Fungal spores from mold growth in moist areas in homes have been associated with health effects in occupants, including allergies and asthma (IOM, 1993). Headaches, respiratory distress, and cardiovascular effects are also associated with exposure to molds.

No specific indicators have been identified at this time to address the human health effects associated with indoor air pollution.

1.4 Stratospheric Ozone

Although ozone is a harmful pollutant at ground level, it plays a valuable role in the stratosphere–the part of the atmosphere at an altitude of 10 to 30 km–by filtering harmful radiation from the sun. The sun's radiation bathes the Earth in ultraviolet (UV) wavelengths of 150 to 400 nanometers (nm). Ultraviolet radiation in the band between 280 and 320 nm, known as UV-B, is harmful to most organisms.

About 90 percent of the planet's ozone at a given time is in a thin layer of the lower stratosphere called the ozone layer, which also includes other gases. Ozone is constantly being created and destroyed by UV radiation. About 95 to 99 percent of UV-B radiation that reaches the Earth's surface is absorbed by ozone and oxygen in the ozone layer (NASA, 2002).

The ozone layer varies in space and time and is highly susceptible to changes in atmospheric chemical reactions by which it is created and destroyed. Scientists in the 1970s and 1980s discovered that human-caused changes to the composition of the atmosphere were leading to depletion of stratospheric ozone (NASA, 2002). They initially identified chlorofluorocarbons (CFCs) as being particularly significant stratospheric ozone depleters. Scientists subsequently identified additional human-produced ozone-depleting substances (ODSs).

This section poses four questions about stratospheric ozone:
- What are the trends in the Earth's ozone layer? (Section 1.4.1)
- What is causing changes to the ozone layer? (Section 1.4.2)
- What human health effects are associated with stratospheric ozone depletion? (Section 1.4.3)
- What ecological effects are associated with stratospheric ozone depletion? (Section 1.4.4)

1.4.1 What are the trends in the Earth's ozone layer?

Indicators
Ozone levels over North America

The most recent authoritative assessment of the Earth's stratospheric ozone is the *Scientific Assessment of Ozone Depletion: 2002* (Scientific Assessment Panel, 2003), conducted under the auspices of the United Nations Environment Programme (UNEP) and the World Meteorological Organization (WMO). The study found an average decrease of about 6 percent in average ozone concentrations between 35 and 60 degrees South for the period 1997 to 2001, compared with pre-1980 average values. It also found an average decrease of 3 percent between 35 and 60 degrees North for the same period (Scientific Assessment Panel, 2003).

It is generally believed that, after years of continuing thinning of the stratospheric ozone layer, the ozone layer will recover over the next several years as a result of international controls of ODSs. The Montreal Protocol on Substances that Deplete the Ozone Layer (Montreal Protocol), for example, restricts global manufacturing of CFCs (Scientific Assessment Panel, 2003).

Scientists largely agree that a thinning of the stratospheric ozone layer causes an increase in the amount of UV radiation, especially UV-B, that reaches the Earth's surface. This outcome is consistent with theories about the physical processes involved, measurable locally by ground-based and satellite-based instruments.

While acknowledging high uncertainty in the estimates, it is estimated that UV irradiance has increased since the early 1980s by 6 to 14 percent at more than ten sites distributed over mid and high latitudes of both hemispheres. Over the past two decades, UV increases are believed to have been considerably greater at higher latitudes. In the Northern Hemisphere, they are believed to be greater in the winter/spring than in the summer/fall (Scientific Assessment Panel, 2003). The estimates of increasing UV-B levels are based on indirect methods and models rather than direct measurements.

Because of the phase-out of ODS, total stratospheric concentrations of ODS seem to have peaked; it is believed that stratospheric ozone concentrations, near the lowest point since systematic measurements began, will not decrease any further and will eventually recover. These developments lead to the conclusion that UV radiation levels reaching the Earth's surface are close to the maximum they will reach as a result of human-induced stratospheric ozone depletion (Scientific Assessment Panel, 2003).

Obtaining reliable measurements of broad trends in levels of UV radiation reaching ground level in North America, however, is a complex task. It is particularly challenging to measure in ways that highlight the relationship between ozone depletion and UV radiation. The amount of incoming UV radiation is affected by several variables, including latitude, season, time of day, snow cover, sea ice cover, surface reflectivity, altitude, clouds, and aerosols. Determining which portion of any change is attributable to ozone depletion is difficult.

The indicator used to address the extent of change to the ozone layer is ozone levels over North America.

Indicator Ozone levels over North America, - Category 1

Data mapped for this indicator are derived from the Total Ozone Mapping Spectrometer (TOMS), flown on NASA's Nimbus-7 satellite. The TOMS measures amounts of backscattered UV radiation at various wavelengths. Backscattered radiation levels at wavelengths where ozone absorption does and does not take place are compared with radiation directly from the sun at the same wavelengths, allowing scientists to derive a "total ozone" amount in the Earth's atmosphere.

The data for this indicator are presented in Dobson Units (DU) which measure how thick the ozone layer would be if compressed in the Earth's atmosphere (at sea level and at 0°C.) One DU is defined to be 0.01 mm thickness at standard temperature and pressure.

What the Data Show

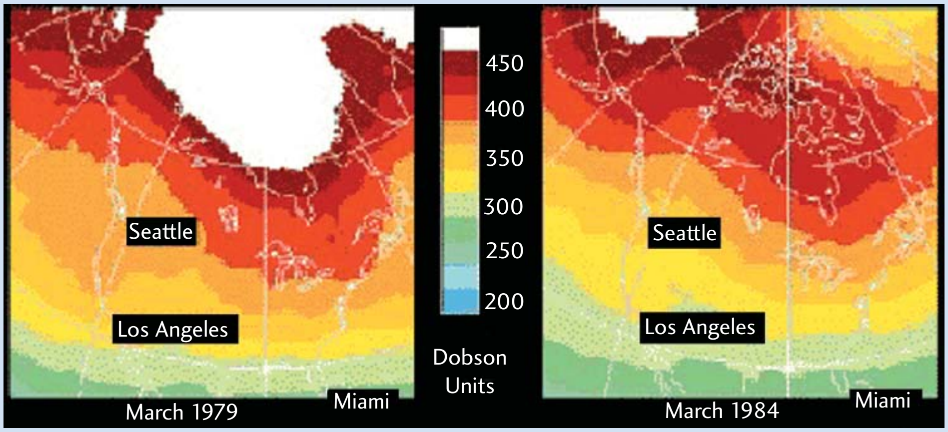
The ozone maps illustrate graphically and quantitatively the thinning of total column ozone over North America during a 15-year period. For example, in 1979, the ozone column over the Seattle area was 391 Dobson Units (DU), but in 1994 it had dropped to 360 DU. Over Los Angeles, the ozone column during that time dropped from 368 DU to 330 DU, and over Miami from 303 DU to 296 DU (Exhibit 1-26) (NASA, March 1979 and March 1994). Although exact calculations cannot be made from Exhibit 1-26, the graph demonstrates thinning of the ozone layer over much of the globe.

In general, ozone depletion is greater at higher latitudes. Therefore, it is predictable that the decrease in the ozone layer over Seattle is greater than over Los Angeles, with the ozone layer over Miami experiencing the lowest depletion among the three cities. However, southern cities also have higher levels of UV-B, so even with less depletion, the net increase in UV-B can exceed that over northern latitudes.

According to the latest estimates in the *Scientific Assessment*, the global-average total column ozone during 1997 to 2001 was about 3 percent below average pre-1980 values (Scientific

Indicator | Ozone levels over North America, March 1979 and March 1994 - Category 1 (continued)

Exhibit 1-26: Ozone levels over North America, 1979 and 1994



Source: NASA, Goddard Space Flight Center. Total Ozone Mapping Spectrometer (TOMS), flown on Nimbus-7 satellite. (January 24, 2003; Available: http://www.epa.gov/ozone/science/glob_dep.html).

Assessment Panel, 2003). Trends over North America reflect this global phenomenon.

Indicator Gaps and Limitations

TOMS provides no data during nighttime or during the longer periods of darkness in polar regions.

Data Source

The data source for this indicator was NASA, Total Ozone Mapping Spectrometer, flown on the Nimbus-7 satellite. March 1979 and March 1994. (See Appendix B, page B-7, for more information.)

1.4.2 What is causing changes to the ozone layer?

Indicators

Worldwide and U.S. production of ozone-depleting substances (ODSs)

Concentrations of ozone-depleting substances (effective equivalent chlorine)

Analyses have shown that the presence of CFCs and other ODSs was negligible before commercial production of CFCs and other ODSs began in the 1930s and 1940s (Scientific Assessment Panel, 2003).

The adoption of the 1987 Montreal Protocol significantly affected production levels, resulting in reduced concentrations of ODSs.

Worldwide emissions are estimated to have been reduced significantly, since peaking in 1993 (Scientific Assessment Panel, 2003). Likewise, there have been marked decreases in U.S. emissions of ODSs over the past decade, resulting in a 79 percent decrease in total ODP-weighted emissions from 1990 to 2000 (EPA, OAP, April 2002).

Two indicators are used to address this question:

- Worldwide and U.S. production of ODSs.
- Concentration of ODSs (effective equivalent stratospheric chlorine).

Indicator: Worldwide and U.S. production of ozone-depleting substances (ODSs) - Category 2

Worldwide ODS production estimates are derived from reports produced by each nation, as required under the Montreal Protocol and subsequent amendments.

Production, consumption, and emissions of ODSs are not identical; even though the ultimate destiny of a given pound of CFCs might be release to the atmosphere, a time lag is involved. ODSs initially are contained—and isolated from the atmosphere—after they are produced. They are likely to stay contained until they are consumed—for example, used as coolant in a refrigerator or as a foaming agent in polystyrene-foam hot cups. Once they are consumed, the ODSs still might not be released to the atmosphere until years later, such as when the cup degrades in a landfill, or when the refrigerator is disposed of or recycled (at which time the ODS may actually be reclaimed for further use).

Because of these complexities, consumption and emissions figures involve significant uncertainties—they are estimated based on rates of conversion. Production figures may be more meaningful, because they are compiled from data which a relatively small number of producing companies must report by law.

Exhibit 1-27: Worldwide ODS production and consumption (ODP-weighted tons), 1986 and 1999

Year	Production	Consumption
1986	1,768,789	1,784,015
1999	312,731	275,382

Source: United Nations Environment Programme, Ozone Secretariat. *Production and Consumption of Ozone Depleting Substances under the Montreal Protocol: 1986-2000*. April 2002.

What the Data Show

There have been marked decreases in worldwide production, and consumption of ODSs over the past 2 decades (Exhibit 1-27). Worldwide ODS production declined from approximately 1.8 million tons in 1986 to 313,000 tons in 1999 (UNEP, 2002). Worldwide measures are presented in ozone depletion potential (ODP)-weighted tons. Each ODS is weighted based on its damage to the stratospheric ozone; this is its ODP. U.S. production of selected ODSs peaked in 1988 and declined by nearly 65 percent in 5 years (Exhibit 1- 28) (USITC, 1994).

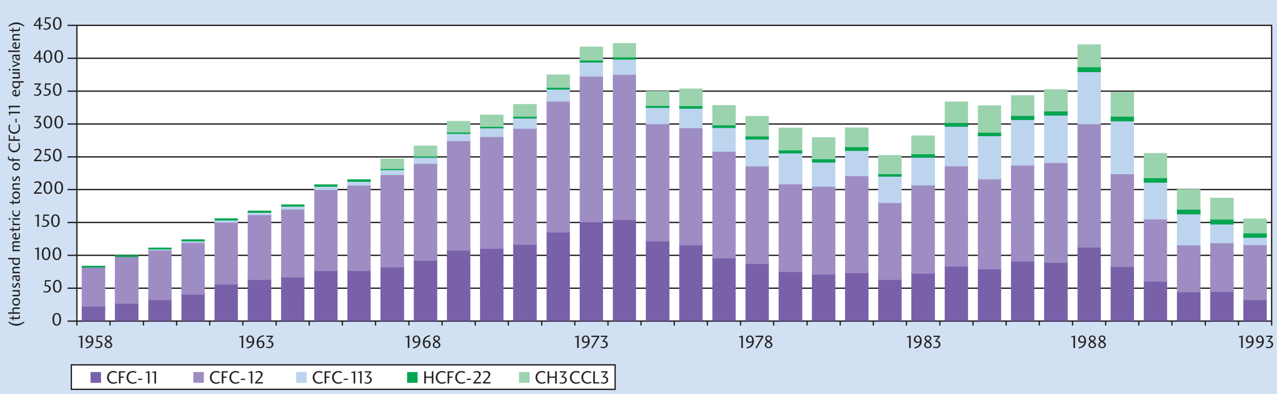
Indicator Gaps and Limitations

In some cases ODS production data are reliable because laws require that they be reported. Coverage from nation to nation is incomplete, however, and sometimes methods are inconsistent. Production estimates for the U.S. are generally reliable as a result of the legal reporting requirement for production figures and the small number of producers involved.

Data Sources

The data sources for this indicator were *Worldwide Estimates: Production and Consumption of Ozone Depleting Substances* 1986-2000, Ozone Secretariat/UNEP, 2002, and *1993 Synthetic Organic Chemicals; U.S. Production and Sales*, U.S. International Trade Commission, 1994. (See Appendix B, page B-7, for more information.)

Exhibit 1-28: U.S. production of selected ozone-depleting chemicals, 1958-1993



Source: U.S. International Trade Commission. *1993 Synthetic Organic Chemicals; U.S. Production and Sales. 1994* (July 3, 2002; *http://www.epa.gov/ozone/science/indicat/index.html*).

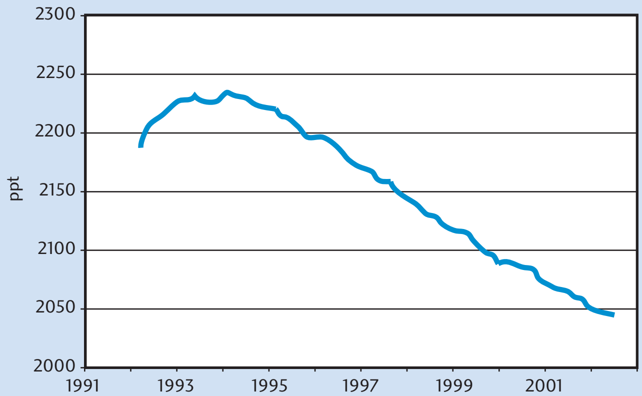
Indicator | Concentrations of ozone-depleting substances (effective equivalent chlorine) - Category 2

Effective equivalent chlorine (EECl), the amount of chlorine and bromine in the lower atmosphere, is used to represent concentrations of ozone-depleting substances. It is a convenient parameter for measuring with a single number the overall potential human effect on stratospheric ozone. EECl is derived by considering the changing concentrations of about a dozen gases that can affect the stratospheric ozone concentration. An index is then developed based on the ability of those gases to catalyze the destruction of ozone relative to the ability of chlorine to do so. The units of EECl are parts per trillion by volume.

What the Data Show

The *Scientific Assessment* states that the total effect of all ozone-depleting halogens in the atmosphere, estimated by calculating chlorine equivalents from atmospheric measurements of chlorine- and bromine- containing gases, continues to decrease. As of mid-2000, equivalent organic chlorine in the troposphere was nearly five percent below the peak value in 1992 to 1994 (Exhibit 1-29). The recent decrease is slightly slower than in the mid-1990s due to the reduced influence of methyl chloroform on this decline (Scientific Assessment Panel, 2003).

Exhibit 1-29: Global total effective equivalent chlorine (EECl), 1992-2002



Source: Updated from Montzka, Stephen A., et al. *Present and future trends in the atmospheric burden of ozone-depleting halogens*. April 1999;
NOAA, Climate Monitoring & Diagnostics Laboratory. Halocarbons and other Atmospheric Trace Species (HATS). 2002. March 18, 2003;
http://www.cmdl.noaa.gov/hats/graphs/graphs.html).

In 1996, EPA measurements indicated that concentrations of methyl chloroform had started to fall, indicating that emissions had been reduced. Concentrations of other ozone-depleting substances in the upper layers of the atmosphere, like CFCs, are also beginning to decrease. Stratospheric chlorine levels have apparently peaked and are expected to slowly decline in coming years (EPA, OAQPS, September 2002). The best current estimate from computer models is that the atmospheric burden of halogens will return to 1980 levels (pre-Antarctic ozone hole) around the middle of this century if the Montreal Protocol and its Amendments are fully adhered to (Scientific Assessment Panel, 2003).

Indicator Gaps and Limitations

The precision of this indicator depends on understanding the chemistry and behavior of the many different gases involved. For example, accurate estimates of the atmospheric lifetime of a gas are essential to assigning it the proper weight relative to other gases. As scientific understanding of atmospheric chemistry improves, calculations continue to be refined.

Data Source

The data source for this indicator was *Scientific Assessment of Ozone Depletion: 2002*, Scientific Assessment Panel of the Montreal Protocol on Substances that Deplete the Ozone Layer, WMO, 2003. (See Appendix B, page B-8, for more information.)

1.4.3 What human health effects are associated with stratospheric ozone depletion?

The increased ground-level UV radiation that can result from stratospheric ozone depletion is expected to have significant adverse human health effects. UV-B radiation is linked to skin cancer, increased incidence of cataracts, and suppression of the immune system (EPA, OAQPS, September 2002). Approximately 1.3 million new cases of skin cancer are diagnosed every year in the U.S., according to the Centers for Disease Control and Prevention (CDC) and the American Cancer Society. Malignant melanoma accounts for about 75 percent of the approximately 9,800 skin cancer deaths in the U.S. annually. The incidence rate of malignant melanoma is increasing by about 3 percent annually, although death rates have remained constant (Wingo, et al., 1999).

Possible increased UV radiation levels is only one of many factors that could affect skin cancer incidence. Others include behavioral changes (people spending more time at the beach or outdoors) and changes in screening for, diagnosis of, and reporting of the disease.

Data on UV-B radiation and tropospheric ozone are used to calculate benefits from accelerated phase-out schedules for ODSs. EPA

Exhibit 1-30: Estimated benefits of phaseout of ozone-depleting substances (sections 604, 606, and 609 of the Clean Air Act)

Health Effects - Quantified	Estimate	Basis for Estimate
■ Melanoma and nonmelanoma skin cancer (fatal)	6.3 million lives saved from skin cancer in the U.S. between 1990 and 2165	Dose-response function based on UV exposure and demographics of exposed populations[1]
■ Melanoma and nonmelanoma skin cancer (non-fatal)	299 million avoided cases of non-fatal skin cancers in the U.S. between 1990 and 2165	Dose-response function based on UV exposure and demographics of exposed populations[1]
■ Cataracts	27.5 million avoided cases in the U.S. between 1990 and 2165	Dose-response function uses a multivariate logistic risk function based on demographic characteristics and medical history[1]
Ecological Effects - Quantified	**Estimate**	**Basis for Estimate**
■ American crop harvests	Avoided 7.5 percent decrease from UV-b radiation by 2075	Dose-response sources: Teramura and Murali (1986), Rowe and Adams (1987)
■ American crops	Avoided decrease from tropospheric ozone	Estimate of increase in troposhpheric ozone: Whitten and Gery (1986). Dose-response source: Rowe and Adams (1987)
■ Polymers	Avoided damage to materials from UV-b radiation	Source of UV-b/stabilizer relationship; Horst (1986)
Health Effects - Unquantified		
Skin cancer: reduced pain and suffering		
Reduced morbidity effects of increased UV. For example: ■ reduced actinic keratosis (pre-cancerous lesions resulting from excessive sun exposure) ■ reduced immune system suppression		
Ecological Effects - Unquantified		
Ecological effects of UV. For example, benefits relating to the following: ■ recreational fishing ■ forests ■ overall marine ecosystem ■ avoided sea level rise, including avoided beach erosion, loss of coastal wetlands, salinity of estuaries and aquifers ■ other crops ■ other plant species ■ fish harvests		
Ecological benefits of reduced trophospheric ozone relating to the overall marine ecosystem, forests, mand-made materials, crops, other plant species, and fish harvests		
Benefits to people and the environment outside the U.S.		
Effects, both ecological and human health, associated with global warming		

Notes:
1) For more detail see EPA's *Regulatory Impact Analysis: Protection of Stratospheric Ozone* (1988).
2) Note that the ecological effects, unlike the health effects, do not reflect the accelerated reduction and phaseout schedule of section 606.
3) Benefits due to the section 606 methyl bromide phaseout are not included in the benefits total because EPA provides neither annual incidence estimates nor a monetary value. The EPA does provide, however, a total estimate of 2,800 avoided skin cancer fatalities in the U.S.

Source: EPA, Office of Air and Radiation. *The Benefits and Costs of the Clean Air Act 1990 to 2010. EPA Report to Congress.* November 1999.

estimates that between 1990 and 2165, in the U.S. alone 6.3 million fatal skin cancers, 299 million cases of non-fatal skin cancers, and 27.5 million cases of cataracts will be prevented because of the worldwide phase-out of ODSs. (EPA, OAR, November 1999) (Exhibit 1-30). These are estimated cumulative effects, so there are no data series or trends to evaluate.

No specific indicators have been identified at this time for human health effects of stratospheric ozone depletion.

1.4.4 What ecological effects are associated with stratospheric ozone depletion?

UV radiation in sunlight affects the physiological and developmental processes of plants. Even though plants have mechanisms to reduce or repair these effects and some ability to adapt to increased UV-B levels, UV radiation can still directly affect plant growth. It can also produce indirect effects such as changes in plant form, distribution of nutrients within the plant, timing of developmental phases, and secondary metabolism. These changes can be even more important than direct damage because of their implications for plant competitive balance, herbivory, plant diseases, and biogeochemical cycles (UNEP, 1994).

UV radiation can also affect aquatic life. UV exposure affects both orientation mechanisms and motility in phytoplankton, resulting in reduced survival rates for these organisms. Scientists have demonstrated a direct reduction in phytoplankton production as a result of ozone depletion-related increases in UV-B (DeMora, et al., 2000). Small increases in UV-B radiation have been found to cause damage in the early developmental stages of fish, shrimp, crab, amphibians, and other animals, the most severe effects being decreased reproductive capacity and impaired larval development. Animals higher on the food chain that depend on these organisms for food could, in turn, be affected (UNEP, 1994).

Increases in UV radiation could also affect terrestrial and aquatic biogeochemical cycles, and, as a result, alter both sources and sinks of greenhouse and chemically important trace gases. These potential changes would contribute to biosphere-atmosphere feedback that attenuates or reinforces the atmospheric buildup of these gases (UNEP, 1994). Synthetic polymers, naturally occurring biopolymers, and some other materials of commercial interest also are adversely affected by UV radiation, but special additives somewhat protect some modern materials from UV-B. Increases in UV-B levels nonetheless will likely accelerate their breakdown, limiting their usefulness outdoors (UNEP, 1994).

No specific indicators have been identified at this time to address the ecological effects associated with stratospheric ozone depletion.

1.5 Climate Change

The issue of global climate change involves changes in the radiative balance of the Earth–the balance between energy received from the sun and emitted from the Earth. This report does not attempt to address the complexities of this issue. For information on the $1.7 billion annual U.S. Global Climate Research Program and Climate Change Research Initiative, please find *Our Changing Planet: The Fiscal Year 2003 U.S. Global Climate Research Program* (November 2002) at www.usgcrp.gov and the *Draft Ten-Year Strategic Plan for the Climate Change Science Program* at www.climatescience.gov.