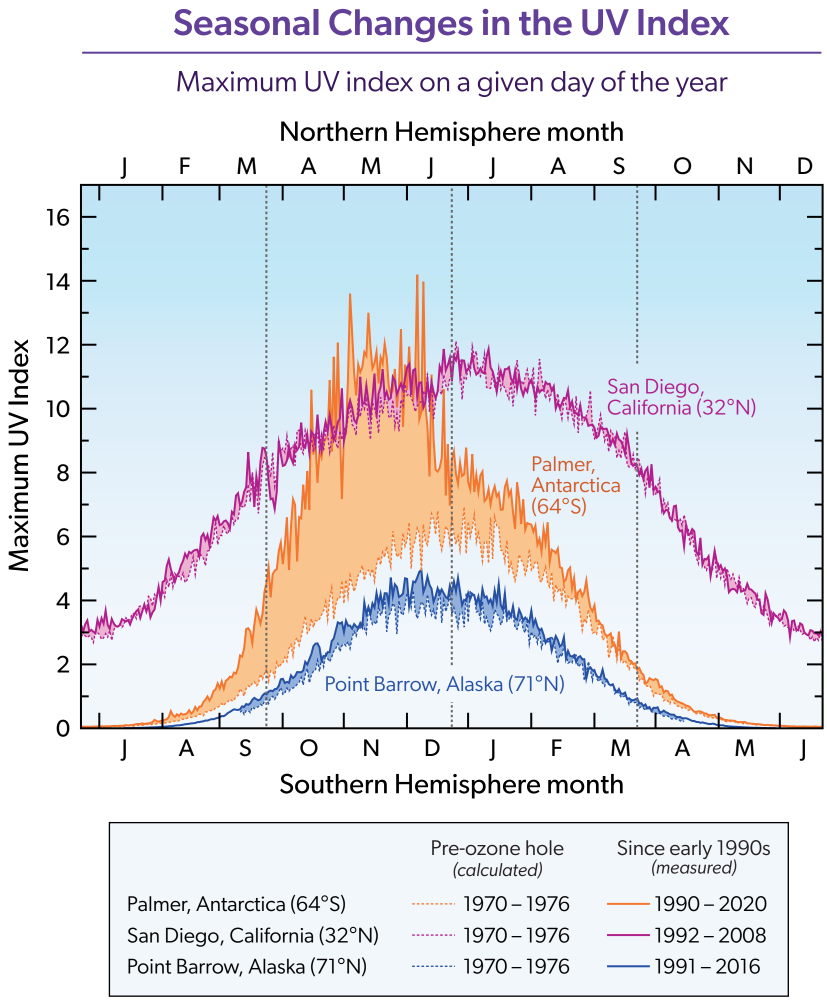

Figure Q16-2. Long-term changes in the UV Index (UVI), which is a measure of the erythemal radiation that reaches the surface. The figure shows the daily maximum UVI at three locations: San Diego, California; Point Barrow near Utqiaġvik in northern Alaska; and Palmer Station in Antarctica. The daily maximum UVI is shown for two time periods: a more recent period corresponding to the availability of measurements starting in the early 1990s (solid lines, as indicated) and a pre-ozone hole time period of 1970–1976, computed using simulated total ozone values at the three locations for this time period. The shaded region for each measurement site represents the difference between the pre-ozone hole UVI and the observed UVI, starting with early 1990s data. The UVI observations from Palmer, Antarctica demonstrate the importance of ozone depletion on the amount of erythemal radiation reaching the surface. For 1990–2020, springtime values of the daily maximum UVI at Palmer equaled or exceeded those measured in spring at San Diego, which is located at a much lower latitude and, as a consequence, experienced much larger values of the daily maximum UVI than Palmer prior to the development of the ozone hole. The three thin vertical dotted lines show the dates of the spring equinox, the summer solstice, and the autumn equinox.

about 20%, and in springtime the UVI in Antarctica doubles without the Montreal Protocol. These illustrative estimates serve as a powerful testament to the benefit of the Montreal Protocol's role in protecting human health and the environment.

UV changes and human health. Over the past several decades, depletion of the stratospheric ozone layer together with societal changes in lifestyle have increased UV radiation exposure for many people. Increased UV exposure has adverse health effects, primarily associated with eye and skin disorders. UV radiation is a recognized risk factor for eye cataracts. For the skin, the most common threat is skin cancer. Over the past decades, the incidence of several types of skin tumors has risen significantly among people of all skin types. On the other hand, an important human health benefit of UV-B radiation exposure is the production of vitamin D, which plays a significant role in bone metabolism and the immune system. Human exposure to solar UV-B radiation requires a careful balance to maintain adequate levels of vitamin D, while minimizing the risks of skin and eye disorders.

Skin cancer in humans typically occurs long after exposure to UV radiation that causes sunburn. Even under the current provisions of the Montreal Protocol and its amendments and adjustments, projections of additional skin cancer cases associated with ozone depletion are largest in the first half of the 21st century. This projection represents a significant global health issue. Since recovery to 1980 values of total ozone averaged over 60°S to 60°N is projected to occur around the middle of this century (see Figure Q20-1), ozone depletion will continue to contribute to adverse human health effects over the coming decades.

In addition to detrimental effects on human health, increases in UV radiation reaching the surface also impact air quality, aquatic and terrestrial plants and ecosystems, biogeochemical cycling, and outdoor materials. The impacts of UV radiation are discussed in greater detail in reports by the Environmental Effects Assessment Panel (EEAP) of the Montreal Protocol on Substances that Deplete the Ozone Layer[3].

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[3] https://ozone.unep.org/science/assessment/eeap