FREQUENTLY ASKED QUESTIONS ABOUT OZONE

Ozone is very rare in our atmosphere, averaging about three molecules of ozone for every 10 million air molecules. In spite of this small amount, ozone plays vital roles in the atmosphere. This appendix to the Executive Summary of the *Scientific Assessment of Ozone Depletion: 1998* provides answers to some of the questions that are most frequently asked about ozone and the changes that have been occurring in recent years. These questions and answers are based on the information presented in this 1998 report, which was prepared by 304 scientists from 35 countries worldwide. Therefore, the information presented here represents the knowledge of a large group of experts from the international scientific community.

Ozone is mainly found in two regions of the Earth's atmosphere. Most ozone (about 90%) resides in a layer that begins between 8 and 18 kilometers (5 and 11 miles) above the Earth's surface and extends up to about 50 kilometers (30 miles). This region of the atmosphere is called the stratosphere. The ozone in this region is commonly known as the ozone layer. The remaining ozone is in the lower region of the atmosphere, which is commonly called the troposphere. The figure below shows an example of how ozone is distributed in the atmosphere.
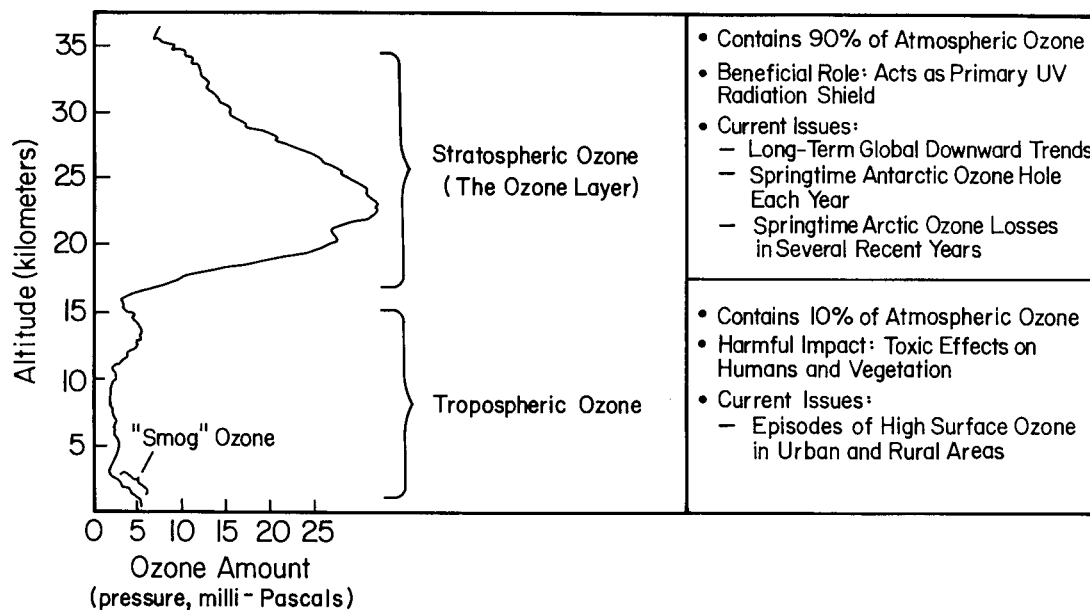
The ozone molecules in these two regions are chemically identical, because they all consist of three oxygen atoms and have the chemical formula O_3. However, they have very different effects on humans and other living beings. Stratospheric ozone plays a beneficial role by absorbing most of the biologically damaging ultraviolet sunlight (called UV-B), allowing only a small amount to reach the Earth's surface. The absorption of ultraviolet radiation by ozone creates a source of heat, which actually forms the stratosphere itself (a region in which the temperature rises as one goes to higher altitudes). Ozone thus plays a key role in the temperature structure of the Earth's atmosphere. Without the filtering action of the ozone layer, more of the Sun's UV-B radiation would penetrate the atmosphere and would reach the Earth's surface. Many experimental studies of plants and animals and clinical studies of humans have shown the harmful effects of excessive exposure to UV-B radiation.

At the Earth's surface, ozone comes into direct contact with life-forms and displays its destructive side. Because ozone reacts strongly with other molecules, high levels of ozone are toxic to living systems. Several studies have documented the harmful effects of ozone on crop production, forest growth, and human health. The substantial negative effects of surface-level tropospheric ozone from this direct toxicity contrast with the benefits of the additional filtering of UV-B radiation that it provides.

The dual role of ozone leads to two separate environmental issues. There is concern about *increases* in ozone in the troposphere. Low-lying ozone is a key component of photochemical smog, a familiar problem in the atmosphere of many cities around the world. Higher

Atmospheric Ozone

Stratospheric Ozone (The Ozone Layer)
- Contains 90% of Atmospheric Ozone
- Beneficial Role: Acts as Primary UV Radiation Shield
- Current Issues:
  - Long-Term Global Downward Trends
  - Springtime Antarctic Ozone Hole Each Year
  - Springtime Arctic Ozone Losses in Several Recent Years

Tropospheric Ozone
- Contains 10% of Atmospheric Ozone
- Harmful Impact: Toxic Effects on Humans and Vegetation
- Current Issues:
  - Episodes of High Surface Ozone in Urban and Rural Areas

Altitude (kilometers) / "Smog" Ozone / Ozone Amount (pressure, milli-Pascals)

amounts of surface-level ozone are increasingly being observed in rural areas as well.

There is also widespread scientific and public interest and concern about *losses* of ozone in the stratosphere. Ground-based and satellite instruments have measured decreases in the amount of stratospheric ozone in our atmosphere. Over some parts of Antarctica, up to 60% of the total overhead amount of ozone (known as the column ozone) is depleted during Antarctic spring (September-November). This phenomenon is known as the Antarctic ozone hole. In the Arctic polar regions, similar processes occur that have also led to significant chemical depletion of the column ozone during late winter and spring in 6 out of the last 9 years. The ozone loss from January through late March has been typically 20-25%, and shorter-period losses have been higher, depending on the meteorological conditions encountered in the Arctic stratosphere. Smaller, but still significant, stratospheric ozone decreases have been seen at other, more-populated regions of the Earth. Increases in surface UV-B radiation have been observed in association with local decreases in stratospheric ozone, from both ground-based and satellite-borne instruments.

The scientific evidence, accumulated over more than two decades of study by the international research community, has shown that human-produced chemicals are responsible for the observed depletions of the ozone layer. The ozone-depleting compounds contain various combinations of the chemical elements chlorine, fluorine, bromine, carbon, and hydrogen and are often described by the general term halocarbons. The compounds that contain only chlorine, fluorine, and carbon are called chlorofluorocarbons, usually abbreviated as CFCs. CFCs, carbon tetrachloride, and methyl chloroform are important human-produced ozone-depleting gases that have been used in many applications including refrigeration, air conditioning, foam blowing, cleaning of electronics components, and as solvents. Another important group of human-produced halocarbons is the halons, which contain carbon, bromine, fluorine, and (in some cases) chlorine and have been mainly used as fire extinguishants. Governments have decided to eventually discontinue production of CFCs, halons, carbon tetrachloride, and methyl chloroform (except for a few special uses), and industry has developed more "ozone-friendly" substitutes.

Two responses are natural when a new problem has been identified: cure and prevention. When the problem is the destruction of the stratospheric ozone layer, the corresponding questions have been the following ones: Can we repair the damage already done? How can we prevent further destruction? Remedies have been investigated that could (1) remove CFCs selectively from the atmosphere, (2) intercept ozone-depleting chlorine before much depletion has taken place, or (3) replace the ozone lost in the stratosphere (perhaps by shipping the ozone from cities that have too much smog or by making new ozone). However, because ozone reacts strongly with other molecules, it is too unstable to be made elsewhere (e.g., in the smog of cities) and transported to the stratosphere. Considering the huge volume of the Earth's atmosphere and the magnitude of global stratospheric ozone depletion, the suggested remedies quickly become much too expensive, too energy consuming, impractical, and potentially damaging to the global environment.

Repair involves the internationally agreed-upon Montreal Protocol and its Amendments and Adjustments. This agreement regulates the production of CFCs and other ozone-depleting substances. Production of the most damaging ozone-depleting substances was eliminated, except for a few critical uses, by 1996 in developed countries and will be eliminated by 2010 in developing countries. As a result, the total concentration of chlorine in the lower atmosphere that can be carried to the stratosphere has peaked already. The concentrations in the stratosphere will likely peak by the end of this decade and then will start to decrease slowly as natural processes remove the ozone-depleting substances. All other things being equal, and with adherence to the international agreements, the ozone layer is expected to recover over the next 50 years or so.

How Can Chlorofluorocarbons (CFCs) Get to the Stratosphere If They're Heavier than Air?

CFCs reach the stratosphere because the Earth's atmosphere is always in motion and mixes the chemicals added into it.

CFC molecules are indeed several times heavier than air. Nevertheless, thousands of measurements from balloons, aircraft, and satellites demonstrate that the CFCs are actually present in the stratosphere. This is because winds and other air motions mix the atmosphere to altitudes far above the top of the stratosphere much faster than molecules can settle according to their weight. Gases such as CFCs that do not dissolve in water and that are relatively unreactive in the lower atmosphere are mixed relatively quickly and therefore reach the stratosphere regardless of their weight.

Measured changes in the concentration of constituents versus altitude teach us more about the fate of compounds in the atmosphere. For example, the two gases carbon tetrafluoride (CF_4, produced mainly as a by-product of the manufacture of aluminum) and CFC-11 (CCl_3F, used in a variety of human activities) are both heavier than air.

Carbon tetrafluoride is completely unreactive at altitudes up to at least 50 kilometers in the atmosphere. Measurements show it to be nearly uniformly distributed throughout the atmosphere (as illustrated in the figure below, the abundance of CF_4 is nearly the same at all altitudes where measurements have been made). There have been measurements over the past two decades of several other completely unreactive gases, both lighter than air (neon) and heavier than air (argon and krypton), that show that they also mix upward through the stratosphere regardless of their weight.

CFC-11 is unreactive in the lower atmosphere (below about 15 kilometers) and is similarly uniformly mixed there, as shown in the figure. However, the abundance of CFC-11 decreases as the gas reaches higher altitudes, because it is broken down by high-energy solar ultraviolet radiation. Chlorine released from this breakdown of CFC-11 and other CFCs remains in the stratosphere for several years, where every chlorine atom destroys many thousands of molecules of ozone.

Atmospheric Measurements of CFC-11 and CF_4
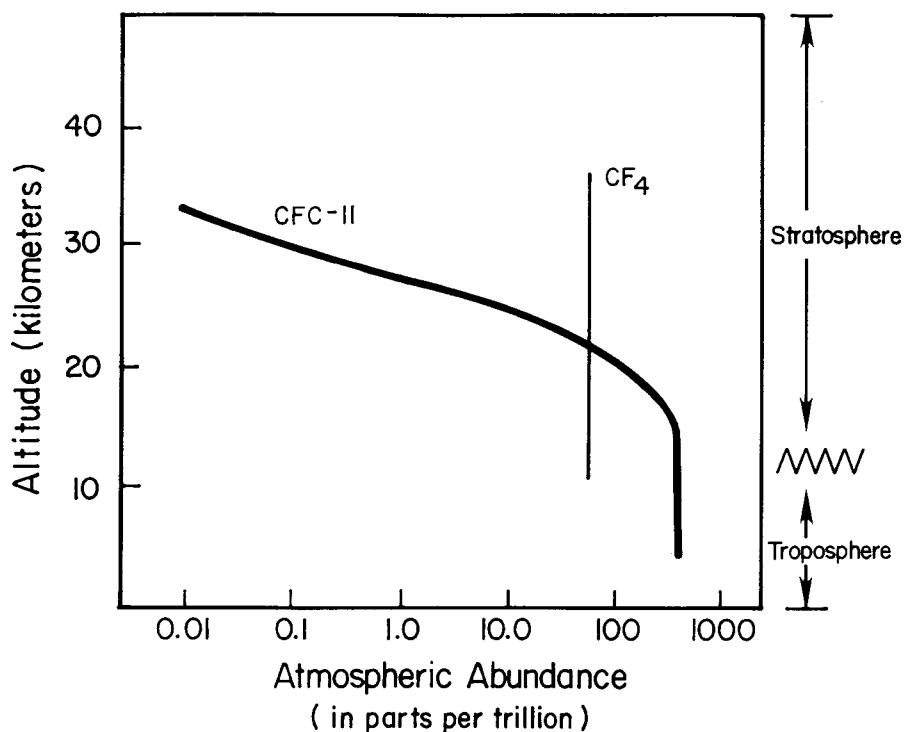
What is the Evidence that Stratospheric Ozone is Destroyed by Chlorine and Bromine?

Numerous laboratory investigations and analyses of worldwide measurements made in the stratosphere have demonstrated that chlorine- and bromine-containing chemicals destroy ozone molecules.

Research studies in the laboratory show that chlorine (Cl) reacts very rapidly with ozone. They also show that the reactive chemical chlorine monoxide (ClO) formed in that reaction can undergo further processes that regenerate the original chlorine, allowing the sequence to be repeated very many times (a chain reaction). Similar reactions also take place between bromine and ozone.

But do these ozone-destroying reactions occur in the "real world"? All the accumulated scientific experience demonstrates that the same chemical reactions do take place in nature. Many other reactions (including those of other chemical species) are often also taking place simultaneously in the stratosphere. This makes the connections among the changes difficult to untangle. Nevertheless, whenever chlorine (or bromine) and ozone are found together in the stratosphere, the ozone-destroying reactions are taking place.

Sometimes a small number of chemical reactions are so dominant in the natural circumstance that the connections are almost as clear as in laboratory experiments. Such a situation occurs in the Antarctic stratosphere during the springtime formation of the ozone hole. Independent measurements made by instruments from the ground and from balloons, aircraft, and satellites have provided a detailed understanding of the chemical reactions in the Antarctic stratosphere. Large areas reach temperatures so low (less than -80˚C, or -112˚F) that stratospheric clouds form, which is a rare occurrence, except during the polar winters. These polar stratospheric clouds allow chemical reactions that transform chlorine species from forms that do *not* cause ozone depletion into forms that do cause ozone depletion. Among the latter is chlorine monoxide, which initiates ozone destruction in the presence of sunlight. The amount of reactive chlorine in such regions is therefore much higher than that observed in the middle latitudes, which leads to much faster chemical ozone destruction. The chemical reactions occurring in the presence of these clouds are now well understood from studies under laboratory conditions that mimic those found naturally in the atmosphere.

Scientists have repeatedly observed a large number of chemical species over Antarctica since 1986. Among the chemicals measured were ozone and chlorine monoxide, which is the reactive chemical identified in the laboratory as one of the participants in the ozone-destroying chain reactions. The satellite maps shown in the figure below relate the accumulation of chlorine monoxide observed over Antarctica and the subsequent ozone depletion that occurs rapidly in a few days over very similar areas.

Similar reactions involving chlorine and bromine have also been shown to occur during winter and spring in the Arctic polar regions, which leads to some chemical depletion of ozone in that region. Because the Arctic is not usually as persistently cold as the Antarctic, fewer stratospheric clouds form, and therefore there is less ozone depletion in the Arctic, which is the subject of a later question.

Chlorine Monoxide and the Antarctic Ozone Hole: Late August 1996
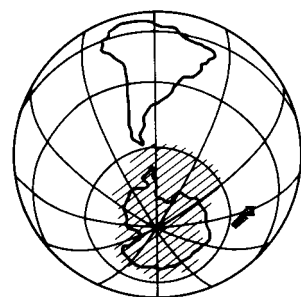
Region of
High Chlorine Monoxide (ClO)
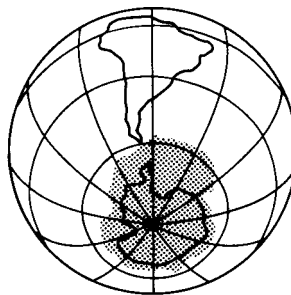
Region of
Low Ozone (O_3)

# Does Most of the Chlorine in the Stratosphere Come from Human or Natural Sources?

Most of the chlorine in the stratosphere is there as a result of human activities, as the figure below illustrates.

Many compounds containing chlorine are released at the ground. Those that dissolve in water cannot reach stratospheric altitudes in significant amounts because they are "washed out" of the atmosphere in rain or snow. For example, large quantities of chlorine are released from evaporated ocean spray as sea salt (sodium chloride) particles. However, because sea salt dissolves in water, this chlorine is taken up quickly in clouds or in ice, snow, or rain droplets and does not reach the stratosphere. Another ground-level source of chlorine is from its use in swimming pools and as household bleach. When released, this chlorine is rapidly converted to forms that dissolve in water and therefore are removed from the lower atmosphere. Such chlorine never reaches the stratosphere in significant amounts. Volcanoes can emit large quantities of hydrogen chloride, but this gas is rapidly converted to hydrochloric acid, which dissolves in rain water, ice, and snow and does not reach the stratosphere. Even in explosive volcanic plumes that rise high in the atmosphere, nearly all of the hydrogen chloride is removed by precipitation before reaching stratospheric altitudes. Finally, although the exhaust from the Space Shuttle and from some rockets does inject some chlorine directly into the stratosphere, the quantities are very small (less than 1% of the annual input from halocarbons in the present stratosphere).

In contrast, the major ozone-depleting human-produced halocarbons — such as chlorofluorocarbons (CFCs) and carbon tetrachloride (CCl_4) — do not dissolve in water, do not react with snow or other natural surfaces, and are not broken down chemically in the lower atmosphere. Therefore, these and other human-produced substances containing chlorine do reach the stratosphere.

Several pieces of evidence combine to establish human-produced halocarbons as the primary source of stratospheric chlorine. First, measurements have shown that the chlorinated species that rise to the stratosphere are primarily manufactured compounds [mainly CFCs, carbon tetrachloride, methyl chloroform, and the hydro-chlorofluorocarbon (HCFC) substitutes for CFCs], together with small amounts of hydrochloric acid (HCl) and methyl chloride (CH_3Cl), which are partly natural in origin. Second, researchers have measured nearly all known gases containing chlorine in the stratosphere. They have found that the emissions of the human-produced halocarbons, plus the much smaller contribution from natural sources, could account for all of the stratospheric chlorine. Third, the *increase* in total stratospheric chlorine measured between 1980 and 1998 corresponds to the known increases in concentrations of human-produced halocarbons during that time.

Primary Sources of Chlorine Entering the Stratosphere in the Early 1990s
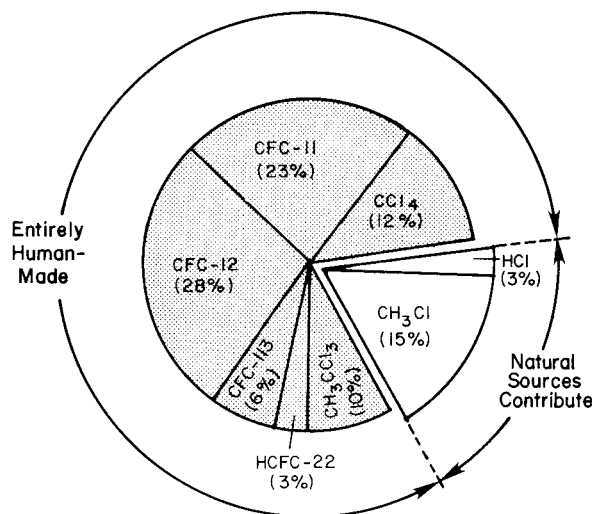
Can Natural Changes Such As the Sun's Output and Volcanic Eruptions Be Responsible for the Observed Changes in Ozone?

Although there are natural forces that cause fluctuations in ozone amounts, there is no evidence that natural changes are contributing significantly to the observed long-term trend of decreasing ozone.

The formation of stratospheric ozone is initiated by ultraviolet (UV) light coming from the Sun. As a result, the Sun's output affects the rate at which ozone is produced. The Sun's energy release (both as UV light and as charged particles such as electrons and protons) does vary, especially over the well-known 11-year sunspot cycle. Observations over several solar cycles (since the 1960s) show that total global ozone levels vary by 1-2% from the maximum to the minimum of a typical cycle. However, changes in the Sun's output cannot be responsible for the observed long-term changes in ozone, because the ozone downward trends are much larger than 1-2%. As the figure below shows, since 1978 the Sun's energy output has gone through maximum values in about 1980 and 1991 and minimum values in about 1985 and 1996. It is now increasing again toward its next maximum around the year 2002. However, the trend in ozone was downward throughout that time. The ozone trends presented in this and previous international scientific assessments have been obtained by evaluating the long-term changes in ozone after accounting for the solar influence (as has been done in the figure below).

Major, explosive volcanic eruptions can inject material directly into the ozone layer. Observations and model calculations show that volcanic particles cannot on their own deplete ozone. It is only the interaction of human-produced chlorine with particle surfaces that enhances ozone depletion in today's atmosphere.

Specifically, laboratory measurements and observations in the atmosphere have shown that chemical reactions on and within the surface of volcanic particles injected into the lower stratosphere lead to enhanced ozone destruction by increasing the concentration of chemically active forms of chlorine that arise from the human-produced compounds like the chlorofluorocarbons (CFCs). The eruptions of Mt. Agung (1963), Mt. Fuego (1974), El Chichón (1982), and particularly Mt. Pinatubo (1991) are examples. The eruption of Mt. Pinatubo resulted in a 30- to 40-fold increase in the total surface area of particles available for enhancing chemical reactions. The effect of such natural events on the ozone layer is then dependent on the concentration of chlorine-containing molecules and particles available in the stratosphere, in a manner similar to polar stratospheric clouds. Because the particles are removed from the stratosphere in 2 to 5 years, the effect on ozone is only temporary, and such episodes cannot account for observed long-term changes. Observations and calculations indicate that the record-low ozone levels observed in 1992-1993 reflect the importance of the relatively large number of particles produced by the Mt. Pinatubo eruption, coupled with the relatively higher amount of human-produced stratospheric chlorine in the 1990s compared to that at times of earlier volcanic eruptions.

Global Ozone Trend, Major Volcanic Eruptions, and Solar Cycles
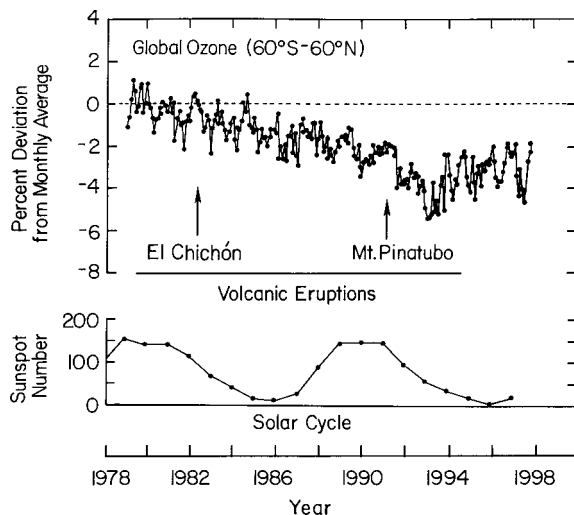
When Did the Antarctic Ozone Hole First Appear?

The springtime Antarctic ozone hole is a new phenomenon that appeared in the early 1980s.

The observed average amount of ozone during September, October, and November over the British Antarctic Survey station at Halley, Antarctica, first revealed notable decreases in the early 1980s, compared with the preceding data obtained starting in 1957. The ozone hole is formed each year when there is a sharp decline (currently up to 60%) in the total ozone over most of Antarctica for a period of about three months (September-November) during spring in the Southern Hemisphere. Late-summer (January-March) ozone amounts show no such sharp decline in the 1980s and 1990s. Observations from three other stations in Antarctica and from satellite-based instruments reveal similar decreases in springtime amounts of ozone overhead. Balloonborne ozone instruments show dramatic changes in the way ozone is distributed with altitude. As the figure below from the Syowa site shows, almost all of the ozone is now depleted at some altitudes as the ozone hole forms each springtime, compared to the normal ozone profile that existed before 1980. As explained in an earlier question (page 24), the ozone hole has been shown to result from destruction of stratospheric ozone by gases containing chlorine and bromine, whose sources are mainly human-produced halocarbon gases.

Before the stratosphere was affected by human-produced chlorine and bromine, the naturally occurring springtime ozone levels over Antarctica were about 30-40% lower than springtime ozone levels over the Arctic. This natural difference between Antarctic and Arctic conditions was first observed in the late 1950s by Dobson. It stems from the exceptionally cold temperatures and different winter wind patterns within the Antarctic stratosphere as compared with the Arctic. This is not at all the same phenomenon as the marked downward trend in ozone over Antarctica in recent years.

Changes in stratospheric meteorology cannot explain the ozone hole. Measurements show that wintertime Antarctic stratospheric temperatures of past decades had not changed prior to the development of the ozone hole each September. Ground, aircraft, and satellite measurements have provided, in contrast, clear evidence of the importance of the chemistry of chlorine and bromine originating from human-made compounds in depleting Antarctic ozone in recent years.

Springtime Depletion of the Ozone Layer over Syowa, Antarctica
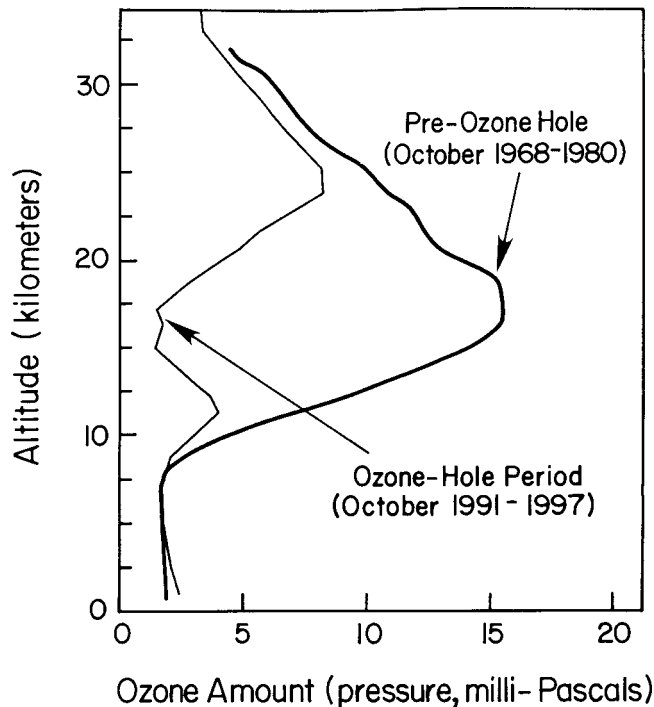
Why Has an Ozone Hole Appeared over Antarctica When CFCs and Halons Are Released Mainly in the Northern Hemisphere?

The Earth's atmosphere is continuously stirred over the globe by winds. As a result, ozone-depleting gases get mixed throughout the atmosphere, including Antarctica, regardless of where they are emitted. The special meteorological conditions in Antarctica cause these gases to be more effective there in depleting ozone compared to anywhere else.

Human emissions of chlorofluorocarbons (CFCs) and halons (bromine-containing gases) have occurred mainly in the Northern Hemisphere. About 90% have been released in the latitudes corresponding to Europe, Russia, Japan, and North America. Gases such as CFCs and halons, which are insoluble in water and relatively unreactive, are mixed within a year or two throughout the lower atmosphere. The CFCs and halons in this well-mixed air rise from the lower atmosphere into the stratosphere mainly in tropical latitudes. Winds then move this air poleward—both north and south—from the tropics, so that air throughout the global strato-sphere contains nearly equal amounts of chlorine and bromine.

In the Southern Hemisphere, the South Pole is part of a very large land mass (Antarctica) that is completely surrounded by ocean. This symmetry is reflected in the meteorological conditions that allow the formation in winter of a very cold region in the stratosphere over the Antarctic continent, isolated by a band of strong winds circulating around the edge of that region. The very low stratospheric temperatures lead to the formation of clouds (polar stratospheric clouds) that are responsible for chemical changes that promote production of chemically active chlorine and bromine. This chlorine and bromine activation then leads to rapid ozone loss when sunlight returns to Antarctica in September and October of each year, which then results in the Antarctic ozone hole. As the figure below depicts, the magnitude of the ozone loss has generally grown through the 1980s as the amount of human-produced ozone-depleting compounds has grown in the atmosphere.

Similar conditions do not exist over the Arctic. The wintertime temperatures in the Arctic stratosphere are not persistently low for as many weeks as over Antarctica, which results in correspondingly less ozone depletion in the Arctic (see the next question).

Schematic of the Growth of the Antarctic Ozone Hole

1979

1986

1991

1996
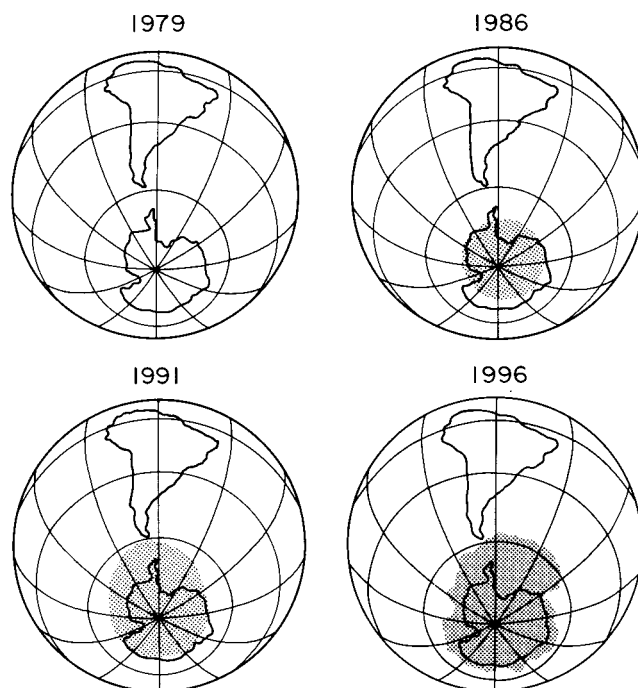
Is There an Ozone Hole over the Arctic?

Significant reductions in ozone content in the stratosphere above the Arctic have been observed during the late winter and early spring (January-March) in 6 of the last 9 years. However, these reductions, typically 20-25%, are much smaller than those observed currently each spring over the Antarctic (the ozone hole).

The difference between ozone content in the two polar regions (see figure below) is caused by dissimilar weather patterns. The Antarctic continent is a very large land mass surrounded by oceans. This symmetrical condition produces very low stratospheric temperatures within a meteorologically isolated region, the so-called polar vortex, which extends from about 65°S to the pole. The cold temperatures lead in turn to the formation of clouds, known as polar stratospheric clouds. These clouds provide surfaces that promote production of forms of chlorine and bromine that are chemically active and can rapidly destroy ozone. The conditions that maintain elevated levels of chemically active chlorine and bromine persist into September and October in Antarctica, when sunlight returns over the region to initiate ozone depletion.
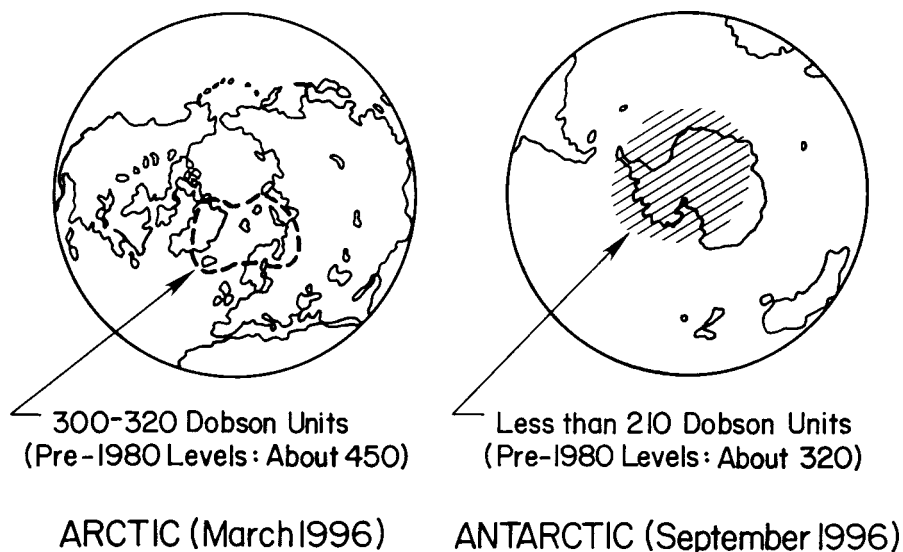
The winter meteorological conditions in the Northern Hemisphere, just like in the Southern Hemisphere, lead to the formation of an isolated region bounded by strong winds, in which the temperature is also cold enough for polar stratospheric clouds to form. However, the geographic symmetry about the North Pole is less than about the South Pole. As a result, large-scale weather systems disturb the wind flow, making it less stable over the Arctic region than over the Antarctic continent. These disturbances prevent the temperature in the Arctic stratosphere from being as cold as in the Antarctic stratosphere, and fewer polar stratospheric clouds are therefore formed. Nevertheless, chemically active chlorine and bromine compounds are also formed over the Arctic, as they are over Antarctica, from reactions at the surface of the clouds. But the cold conditions rarely persist into March, when sufficient sunlight is available to initiate large ozone depletion.

In recent years, there has been a string of unusually cold winters in the Arctic, compared with those in the preceding 30 years. The cold and persistent conditions have led to enhanced ozone depletion, because the atmospheric concentrations of ozone-depleting gases have also been relatively large during these years. However, the cause of the observed change in meteorological conditions is not yet understood. Such conditions might persist over the coming years, further enhancing ozone depletion. But it is also possible that, in the next few years, they could revert to conditions characteristic of a decade ago. In the latter case, chemical ozone depletion in the Arctic would be expected to diminish.

Therefore, although there has been significant ozone depletion in the Arctic in recent years, it is difficult to predict what may lie ahead, because the future climate of the Arctic stratosphere cannot be predicted with confidence.

A Schematic of the Ozone over the Arctic and Antarctica in 1996

300-320 Dobson Units
(Pre-1980 Levels: About 450)

Less than 210 Dobson Units
(Pre-1980 Levels: About 320)

ARCTIC (March 1996)   ANTARCTIC (September 1996)

Is the Depletion of the Ozone Layer Leading to an Increase in Ground-Level Ultraviolet Radiation?

The depletion of the ozone layer leads, on the average, to an increase in ground-level ultraviolet radiation, because ozone is an effective absorber of ultraviolet radiation.

The Sun emits radiation over a wide range of energies, with about 2% in the form of high-energy, ultraviolet (UV) radiation. Some of this UV radiation (UV-B) is especially effective in causing damage to living beings, for example, sunburn, skin cancer, and eye damage to humans. The amount of solar UV radiation received at any particular location on the Earth's surface depends upon the position of the Sun above the horizon, the amount of ozone in the atmosphere, and local cloudiness and pollution. Scientists agree that, in the absence of changes in clouds or pollution, decreases in atmospheric ozone lead to increases in ground-level UV radiation.

The largest decreases in ozone during the past 15 years have been observed over Antarctica, especially during each September and October when the ozone hole forms. During the last several years, simultaneous measurements of UV radiation and total ozone have been made at several Antarctic stations. In the late spring, the biologically damaging ultraviolet radiation in parts of the Antarctic continent can exceed that in San Diego, California, where the Sun is much higher above the horizon.

In areas or the world where smaller ozone depletion has been observed, UV-B increases are more difficult to detect. In particular, detection of trends in UV-B radiation associated with ozone decreases can be further complicated by changes in cloudiness, by local pollution, and by difficulties in keeping the detection instrument in precisely the same operating condition over many years. Prior to the late 1980s, instruments with the necessary accuracy and stability for measurement of small long-term trends in ground-level UV-B were not available. Therefore, the data from urban locations with older, less-specialized instruments provide much less reliable information, especially since simultaneous measurements of changes in cloudiness or local pollution are not available. When high-quality measurements have been made in other areas far from major cities and their associated air pollution, decreases in ozone have regularly been accompanied by increases in UV-B. This is shown in the figure below, where clear-sky measurements performed at six different stations demonstrate that ozone decreases lead to increased UV-B radiation at the surface in amounts that are in good agreement with that expected from calculations (the "model" curve).

Increases in Erythemal (Sunburning) Ultraviolet Radiation Due to Ozone Decreases
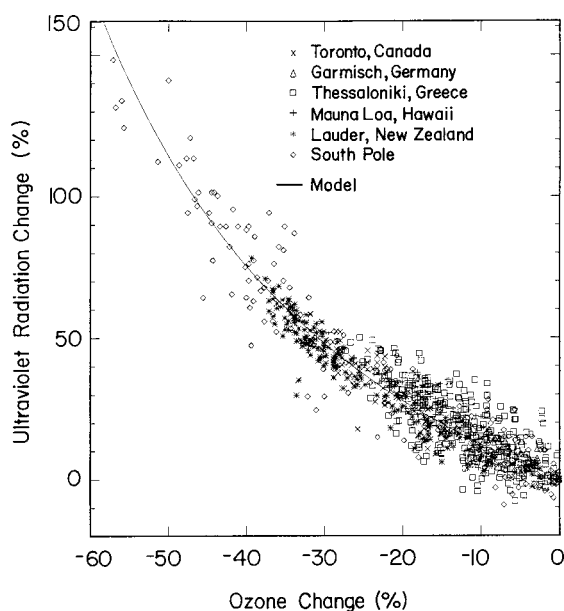
Does Ozone Depletion Cause Climate Change?

Ozone depletion and climate change are linked in a number of ways, but ozone depletion is not a major cause of climate change.

Atmospheric ozone has two effects on the temperature balance of the Earth. It absorbs solar ultraviolet radiation, which heats the stratosphere. It also absorbs infrared radiation emitted by the Earth's surface, effectively trapping heat in the troposphere. Therefore, the climate impact of changes in ozone concentrations varies with the altitude at which these ozone changes occur. The major ozone losses that have been observed in the lower stratosphere due to the human-produced chlorine- and bromine-containing gases have a cooling effect on the Earth's surface. On the other hand, the ozone increases that are estimated to have occurred in the troposphere because of surface-pollution gases have a warming effect on the Earth's surface, thereby contributing to the "greenhouse" effect.

In comparison to the effects of changes in other atmospheric gases, the effects of both of these ozone changes are difficult to calculate accurately. In the figure below, the upper ranges of possible effects from the ozone changes are indicated by the open bars, and the lower ranges are indicated by the solid bars.

As shown in the figure, the increase in carbon dioxide is the major contributor to climate change. Carbon dioxide concentrations are increasing in the atmosphere primarily as the result of the burning of coal, oil, and natural gas for energy and transportation. The atmospheric abundance of carbon dioxide is currently about 30% above what it was 150 years ago. The relative impacts on climate of various other "greenhouse" gases are also shown on the figure.

There is an additional factor that indirectly links ozone depletion to climate change; namely, many of the same gases that are causing ozone depletion are also contributing to climate change. These gases, such as the chlorofluorocarbons (CFCs), are greenhouse gases, absorbing some of the infrared radiation emitted by the Earth's surface, thereby effectively heating the Earth's surface.

Conversely, changes in the climate of the Earth could affect the behavior of the ozone layer, because ozone is influenced by changes in the meteorological conditions and by changes in the atmospheric composition that could result from climate change. The major issue is that the stratosphere will most probably cool in response to climate change, therefore preserving over a longer time period the conditions that promote chlorine-caused ozone depletion in the lower stratosphere, particularly in polar regions. At present, the amplitude and extent of such a cooling, and therefore the delay in the recovery of the ozone layer, still have to be assessed.

Relative Importance of the Changes in the Abundance of Various Gases in the Atmosphere
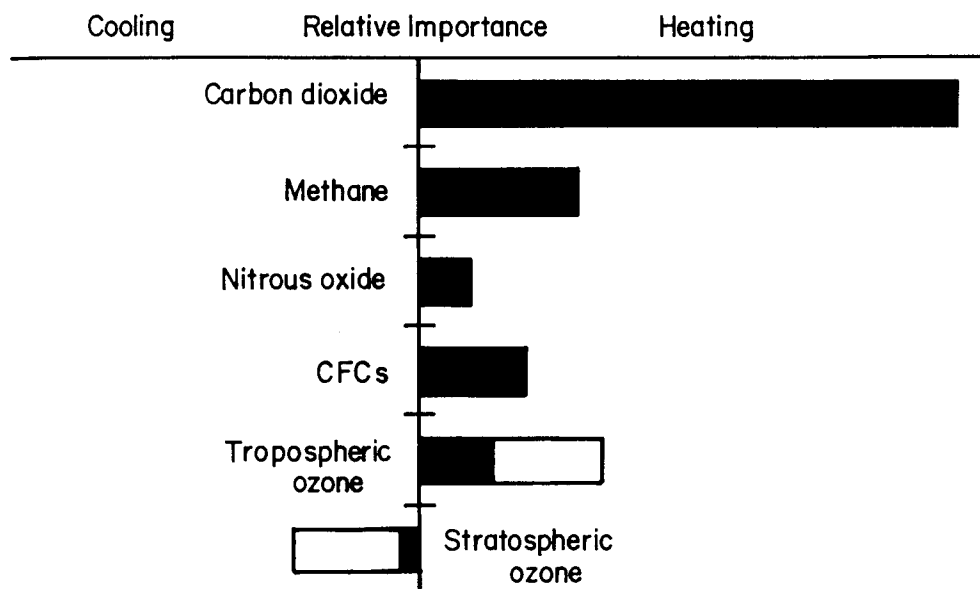
How Severe Is the Ozone Depletion Now?

Stratospheric ozone depletion, caused by increasing concentrations of human-produced chemicals, has increased since the 1980s. The springtime loss in Antarctica is the largest depletion. Currently, in nonpolar regions, the ozone layer has been depleted up to several percent compared with that of two decades ago.

As the figure below indicates, the magnitude of ozone depletion varies between the regions of the Earth. For example, there has been little or no ozone depletion in the tropics (about 20 degrees north and south of the equator). The magnitude of the depletion also depends on the season. From 1979 to 1997, the observed losses in the amount of ozone overhead have totaled about 5-6% for northern midlatitudes in winter and spring, about 3% for northern midlatitudes in summer and fall, and about 5% year round for southern midlatitudes. Since the early 1980s, the ozone hole has formed over Antarctica during every Southern Hemisphere spring (September to November), in which up to 60% of the total ozone is depleted. Since the early 1990s, ozone depletion has also been observed over the Arctic, with the ozone loss from January through late March typically being 20-25% in most of the recent years. All of these decreases are larger than known long-term natural variations.

The large increase in atmospheric concentrations of human-made chlorine and bromine compounds is re-sponsible for the formation of the Antarctic ozone hole. Furthermore, the overwhelming weight of evidence indicates that those same compounds also play a major role in the ozone depletion in the Arctic and at midlatitudes.

In addition to these long-term changes, transient effects have also been observed in the stratospheric ozone layer following major volcanic eruptions such as Mt. Pinatubo in 1991. During 1992 and 1993, ozone in many locations dropped to record low values. For example, springtime depletions exceeded 20% in some populated northern midlatitude regions, and the levels in the Antarctic ozone hole fell to the lowest values ever recorded. These unusually large, but short-term, ozone decreases of 1992 and 1993 are believed to be related in part to the large amounts of volcanic particles injected into stratosphere, which temporarily increased the ozone depletion caused by human-produced chlorine and bromine compounds, much as polar stratospheric clouds increase these chemicals' effect on ozone depletion in polar regions. Because these particles settle out of the stratosphere within a few years, the ozone concentrations have largely returned to the depleted levels consistent with the downward trend observed before the Mt. Pinatubo eruption. Should a similar eruption occur in the coming decade, ozone losses of the same magnitude might be expected, because the chlorine levels in the stratosphere will still be high.

Schematic of the North-to-South Ozone Depletion: 1979-1997
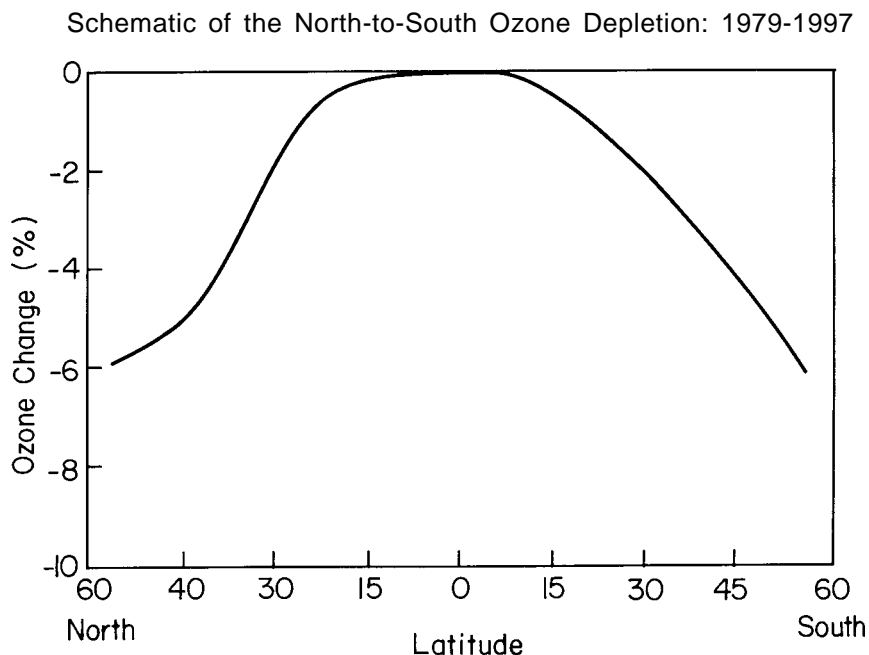
Is the Ozone Layer Expected to Recover? If So, When?

The ozone depletion caused by human-produced chlorine and bromine compounds is expected to gradually disappear by about the middle of the 21st century as these compounds are slowly removed from the stratosphere by natural processes. This environmental achievement is due to the landmark international agreement to control the production and use of ozone-depleting substances. Full compliance would be required to achieve this expected recovery.

In 1987, the recognition of the potential for chlorine and bromine to destroy stratospheric ozone led to the Montreal Protocol on Substances that Deplete the Ozone Layer, as part of the 1985 Vienna Convention for the Protection of the Ozone Layer, to reduce the global production of ozone-depleting substances. Subsequently, global observations of significant ozone depletion have prompted amendments to strengthen the treaty. The 1990 London Amendment calls for a ban on the production of the most damaging ozone-depleting substances by 2000 in developed countries and 2010 in developing countries. The 1992 Copenhagen Amendment changed the date of the ban to 1996 in developed countries. Further restrictions on ozone-depleting substances have been agreed upon in Vienna (1995) and Montreal (1997).

The figure on the right shows past and projected stratospheric abundances of chlorine and bromine without the Protocol, under the Protocol's original provisions, and under its subsequent agreements. Without the Montreal Protocol and its Amendments, continuing use of chlorofluorocarbons (CFCs) and other ozone-depleting substances would have increased the stratospheric abundances of chlorine and bromine tenfold by the mid-2050s compared with the 1980 amounts. Such high chlorine and bromine abundances would have caused very large ozone losses, which would have been far larger than the depletion observed at present.

In contrast, under the current international agreements that are now reducing the human-caused emissions of ozone-depleting gases, the net tropospheric concentrations of chlorine- and bromine-containing compounds started to decrease in 1995. Because 3 to 6 years are required for the mixing from the troposphere to the stratosphere, the stratospheric abundances of chlorine are starting to reach a constant level and will slowly decline thereafter. With full compliance, the international agreements will eventually eliminate most of the emissions of the major ozone-depleting gases. All other things being constant, the ozone layer would be expected to return to a normal state during the middle of the next century. This slow recovery, as compared with the relatively rapid onset of the ozone depletion due to CFC and bromine-containing halon emissions, is related primarily to the time required for natural processes to eliminate the CFCs and halons from the atmosphere. Most of the CFCs and halons have atmospheric residence times of about 50 to several hundred years.

However, the future state of the ozone layer depends on more factors than just the stratospheric concentrations of human-produced chlorine and bromine. It will also be affected to some extent by the changing atmospheric abundances of several other human-influenced constituents, such as methane, nitrous oxide, and sulfate particles, as well as by the changing climate of the Earth. As a result, the ozone layer is unlikely to be identical to the ozone layer that existed prior to the 1980s. Nevertheless, the discovery and characterization of the issue of ozone depletion from chlorine and bromine compounds and a full global compliance with the international regulations on their emissions will have eliminated what would have been, as the figure illustrates, a major deterioration of the Earth's protective ultraviolet shield.

Effect of the International Agreements on Ozone-Depleting Stratospheric Chlorine/Bromine