

Ozone Depletion: When Less Is Not Enough

The term “ozone hole” by now is widely recognized although far less widely understood.

What is it? Where is it? How big is it? What caused it? What will become of it? And what implications does it have for your audience?

The ozone hole and its causes combine in one story the intrigue of

- ♦ ground-breaking science (a product with many beneficial uses discovered belatedly to be harmful to the environment)
- ♦ a precedent-setting international accord based on a scientific consensus achieved only after years of intense debate
- ♦ development of cleaner products to replace products — chlorofluorocarbons — which themselves had been

introduced as a substitute for more environmentally risky solvents.

The Ozone Layer — Earth’s Protector

Ozone is a pungent, slightly bluish gas. It is a molecule made up of three oxygen atoms (O_3), and thus a close chemical cousin to the more stable and abundant oxygen molecule which is needed for human respiration and is comprised of two oxygen atoms (O_2). Ozone is formed when two-atom oxygen molecules are separated, or dissociated, as a result of ultraviolet radiation from the sun. Then individual atoms of oxygen combine with individual molecules of oxygen ($O + O_2 \dots O_3$).

One of the first things a fledgling environmental journalist learns in covering pollution and stratospheric ozone issues is that there is “good ozone” and “bad ozone.” The bad ozone is recognizable as the “smog” that plagues Los Angeles, Mexico City, Albuquerque, Denver, Chicago, New York City, and many other major urban areas.

The distinction between “good” and “bad” ozone is a fundamental one, but one much of the lay public perhaps has yet to learn.

Despite the widespread urban smog problem, about 90 percent of Earth’s ozone actually is in the stratosphere, a layer of the atmosphere well above Earth’s surface. It lies above the troposphere, the miles-thick lower layer where air is densest and where most weather occurs. The stratosphere begins at an altitude of about 8 km at the poles (17 km at the Equator) and extends upward to about 50 km (see Figure 14).

Ozone in the stratosphere could be called “good ozone,” because it shields Earth from otherwise destructive ultraviolet radiation. Much of the remaining 10 percent of the ozone — the “bad ozone” — lies close to the planet’s surface, in the troposphere, where at certain concentrations it is harmful to public health and welfare.

Casual observers who hear more about smog than about ultraviolet radiation might get the impression that there simply is too much ozone in Earth’s atmosphere, period. In a sense they would be right: there is too much in some places — but also the risk of not enough in others, where it is needed. On the other hand, it is important for environmental reporters and their audiences to recognize that ozone molecules overall are exceptionally rare in Earth’s atmosphere.

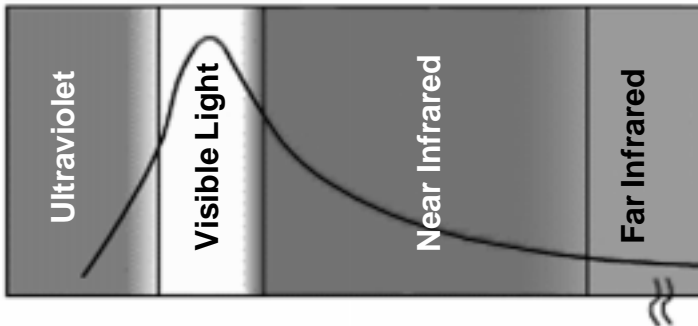
Fewer than one in every million molecules of oxygen is ozone, a ratio which both underscores and belies the critical role ozone plays in protecting the global environment.

The total amount of ozone in the atmosphere, if compressed to the pressure at Earth’s surface, would fit into a layer about one-eighth of an inch thick. That thin layer is critical in making Earth’s environment hospitable for human beings.

A key point: ozone absorbs ultraviolet radiation from the sun that can damage DNA in living systems. This radiation, called UV-B, occurs at wavelengths between 280 and 320 nanometers (the unit equal to one-billionth of a meter). Its ability to absorb UV-B makes ozone an essential defense in protecting humans against the UV-B wavelengths which can pose the greatest threats of biological damage.

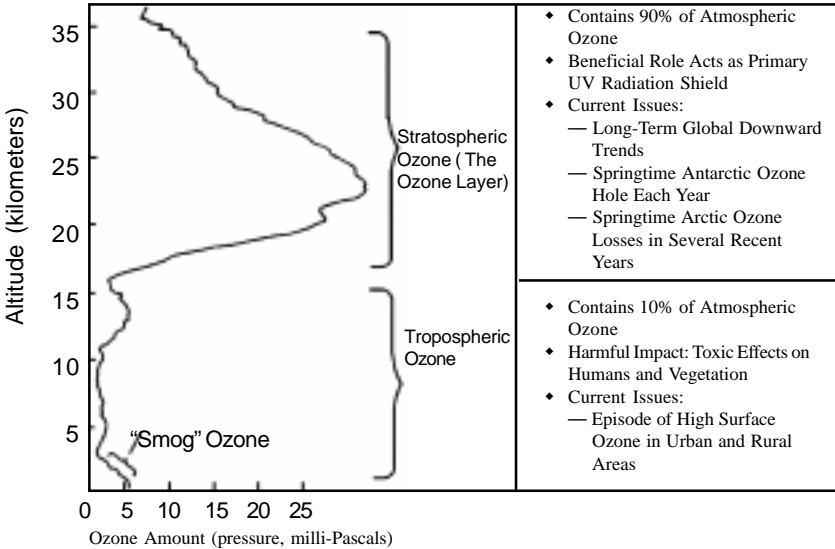
Climate and the atmosphere are not static, however, and neither is the

Figure 13. Solar Radiation Spectrum



Source: University of Wisconsin-Stevens Point, http://www.uwsp.edu/acaddept/geog/faculty/ritter/geog101/lecture_radiation_energy_balance.html

Figure 14. Temperature Profile and Distribution of Ozone



Source: Aeronomy Laboratory, National Oceanic and Atmospheric Administration, <http://www.al.noaa.gov/WWWHD/pubdocs/Assessment98/faq.html>

ozone layer. The amount of ozone in the stratosphere in fact varies at different latitudes, at different altitudes in the atmosphere, and at different times of the year. It also varies from year to year. For example, the total ozone in north temperate latitudes has exhibited strong seasonal cycles with maximum concentrations in March-April and minimum in October-November. Natural variation can be as great as 25 percent at high latitudes.

Reporters might find scientists noting that there are both temporal and spatial changes in ozone quantities and concentrations. Audiences may understand that concept better if reporters explain that ozone quantities and concentrations naturally vary by geographical location and by time of year.

In addition, ozone molecules in the stratosphere are constantly being created and destroyed, over and over. New ozone molecules are constantly being created in chemical reactions caused by the sun. When oxygen molecules (O_2) are struck by the sun's rays, they split apart into single oxygen atoms (O), which are very reactive. The oxygen atoms bond with oxygen molecules to form ozone (O_3).

Ozone molecules are constantly being destroyed by natural compounds containing nitrogen, hydrogen, and chlorine. The nitrogen comes from soils and the ocean, the hydrogen comes mostly from atmospheric water vapor, and the chlorine comes from the oceans. Ozone is also continuously being destroyed when it absorbs ultraviolet light. This process produces atomic oxygen (O) that reacts with molecular oxygen (O₂) to form another ozone molecule (O₃).

With creative and destructive forces balanced, the average amount of ozone in the stratosphere since Earth's current atmosphere developed is believed to have remained fairly constant. The scientific and public policy issue now surrounding stratospheric ozone arises as a result of concern that ozone destruction resulting from releases of chlorofluorocarbons and halons may be upsetting the natural balance.

All this detail on the formation and destruction of ozone goes beyond what reporters, editors, and news directors could expect to cover in a general circulation newspaper or in a 90-second TV or radio spot. But it's important that professional environmental journalists understand these complex issues, if only so that all their audiences need not understand them themselves. Reporters with a fundamental grasp of stratospheric ozone formation and destruction can spare their audiences a likely misunderstanding.

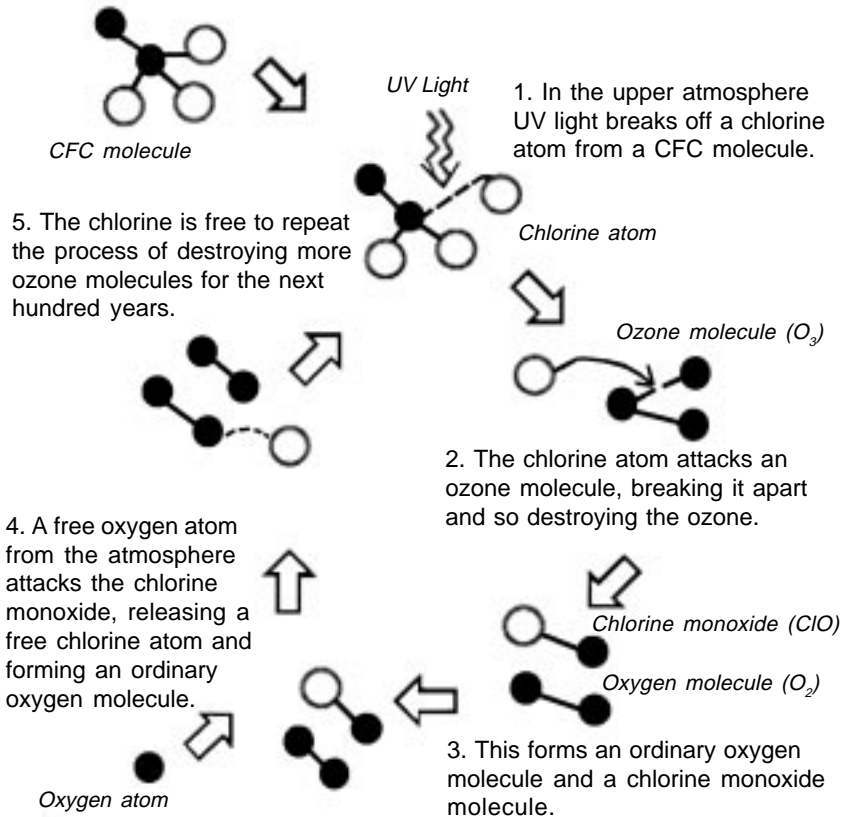
For those journalists perhaps steeped more in the social than in the physical sciences, there is no simple shortcut to understanding ozone formation and destruction. But one concise explanation was published in a September 1989 issue of *Scientific American*. That magazine's "Managing Planet Earth" special issue for that month is a valuable resource for reporters wanting authoritative background on global climate and global change issues.

CFCs and Stratospheric Ozone — The Chemistry

The cliché that "If something sounds too good to be true ... it usually is" has a special meaning for journalists trained in the fine art of skepticism. For reporters, it's often a blinking red light: Caution. Proceed slowly. Stop and think.

The metaphor is apt to a consideration of chlorofluorocarbons, or CFCs. Since their discovery and commercialization in the 1930s and 1940s, CFCs in many ways had seemed "too good to be true." They were relatively inexpensive, highly effective, stable in the atmosphere, and nontoxic to humans. It is some of those very properties and characteristics that led to their widespread use throughout broad sectors of modern society. Electronics manufacturers, for instance, shifted to use of CFCs as cleaning solvents in the early 1980s in significant part to get away from

Figure 15. How Ozone Is Destroyed



Source: Drawn from "The Hole Story," University of Hawaii Sea Grant, 1992, and U.S. Environmental Protection Agency

the groundwater contamination problems associated with their use of other solvents, such as methylene chloride and trichloroethylene. For a wide variety of industrial purposes, CFCs in effect became a "chemical of choice," a veritable "wonder chemical" precisely because they do not break down in the lower atmosphere.

The problem, of course, is the proverbial Achilles' heel. When released in the atmosphere, CFCs travel up to the stratosphere, where ultraviolet radiation strikes them and leads to releases of chlorine. That chlorine acts as a catalyst, repeatedly combining with and breaking apart ozone molecules and forming the single oxygen molecule and one chlorine monoxide molecule (see Figure 15).

The chlorine monoxide molecule then can combine with an oxygen atom, forming an oxygen molecule and freeing the chlorine to begin the process all over again. Through this repetitive cycle, a single chlorine atom can destroy thousands of ozone molecules before it is eventually neutralized. That makes CFCs, and their released chlorine, highly efficient when it comes to destroying stratospheric ozone, although not all CFCs and not all solvents are equally harmful to the ozone layer.

For instance, methyl chloroform and carbon tetrachloride, common industrial solvents, act in a similar fashion, although the quantities of chlorine are somewhat lower. In addition, the bromine released by halons (fluorocarbons containing bromine) in the stratosphere acts in a similar manner to destroy ozone. While there is much less bromine than chlorine in the stratosphere, it is more reactive and accounts for a significant portion of ozone depletion. (The umbrella term “halocarbons” is used to refer to CFCs and halons.)

To a significant extent, the scientific and public policy issues that confront the world community in the ozone-hole debate boil down to this: the addition of more chlorine- and bromine-containing chemicals to the stratosphere will tilt the natural balance of creation and destruction of ozone by adding more and more ozone-destructive chemical forces.

As mentioned above, different halocarbons have varying expected lifetimes in the atmosphere and varying abilities to destroy ozone. In scientific jargon, they have differing “ozone depletion potential” (ODP).

Figure 16. Ozone Depletion Potential

	Ozone Depletion Potential	Atmospheric Lifetime (Years)
CFC-11	1.0	50
CFC-12	1.0	102
CFC-113	0.8	85
CFC-114	1.0	300
CFC-115	0.6	1,700
HCFC-22	0.05	12.1
Methyl Chloroform	0.10	4.9
Carbon Tetrachloride	1.1	42
Halon-1211	3.0	20
Halon-1301	10.0	65
Halon-2402	6.0	20

Source: IPCC, U.S. Environmental Protection Agency.

Most halocarbons are long-lived: they can survive in the atmosphere for decades, some for several centuries.

Each individual chemical covered under the Montreal Protocol (See sidebar, Montreal Protocol, page 62) is assigned an ODP per molecule, a measure of its relative ability to destroy ozone molecules in the stratosphere, using CFC-11 and CFC-12 as the standard unit (see Figure 16).

A chemical's ODP is determined by the number of chlorine or bromine atoms in the molecule, its atmospheric lifetime (how long it takes before it is broken down or removed from the atmosphere), and the specific mechanisms involved in breaking it down.

Landmark Discoveries

In 1974 two University of California-Irvine chemists, F. Sherwood Rowland and Mario Molina, published a seminal research article in the British science journal *Nature*. Rowland and Molina reported that their research had found that because CFCs are extremely stable in the lower atmosphere, they could drift up into the stratosphere. There, they wrote, the CFCs could break apart when hit by the sun's high-energy radiation and release large quantities of chlorine in the stratosphere. Each chlorine atom, the two predicted, could potentially destroy 100,000 ozone molecules. The scientists wrote that decades of CFC use could cause substantial declines in the concentration of stratospheric ozone.

How did the media react to the Rowland and Molina report? According to science writer Sharon L. Roan of the *Orange County Register* in Santa Ana, California, media response was "tepid," perhaps because the authors "weren't known as atmospheric chemists or because the implications of the theory seemed like something out of a bizarre science fiction novel." Writing in the 1989 book *Ozone Crisis: The 15-Year Evolution of a Sudden Global Emergency*, Roan said the story got little play beyond California and the "two scientists" credited in a piece run by Reuters "certainly didn't seem destined for the science hall of fame."

"This was a rather esoteric problem," Roan continued. "It consisted of invisible gas, invisible radiation, and a delayed reaction. It was no wonder the public had a hard time relating to it."

So, too, to some extent, did other scientists, whose reactions Roan characterizes as "equally slow to surface."

Over time, however, Rowland and Molina's ozone-depletion hypothesis stimulated a great deal of scientific research into the many complex issues involved. It also stimulated widespread scientific and public policy debate, as it called into question modern society's romance with a ubiquitous "wonder chemical" through which industrial fortunes were being

The Montreal Protocol

The Montreal Protocol called for a freeze on production and use of halocarbons at 1986 levels by mid-1989, and over the next 10 years a reduction in CFC production by half.

However, many were still concerned that the measures called for in the Protocol were insufficient to prevent further damage to the ozone layer, and in 1990, international representatives met in London and voted to significantly strengthen the Montreal Protocol in what is known as the London Amendments. The Amendments regulate 10 additional CFCs and call for a complete phaseout of CFCs by the year 2000, a phaseout of halons (except for essential uses) by 2000, and a phaseout of carbon tetrachloride by 2000 and methyl chloroform by 2005.

Under the 1990 Amendments, developing countries are given a 10-year grace period on deadlines to allow them to meet “basic domestic needs.” The treaty also establishes an environmental fund, paid for by developed nations, to help developing nations switch to more “ozone-friendly” chemicals.

Amendments to the Protocol adopted in Copenhagen in 1992 accelerated schedules for the phase-out of CFCs, methyl chloroform, carbon tetrachloride, and halons. The Copenhagen amendments also added methyl bromide and hydrobromofluorocarbons to the list of controlled substances.

Further amendments Vienna (1995), Montreal (1997), and Beijing (1999) focused on deadlines for phasing out methyl bromide and HCFCs, among other things.

earned. Instead of remaining in the esoteric world of scientific debate, Rowland and Molina’s research came to front-and-center in the public policy field. The two eventually won the Nobel Prize for Chemistry in 1995, along with Prof. Paul Crutzen, who had been working on the problem since 1970.

The challenge was daunting even for the best scientific minds: to understand all that Rowland and Molina theorized was happening with CFCs and stratospheric ozone, “researchers needed to go far beyond atmospheric chemistry,” writes Ambassador Richard E. Benedick. According to Benedick, who as a State Department official in the Reagan Administration played a lead role in negotiating the Montreal Protocol, the scientific community, in digesting Rowland and Molina’s analyses, “had to bridge disciplines, examining Earth as an interrelated system of physical, chemical, and biological processes taking place on land, in water, and in

the atmosphere. ... Scientists developed ever more sophisticated computer models simulating, for decades into the future, the stratospheric interplay between radiative, chemical, and physical processes, and utilized balloons, rockets, and satellites to track remote gases measured in parts per trillion of volume.” Calculations of ozone loss needed to take into account seasonal variations, the 11-year solar cycle, and numerous other complicating factors.

In addition to the media and scientific community’s response to the Rowland and Molina research, there was also the public policy response, culminating in a May 11, 1977, announcement by three federal agencies — the Consumer Product Safety Commission, Environmental Protection Agency, and Food and Drug Administration — of a timetable for phasing out nonessential uses of CFCs in aerosol spray products.

This raises two important points for reporters: they do a disservice to their audiences when their reporting suggests that “aerosol sprays” are still the problem facing ozone; it’s not aerosols per se, but rather the CFCs used as propellants until various countries’ bans eventually took effect. The second point: ending the use of CFCs in aerosols obviously did not “solve” the ozone depletion problem. The many other industrial uses of halocarbons — as solvents, degreasers, refrigerants, and foaming agents, for example — were still releasing large amounts into the atmosphere. These two mistaken impressions are, regrettably, common ones in reporting on the issue.

In 1985 an international agreement, the Vienna Convention, was signed after three years of negotiating under the auspices of the United Nations Environment Programme. The Vienna Convention established mechanisms for international cooperation in research, monitoring, and exchange of data on emissions, on concentrations of CFCs and halons, and on the status of the stratospheric ozone. It also set a framework for international negotiations on actual reductions of emissions.

That same year, 1985, marked another seminal development in the evolution of scientific and public policy recognition of the stratospheric ozone issue — the discovery of the Antarctic “ozone hole.”

The British Antarctic Survey in 1985 reported that the ozone layer over Antarctica had shrunk each year since the late 1970s. The discovery was published in the science journal *Nature* on May 16, 1985. The British scientists, led by Joe Farman, found that almost all the ozone at certain altitudes was destroyed over a period of a few weeks in the spring. The reported ozone loss was much larger than even the “worst cases” predicted by scientific models.

Prior to the British Antarctic Survey discovery, many scientists had been uncertain over whether ozone levels had actually started to drop.

What is a Dobson Unit?

Dobson units measure the total amount of ozone in a column of air from ground level to the top of the atmosphere, based on spectral analysis of absorbed ultraviolet light. The number of Dobson units corresponds directly with the “thickness” of the ozone layer. If all the ozone in the column were compressed to a standard 0°C and 1 atmosphere pressure, 100 DU would be a 1mm thick layer of ozone. While measurements vary widely according to time and place, a typical reading for a healthy polar ozone layer might be in the 300-450 DU range.)

Farman’s findings showed dramatically that they had.

In September 1987, the United States joined the international community in signing a landmark global agreement, the Montreal Protocol, setting limits on the use of CFCs and halons, and later other substances, was eventually signed by more than 160 nations, representing most of the industrialized and developing world.

Scientific data from American expeditions to Antarctica in 1986 and 1987 and from National Aeronautics and Space Administration’s 1987 aircraft missions confirmed for most in the scientific community that chlorine from CFCs and bromine from halons and methyl bromide are responsible for ozone destruction and for the ozone hole itself. In 1988, NASA’s and the National Oceanic and Atmospheric Administration’s (NOAA’s) joint Ozone Trends Panel Report provided a comprehensive international scientific assessment of previous stratospheric gas measurements. The NASA/NOAA “Ozone Trends” report substantiated the ozone depletion theory.

Ozone Trends

There were more worrisome findings to come. In Antarctica, a new “record low” was reported October 18, 1993, in a NASA press release based on data obtained by NASA’s Goddard Space Flight Center and NOAA’s Climate Monitoring and Diagnostic Laboratory.

“These record low levels [of Antarctic ozone] were recorded at the South Pole Station, Antarctica, at the end of September and early October 1993, and confirmed by satellite measurements,” NASA said in the release that reported values less than 100 Dobson units (DU), down from 275 DU in mid-August.

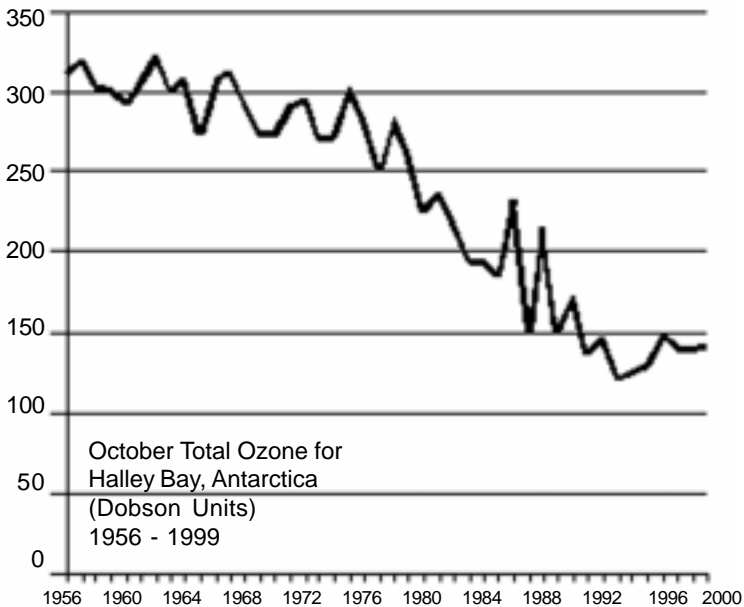
The 1993 ozone hole was associated with an unusually cold and stable air mass in the stratosphere over Antarctica during that year’s

southern winter and spring. It turned out that this was not a coincidence. During the 1990s scientists were gaining a much deeper understanding of the complex atmospheric chemistry involved in ozone depletion — and of the reasons why the ozone hole appeared primarily over Antarctica at a certain time of year.

During winter in the Southern Hemisphere (May-July) the South Pole is in total darkness. At that time, a strong circumpolar wind develops in the middle to lower stratosphere (the altitude where most of the ozone layer resides). This “polar vortex” isolates the air mass over the pole, which in the absence of sunlight gets colder and colder. When it gets down to -80°C (or -112°F), a strange new kind of cloud develops — one which does not consist of water droplets, or even the tiny ice crystals that sometimes make up the cirrus clouds we see in the upper troposphere.

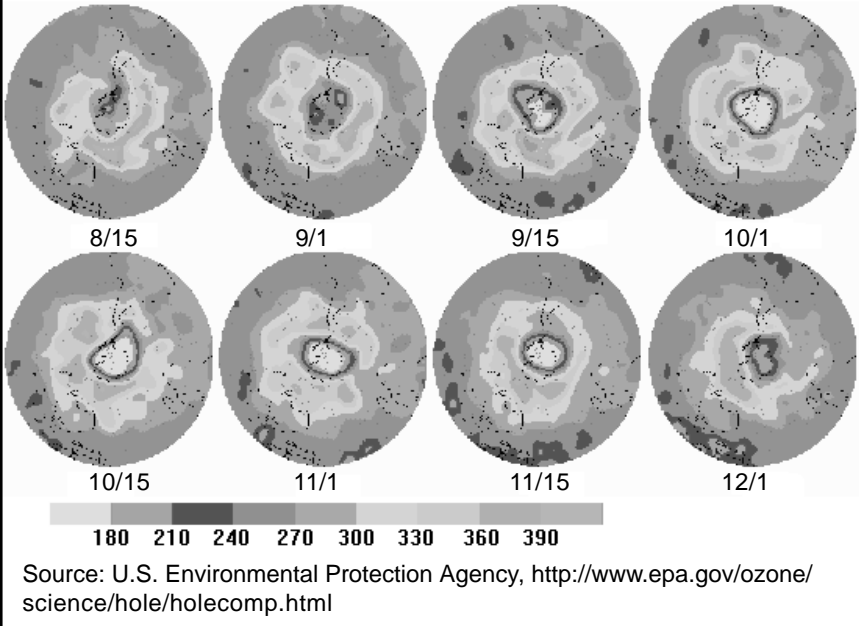
These “polar stratospheric clouds” (PSCs) are made up of nitric acid trihydrate, and droplets of water-ice with nitric acid dissolved in them. The droplets in these PSCs are especially talented at breaking up the various chlorine- or bromine-containing molecules in the atmosphere and releasing

Figure 17. Worsening Ozone Hole



Source: British Antarctic Survey, <http://www.nerc-bas.ac.uk/public/icd/jds/ozone/data/zoz5699.dat>

Figure 18. Decline in the Ozone Shield



free chlorine (or bromine) in the form of two-atom molecules (Cl_2).

The final blow comes when sunlight returns to the South Pole region at the beginning of polar spring (August-November). Sunlight splits those two-atom chlorine molecules into single chlorine atoms — the form which destroys ozone. The comparatively sudden appearance of so many chlorine atoms is what starts the catalytic reaction which just as suddenly creates the ozone hole.

NASA and NOAA noted in the 1993 release that the record ozone hole “may have been affected by the continued presence of sulfuric acid in the upper atmosphere created by the June 1991 eruption of Mount Pinatubo in the Philippines.”

But that “natural” cause of a worsening ozone hole was hardly enough to justify the delays which producers and users of ozone-depleting substances might have wanted in control measures.

By the late 1990s it was clear that the worsening ozone holes were not just a blip or a hiccup. Consistent measurements over as many as seven decades were showing a continuing downtrend in the ozone layer since 1970 or earlier (see Figure 17).

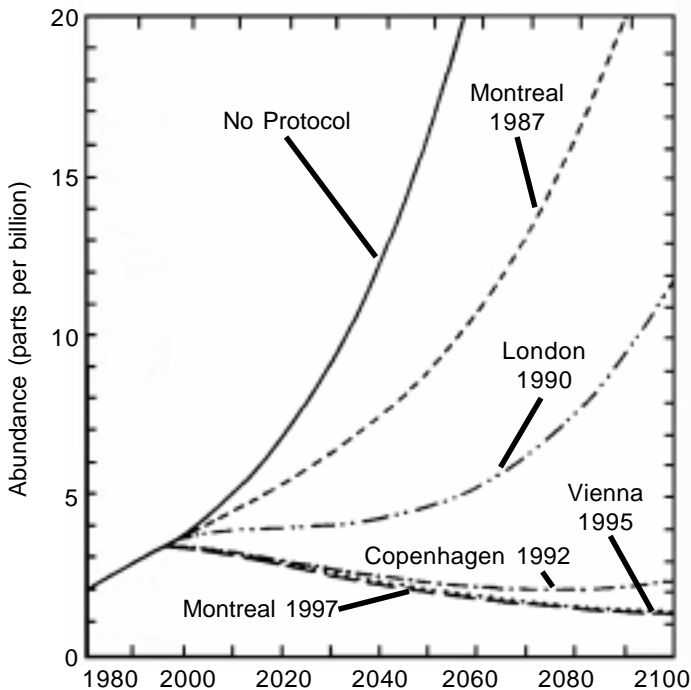
The closest thing to a summary of scientific consensus on the issue was the WMO/UNEP *Scientific Assessment of Ozone Depletion*, pub-

lished in 1994 (with an update in 1998). While acknowledging that Mt. Pinatubo contributed to the record ozone holes of 1992 and 1993, the experts held to the conclusion that human-induced bromine and chlorine compounds were causing polar ozone depletion, because direct measurements now associated the two.

Moreover, the UNEP/WMO Assessments concluded, even though natural causes put some chlorine and bromine into the lower atmosphere, most of the chlorine and bromine that reached the stratosphere came from human sources.

There was still more bad news. In 1998 UNEP/WMO reported that significant ozone reductions had occurred in the stratosphere above the Arctic during the late winter and early spring (January-March) in 6 of the previous 9 years. Because of different weather patterns, the Arctic ozone reductions, typically 20-25 percent, were smaller than the reductions in the Antarctic ozone hole, where on the order of 60-70 percent of total column

Figure 19. Effect of International Agreements on Ozone-depleting Stratospheric Chlorine/Bromine



Source: UN Environmental Programme Ozone Secretariat

How BIG is the Ozone Hole?

Bigger than most people can imagine. The hole that developed during the Antarctic winter of 1998 covered an area of some 26 million square kilometers — that's about 10 million square miles.

The surface area of North America, by comparison, is 8.1 million square miles, about 21 million square kilometers. Antarctic's surface area covers about 5.4 million square miles, just over 14 million square kilometers.

The 1998 Antarctic ozone hole was the largest on record since ozone holes were first measured in the 1980s. The hole for 1999 was somewhat smaller — which some scientists took as a sign that the worsening trend had bottomed out. The hole is measured by an array of instruments managed by the National Aeronautics and Space Administration (NASA) and National Oceanic and Atmospheric Administration (NOAA).

ozone is lost, and nearly all the ozone within the lower stratosphere.

After the winter of 1999-2000, however, NASA and a team of European scientists reported an ominous observation: in a layer at about 60,000 feet above the Arctic, more than 60 percent of the ozone was lost. It had been one of the coldest Arctic winters on record, and scientists had observed that polar stratospheric clouds formed earlier than usual that year, covered a wider area, and lasted longer. While total ozone over the whole area for the total column was down only about 16 percent compared to the early 1980s, the implication was that the Arctic was not immune from processes like those that formed the Antarctic ozone hole.

It was one of a growing number of reminders of how closely global climate change might be linked to stratospheric ozone depletion. The cold Arctic stratosphere that year resulted partly from a change in global atmospheric circulation patterns. CFC's, of course, were worth keeping out of the atmosphere not only because they depleted the ozone layer, but also because they were potent greenhouse gases in and of themselves. Things are made more complex by the fact that ozone, too, is a greenhouse gas.

Global greenhouse warming theory led scientists to expect a cooling of the stratosphere as heat was trapped in the atmosphere below it. Scientists measured an actual cooling trend in the lower stratosphere during 1979-1994, and they attributed this to loss of ozone in that layer.

Still other UNEP/WMO findings went beyond the special circumstances of the cold polar stratosphere. In 1994, they reported finding

The Mount Pinatubo Eruption in June 1991

Mount Pinatubo in the Philippines erupted in June 1991 and spewed an estimated 20 million tons of sulfur dioxide into the stratosphere up to an elevation of 25 kilometers (about 15 miles). Most volcanoes are localized, and their debris never reaches the stratosphere. The sulfur dioxide from Pinatubo, carried by winds in the stratosphere, was transformed photochemically to sulfuric acid, forming a layer of small droplets (aerosols) that blanketed much of the globe.

Scientists at the time believed that aerosols in the stratosphere would scatter sunlight back to space and absorb terrestrial heat radiation — cooling the lower atmosphere while warming the stratosphere. They were excited by the opportunity that Mt. Pinatubo provided to check their theories. In fact, the global “experiment” confirmed their thinking, and allowed finer adjustment of global circulation models to account for aerosols. It also gave a clearer sense of the global climate system’s sensitivity to forcing.

The global climate impacts of the Pinatubo eruption peaked in late 1993, about two years after the eruption occurred.

steady decreases of 2-4 percent in total column ozone during the 1980s in both Northern and Southern Hemisphere midlatitudes (30-60°) — although they were not as dramatic as the Antarctic “hole.” In 1998 they reported that this downtrend did not continue after the atmosphere recovered from Mt. Pinatubo in the 1990s. They saw no downtrend in total column ozone near the equator (20°N-20°S).

In 1998, UNEP/WHO also reported that “the total combined abundance of ozone-depleting compounds in the lower atmosphere [troposphere] peaked in about 1994 and is now slowly declining.” Bromine was still increasing, but that was offset by greater declines in chlorine.

UNEP/WHO estimated in 1998 that the combined abundance of stratospheric chlorine and bromine would peak by the year 2000 — peaking somewhat later than in the troposphere because of the time required for the chemicals to work their way up into the stratosphere.

But even while the increase in chlorine and bromine from the chemicals restricted under the Montreal Protocol (CFCs, carbon tetrachloride, and methyl chloroform, mainly) was nearing a halt, UNEP/WHO in 1998 found that “the observed abundances of the substitutes for the CFCs are increasing.” The substitutes were principally hydrochlorofluorocarbons (HCFCs) and hydrofluorocarbons (HFCs) (see Figure 20).

Between 1986 and 1991, worldwide consumption of CFCs -11, -12 and

Figure 20. Annual Global Fluorocarbon Production (Metric tons)

	CFC-11	CFC-12	CFC-113	CFC-114	CFC-115	HCFC-22	HCFC-142b
1987	382,050	424,726	225,812	17,098	12,772	173,304	6,883
1998	<u>14,600</u>	<u>33,269</u>	<u>1,589</u>	<u>1,199</u>	<u>922</u>	<u>261,175</u>	<u>37,974</u>
	367,450	391,457	224,223	15,899	11,805	87,871	31,091
	-96%	-9.2%	-99.3%	-93%	-92.85	+50.7%	+452%

Source: Alternative Fluorocarbons Environmental Acceptability Study

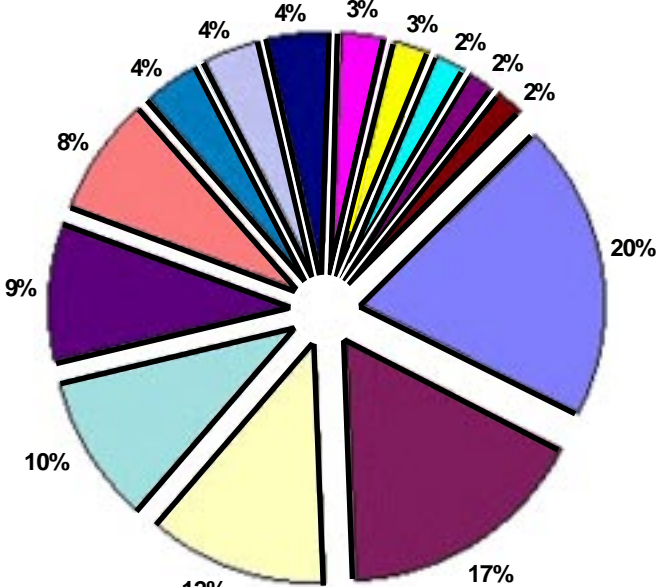
-113 decreased by 40 percent, ahead of the schedule outlined in the Montreal Protocol and faster even than called for in the more ambitious 1990 London Amendments to the Montreal Protocol, according to the IPCC. American manufacturers earlier wedded to the notion that CFCs were unique and irreplaceable, for instance, were finding themselves moving quickly to alternative processes and chemicals. Reductions in CFC use in industrialized countries have come from such things as: substituting hydrocarbons as aerosol propellants and as blowing agents for flexible foams; using aqueous or semi-aqueous systems; using no-clean technologies, for instance in electronics manufacturing and assembly, or substituting alcohol and other solvents in place of CFC solvents; recovering and recycling CFC refrigerants and increasing the use of products with reduced ozone depletion potential and of ammonia for refrigeration and air conditioning.

During the 1990s U.S. and world attention turned to another ozone-depleting chemical not covered in the original 1987 treaty — methyl bromide. It was widely used as a pesticide in a variety of agricultural and food production situations. For example, methyl bromide is commonly injected into soil to kill nematodes, or pumped as a fumigant into warehouses where food is stored. It has significant ozone depletion potential, although not as much as was once thought. In 1999 the government estimated some 21,000 tons of the gas were being used annually in U.S. agriculture — out of 72,000 tons used worldwide. It also comes from natural sources such as the oceans. The Montreal Protocol countries first froze production in 1992, then set a phase-out timetable in 1995, and finally accelerated that phase-out in 1997. The U.S. EPA, which has authority to ban ozone-depleting substances under the 1990 Clean Air Act, has set a schedule for phasing out methyl bromide from most uses by 2005.

A good news story? Perhaps. A “success”? Quite possibly. But it is still too soon to tell exactly how it will come out.

CFCs, as noted, are long-lived in the atmosphere and have lifetimes

Figure 21. Uses of Chlorofluorocarbons (CFCs)



- 20% Refrigerants in automobile air-conditioning systems
- 17% Rigid foam insulation in homes and offices
- 12% Solvents for cleaning electronic components
- 10% Blown foam, insulating materials in refrigeration storage tanks, etc
- 9% Refrigerants in commercial refrigeration systems
- 8% Solvents for degreasing metal parts
- 4% Aerosol sprays
- 4% Refrigerants in large commercial air-conditioning systems
- 4% Miscellaneous uses
- 3% Cushioning foams in automobiles, airplane seats, furniture
- 3% Disinfectants or sterilants in hospitals
- 2% Refrigerants in home refrigerators
- 2% Polystyrene foam plastics, such as fast-food containers
- 2% Food freezants

Source: Ong Aik Leng, <http://home1.pacific.net.sg/~kaneco/ghgases.htm>

measured by years and decades, not by days and weeks. Even with reduced global consumption and releases of CFCs, those already released to the atmosphere and those already in the stratosphere will continue to destroy ozone molecules long into the future (see Figure 16).

The UNEP/WMO scientific panel, which had revised overly optimistic and overly pessimistic predictions often before, would not give an unambiguous forecast for the recovery of the ozone layer in its 1998 Assessment. If bromine and chlorine compounds were all that mattered, they said, and if Montreal Protocol timetables were actually followed, the worst ozone loss would probably be over within the first two decades of the 21st century. But they left in doubt just how quickly the ozone layer would

recover. They noted that chlorine and bromine falloff might be “much slower” than the buildup — and that other factors such as volcanoes, nitrous oxide, methane, and water vapor could also slow recovery.

Sources of CFC Releases

As was mentioned earlier, the properties and characteristics of CFCs — CFCs are nontoxic, noncorrosive, nonflammable, and extremely stable (nonreactive with most other substances) — had made them ideally suited for a variety of purposes. The use of CFCs expanded significantly in the 1950s and 1960s with production increasing at an average rate of 10 percent annually over a period of nearly three decades.

Major categories of products (see Figure 21) that used CFCs and halons prior to the imposition of use restrictions and bans have included:

- ◆ rigid foams (closed cell) — used for insulation and packaging
- ◆ flexible foams (open cell) — used in furniture, bedding and car seats
- ◆ refrigerators — home and retail food
- ◆ air conditioners — automobile, room, and chillers
- ◆ solvents — for cleaning electronic circuit boards and metal parts and assemblies
- ◆ hospital sterilants
- ◆ fire extinguishers (using halons)
- ◆ aerosols — propellants in aerosol sprays, used mostly in Europe and Japan.

Prior to the U.S., Canadian, and Swedish 1978 bans on use of CFCs as propellants in aerosol sprays, aerosols had constituted the single largest application for CFCs. (CFCs continued being used as aerosol sprays in many other countries long after the 1978 bans in those three western countries, and CFC worldwide production in fact continued to increase long after the aerosol ban had taken effect.)

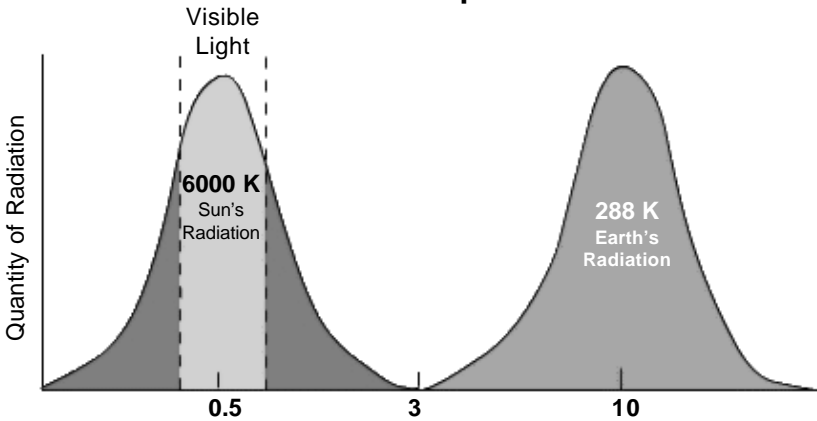
Health and Environmental Impacts

Ozone in the stratosphere protects Earth from damaging amounts of ultraviolet (UV) radiation. A depleted ozone layer would allow more of the sun’s damaging rays to reach Earth’s surface.

Each one percent depletion in stratospheric ozone increases exposure to damaging ultraviolet radiation by 1.5 to 2 percent, according to the EPA. Human health effects of excessive UV-B primarily involve exposed organs such as the skin and the eyes.

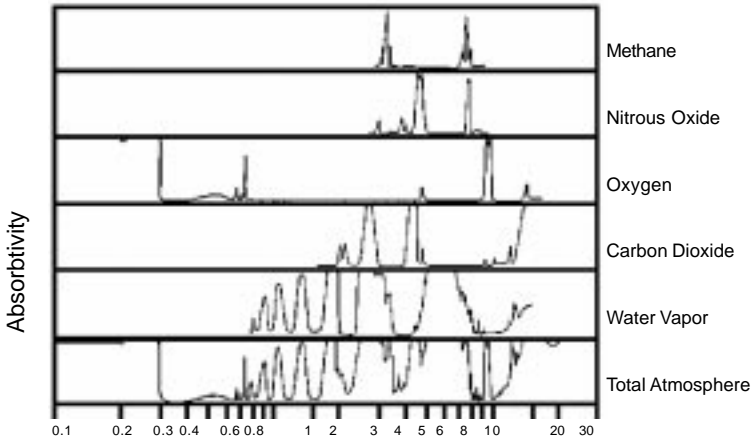
Radiation with wavelengths between 280 and 320 nm — the UV-B range which is partially blocked out by ozone — can result in premature skin aging and in increased incidences of skin cancer in humans and damage to plants and other animals.

Figure 22. Comparison of Solar and Earth Radiation Spectra



Source: University of Wisconsin-Stevens Point, http://www.uwsp.edu/acaddept/geog/faculty/ritter/geog101/lecture_radiation_energy_balance.html

Figure 23. Absorption Spectra of Atmospheric Gases



Source: International Institute of Theoretical and Applied Physics, Iowa State University, <http://www.iitap.iastate.edu/gcp/forcing/images/image7.gif>

Radiation with wavelengths greater than 320 nm, the UV-A range, is not absorbed significantly by ozone and, in fact, is needed in humans for the formation of vitamin D. UV-C radiation, with wavelengths between 200 and 280 nm, can cause severe biological consequences and

is totally removed by stratospheric ozone. The Achilles heel for terrestrial life is in the narrow UV-B band from 320 to 280 nm. As the wavelengths of these rays shorten, they do more damage to living things and their DNA. Fortunately, the UV-absorbing properties of ozone increase steeply in this same band.

Potential human health effects of increased UV radiation are described below:

Increases in Skin Cancers.

According to EPA, three distinct types of skin cancer would increase if the ozone layer is depleted. Basal and squamous cell skin cancers are the two most common types, now affecting about 500,000 people annually in the United States. If detected early, these cancers are treatable. The third type, malignant melanoma, is far less common, but substantially more harmful. About 25,000 cases now occur annually, resulting in 5,000 deaths and accounting for about 65 percent of all skin cancer deaths.

While scientists by and large agree that increased UV-B exposure can increase the incidence of the milder basal and squamous cell skin cancers, details of the relationship to malignant melanoma are less certain. For the milder forms there appears to be a direct correlation between time spent in the sun and susceptibility to skin cancer — it generally occurs in people in their 70s and 80s on areas of the skin usually exposed to sunlight (such as the face or hands). EPA estimates that a 2 percent increase in UV-B radiation would result in a 2 to 6 percent increase in incidences of non-melanoma skin cancer. Malignant melanoma, however, usually occurs in younger people and in skin areas not necessarily exposed to sunlight. It tends to occur most commonly among groups of people less likely to have spent significant amounts of time outdoors.

The risk of developing malignant melanoma is directly related to the sensitivity of an individual's skin to the sun (i.e., fair-skinned are more susceptible than darker-skinned individuals). The victims are almost exclusively Caucasians, particularly fair-skinned Caucasians. The incidence of malignant melanoma has been increasing among light-skinned populations around the world for decades.

Suppression of the Human Immune Response System.

According to EPA, research to date suggests that exposure to UV radiation weakens the ability of the immune system to fend off certain diseases.

Damage to Human Eye.

UV radiation can damage the cornea and conjunctiva (mucus mem-

brane covering the eye), the lens, and the retina. UV can cause photokeratitis, or “snow blindness,” similar to sunburn of the cornea and conjunctiva. Increased exposure to UV radiation from ozone depletion is expected to increase the number of people experiencing cataracts. Cataracts cloud the lens of the eye, limiting vision, and if not operated on can cause blindness.

Other potential harmful effects linked to stratospheric ozone depletion are described:

Damage to Crops and Other Terrestrial Ecosystems.

Absorption of UV radiation varies widely from one organism to the next. In general, UV radiation “deleteriously affects plant growth, reducing leaf size, limiting the area available for energy capture. Plant stunting and a reduction in total dry weight are also typically seen in UV-irradiated plants,” according to EPA.

However, reliable scientific information on the effects of UV on plants is limited. Only four out of 10 terrestrial plant ecosystems (temperate forest, agricultural, temperate grassland, and tundra and alpine ecosystem) have been studied. In addition, much of the existing data come from greenhouses where plants are more sensitive to UV-B than those grown outdoors.

Studies at the University of Maryland have found that two-thirds of the plants studied displayed some degree of UV sensitivity, and there are indications that some weeds are more UV-B resistant than crops. Some research has suggested that a 25 percent ozone depletion could result in a comparable reduction in total soybean crop yield.

Many organisms have developed mechanisms for protecting themselves from UV-B they may: limit exposure (some aquatic organisms avoid activity in the middle of the day when UV is strongest); shield themselves with pigment; repair damaged DNA; or repair tissue damage (e.g., from burns). However, for many organisms these mechanisms may not be sufficient to protect against increased levels of UV-B.

Damage to Certain Marine Organisms.

Phytoplankton and zooplankton, marine organisms which play crucial roles in complex ecological food webs, are sensitive to UV radiation. Because UV-B radiation is absorbed by only a few layers of cells, large biological systems are more protected and smaller systems, such as unicellular organisms in aquatic ecosystems are among the most severely affected by UV.

According to a report by the Environmental Policy Institute and the Institute for Energy and Environmental Research, many plankton species

Ozone: Chronology of Key Events

- 1974 Professors F. Sherwood Rowland and Mario Molina publish in *Nature* magazine theories of ozone depletion.
- 1975 Oregon becomes the first state to ban CFCs in aerosol sprays.
- 1977 United Nations Environment Programme (UNEP) hosts its first international meeting on ozone depletion; recommends “World Plan of Action of the Ozone Layer” and establishes annual science review.
- 1977 Ozone protection amendment passes as part of the U.S. Clean Air Act.
- 1978 United States bans use of CFCs in nonessential aerosols, followed by Canada, Denmark, Finland, Norway, and Sweden.
- 1980 European Community reduces aerosol use by 30 percent and enacts capacity cap.
- 1980 U.S. Environmental Protection Agency (EPA) announces U.S. intention to freeze all CFC production at 1979 levels.
- 1984 A British research group detects a 40 percent ozone loss over Antarctica during the austral spring.
- 1985 Convention for the Protection of the Ozone Layer held in Vienna. Agreements reached on research, monitoring, and data exchange; no agreement reached on CFC controls.
- 1985 British scientists publish data showing seasonal Antarctic ozone hole.
- 1985 NASA satellite photographs confirm ozone hole over Antarctica.
- 1987 Montreal Protocol on Substances that Deplete the Ozone Layer adopted. Parties call for CFC reductions of 50 percent by 1999.
- 1987 Antarctic ozone expedition finds chlorine chemicals to be the primary cause of ozone depletion.
- 1988 Ozone Trends Panel releases new evidence that CFCs are causing ozone depletion globally and over the Antarctic.
- 1989 NASA’s reports finding same destructive chlorine and bromine compounds in the Arctic that cause the Antarctic ozone hole.
- 1990 Amendments to Montreal Protocol at meeting in London — Parties agree to accelerate phaseout of ozone depleting chemicals.
- 1990 Clean Air Act Amendments of 1990 provide for a phase-out of production and sale of CFCs and several other chemicals, going beyond the restrictions in the Montreal Protocol.

- 1993 NASA and NOAA report data showing “record lows” in Antarctic ozone levels in late September and early October, including “Lowest values of total column ozone ever measured.”
- 1992 Amendments to Montreal Protocol at meeting in Copenhagen — Parties agree to accelerate the schedules for phase out of CFCs, methyl chloroform, carbon tetrachloride and halons and to add methyl bromide and hydrobromofluorocarbons to the list of controlled substances.
- 1994 WMO and UNEP publish *Scientific Assessment of Ozone Depletion: 1994*.
- 1995 Amendments to Montreal Protocol at meeting in Vienna — Parties agreed to phase down the use of HCFCs in developing countries and to phase out production of methyl bromide in developed countries by 2010.
- 1995 Professor Paul Crutzen, Professor Mario Molina and Professor F. Sherwood Rowland receive the Nobel Prize in Chemistry.
- 1997 Amendments to Montreal Protocol at meeting in Montreal — Parties agree to advance the deadline for methyl bromide in developing countries to 2005 and in developed countries to 2015.
- 1998 UNEP and WMO published the *Scientific Assessment of the Ozone Layer: 1998*. It states that the ozone hole has continued to appear during the austral springs with ozone column losses of 40 – 55% during the months of September and October.
- 1998 Environmental ministers from G-8 countries agree to a plan to reduce smuggling of CFCs.
- 1998 WMO report that the ozone hole over the Antarctic was the largest it had ever been in October 1998.
- 1999 UNEP announces an international agreement requiring countries to establish licensing systems for trading ozone-depleting chemicals (to prevent smuggling of CFCs).
- 1999 Amendments to Montreal Protocol at meeting in Beijing — Parties agree to a phaseout of HCFCs in developed countries by 2020 and in developing countries by 2040, and to provide an additional \$440 million for the Montreal Protocol fund to assist developing countries to meet deadlines.
- 2000 NASA and the European Union report that a portion of Earth’s ozone layer thinned to record low levels (more than 60 percent of the layer lost) around the Arctic region during the 1999-2000 winter.

seem already to be at or near their maximum tolerance of UV radiation. Thus, even limited increases in UV-B levels might have a dramatic impact on plankton life and on entire marine ecosystems. Some research suggests that ozone depletion is more likely to change the composition of living organic materials on the ocean's surface than to reduce its overall mass.