NASA Facts

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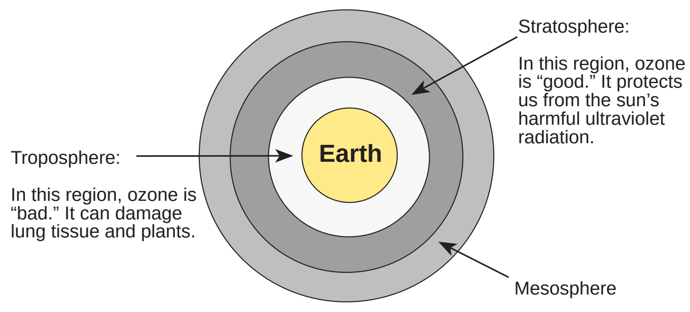
The Earth Science Enterprise Series

These articles consider Earth's many dynamic processes and their interactions.

Ozone: What is it, and why do we care about it?

Ozone is a relatively unstable molecule found in Earth's atmosphere. Most ozone is concentrated below a 30-mile (48-km) height. An ozone molecule is made up of three atoms of oxygen. Although it represents only a tiny fraction of the atmosphere, ozone is crucial for life on Earth.

Depending on where ozone resides, it can protect or harm life on Earth. High in the atmosphere—about 15 miles (24 km) up—ozone acts as a shield to protect Earth's surface from the sun's harmful ultraviolet radiation. Without this shield, we would be more susceptible to skin cancer, cataracts, and impaired immune systems. Closer to Earth, in the air we breathe, ozone is a harmful pollutant that causes damage to lung tissue and plants.



Ozone in Earth's Atmosphere

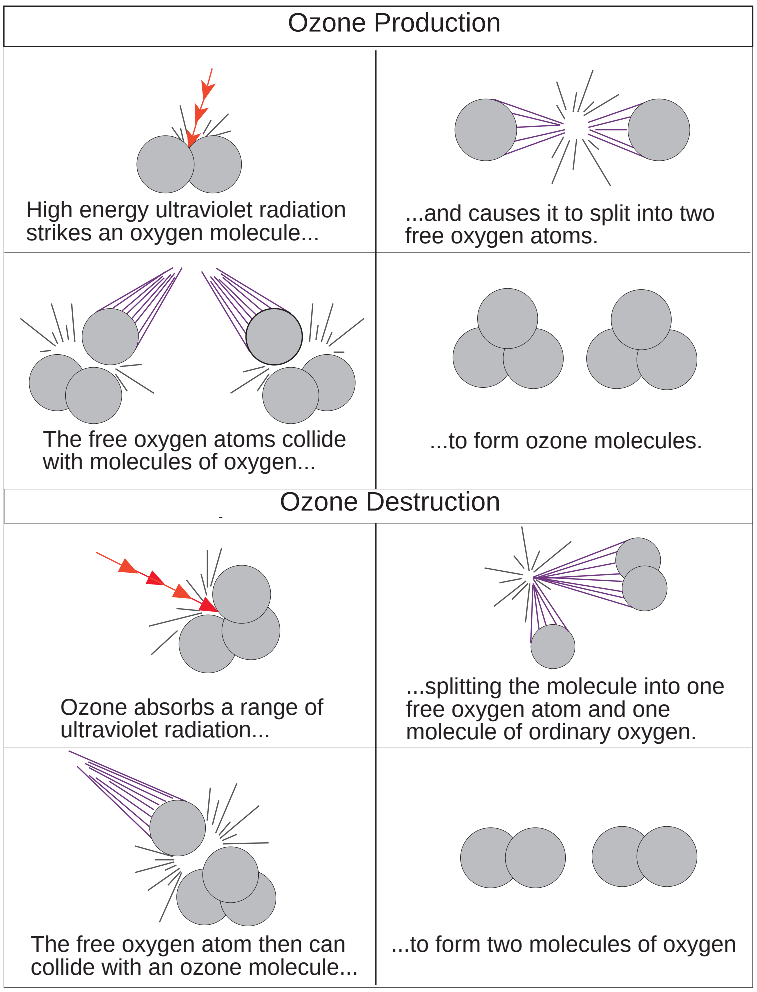
The amounts of "good" and "bad" ozone in the atmosphere depend on a balance between processes that create ozone and those that destroy it. An upset in the ozone balance can have serious consequences for life on Earth. Scientists are finding evidence that changes are occurring in ozone levels—the "bad" ozone is increasing in the air we breathe, and the "good" ozone is decreasing in our protective ozone shield. This article describes processes that regulate "good" ozone levels.

Ozone Balance in the Stratosphere

Fifteen to thirty kilometers up in the atmosphere, in the region called the stratosphere, ozone is created and destroyed primarily by ultraviolet radiation. The air in the stratosphere is bombarded continuously by ultraviolet radiation from the sun. When high-energy ultraviolet rays strike molecules of ordinary oxygen (O_2), they split the molecule into two single oxygen atoms, known as atomic oxygen. A freed oxygen atom then can combine with an oxygen molecule (O_2) to form a molecule of ozone (O_3).

The characteristic of ozone that makes it so valuable to us—its ability to absorb a range of ultraviolet rays—also causes its destruction. When an ozone molecule (O_3) absorbs even low-energy ultraviolet radiation, it splits into an ordinary oxygen molecule (O_2) and a free oxygen atom (O). The free oxygen atom then may join up with an oxygen molecule to make another ozone molecule, or it may steal an oxygen atom from an ozone molecule to make two ordinary oxygen molecules. These processes of ozone production and destruction, initiated by ultraviolet radiation, are called the "Chapman Reactions."

Natural forces other than the Chapman Reactions also affect the concentration of ozone in the stratosphere. Because ozone is a highly unstable molecule, it reacts very easily, readily donating its “extra” oxygen atom to nitrogen, hydrogen, and chlorine found in natural compounds. These elements always have existed in the stratosphere, released from both land and ocean sources.



In addition, scientists are finding that ozone levels change periodically as part of regular natural cycles such as the changing seasons, winds, and solar cycles. Moreover, volcanic eruptions may inject materials into the stratosphere that can lead to increased destruction of ozone.

Over the Earth’s lifetime, natural processes have regulated the balance of ozone in the stratosphere. A simple way to understand the ozone balance is to think of a leaky bucket. As long as water is poured into the bucket at the same rate that water is leaking out, the amount of water in the bucket will remain the same. Likewise, as long as ozone is being created at the same rate that it is being destroyed, the total amount of ozone will remain the same.

Starting in the early 1970’s, however, scientists have found evidence that human activities are disrupting the ozone balance. Human production of chlorine-containing chemicals such as chlorofluorocarbons (CFCs) has added an additional factor that destroys ozone. CFCs are compounds made up of chlorine, fluorine and carbon bound together. Because they are extremely stable molecules, CFCs do not react easily with other chemicals in the lower atmosphere. One of the few forces that can break up CFC molecules is ultraviolet radiation. In the lower atmosphere, however, CFCs are protected from ultraviolet radiation by the ozone layer itself. CFC molecules thus are able to migrate intact up into the stratosphere. Although the CFC molecules are heavier than air, the mixing processes of the atmosphere carry them into the stratosphere.

Once in the stratosphere, the CFC molecules no longer are shielded from ultraviolet radiation by the ozone layer. Bombarded by the sun’s ultraviolet energy, CFC molecules break up and release their chlorine atoms. The free chlorine atoms then can react with ozone molecules, taking one oxygen atom to form chlorine monoxide and leaving an ordinary oxygen molecule.

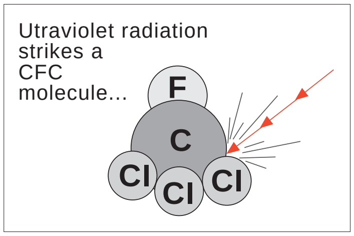
If each chlorine atom released from a CFC molecule destroyed only one ozone molecule, CFCs would pose very little threat to the ozone layer. However, when a chlorine monoxide molecule encounters a free atom of oxygen, the oxygen atom breaks up the chlorine monoxide, stealing the oxygen atom and releasing the chlorine atom back into the stratosphere to destroy more ozone. This reaction happens over and over again, allowing a single atom of chlorine to act as a catalyst, destroying many molecules of ozone.

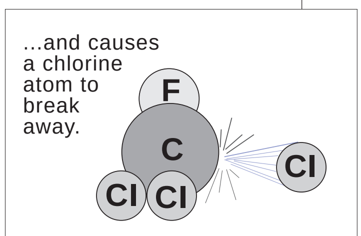
Fortunately, chlorine atoms do not remain in the stratosphere forever. When a free chlorine atom reacts with gases such as methane (CH_4), it is bound up into a molecule of hydrogen chloride (HCl), which can be carried downward from the stratosphere into the troposphere, where it can be washed away by rain. Therefore, if humans stop putting CFCs and other ozone-destroying chemicals into the stratosphere, the ozone layer eventually may repair itself.

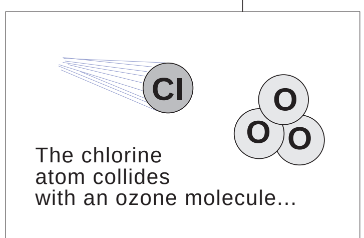
Ozone Depletion

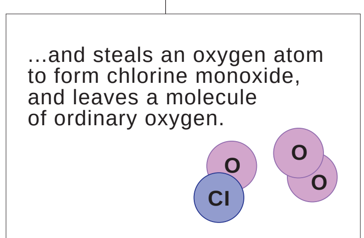
The term “ozone depletion” means more than just the natural destruction of ozone, it means that ozone loss is exceeding ozone creation. Think again of the “leaky bucket.” Putting additional ozone-destroying compounds such as CFCs into the atmosphere is like causing the “bucket” of ozone to spring extra leaks. The extra leaks cause ozone to leak out at a faster rate—faster than ozone is being created. Consequently, the level of ozone protecting us from ultraviolet radiation decreases.

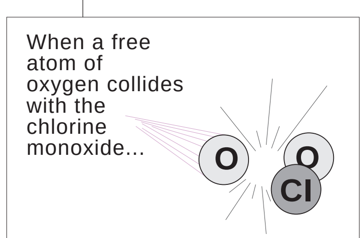
In the area over Antarctica, there are stratospheric cloud and ice particles that are not present at warmer latitudes. Reactions occur on the surface of the ice particles that accelerate the ozone destruction caused by stratospheric chlorine. This phenomenon has

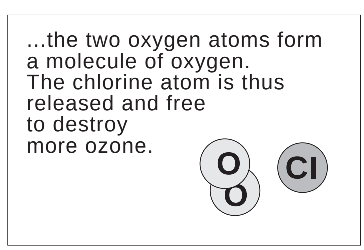












caused documented decreases in ozone concentrations over Antarctica. In fact, ozone levels drop so low in spring in the southern hemisphere that scientists have observed what they call a “hole” in the ozone layer.

In addition, scientists have observed declining concentrations of ozone over the whole globe. In the second half of 1993, for example, world-wide ozone levels were the lowest ever recorded.

Monitoring Ozone from Space

Since the 1920’s, ozone has been measured from the ground. Scientists place instruments at locations around the globe to measure the amount of ultraviolet radiation getting through the atmosphere at each site. From these measurements, they calculate the concentration of ozone in the atmosphere above that location. These data, although useful in learning about ozone, are not able to provide an adequate picture of global ozone concentrations.

Contrary to the image created by the term “ozone layer,” the amount and distribution of ozone molecules in the stratosphere vary greatly over the globe. Ozone molecules are transported around the stratosphere much as water clouds are transported in the troposphere. Therefore, scientists observing ozone fluctuations over just one spot could not know whether a change in local ozone levels meant an alteration in global ozone levels, or simply a fluctuation in the concentration over that particular spot. Satellites have given scientists the ability to overcome this problem because they provide a picture of what is happening simultaneously over the entire Earth.

Scientists now are confident that stratospheric ozone is being depleted worldwide—partly due to human activities. However, scientists still do not know *how much* of the loss is the result of human activity, and how much is the result of fluctuations in natural cycles.

Predicting Ozone Levels

If scientists can separate the human and natural causes of ozone depletion, they can formulate improved models for predicting ozone levels. The predictions of early models already have been used by policy makers to determine what can be done to reduce the ozone depletion caused by humans. For example, faced with the strong possibility that CFCs could cause serious damage to the ozone layer, policy makers from around the world in 1987 signed a treaty known as the *Montreal Protocol.* This treaty set strict limits on the production and use of CFCs. By 1990, the growing amount of scientific evidence against CFCs prompted diplomats to strengthen the requirements of the Montreal Protocol. The revised treaty called for a complete phaseout of CFC production in the developed countries by the year 1996.

However, scientists agree that much remains to be learned about the interactions that affect ozone. To create accurate models, scientists must study simultaneously all of the factors affecting ozone creation and destruction. Moreover, they must study these factors from space continuously, over many years, and over the entire globe. NASA's Earth Observing System (EOS) will allow scientists to study ozone in just this way. The EOS series of satellites will carry a sophisticated group of instruments that will measure the interactions within the atmosphere that affect ozone. Building on the many years of data gathered by previous NASA missions, these measurements will increase dramatically our knowledge of the chemistry and dynamics of the upper atmosphere and our understanding of how human activities are affecting Earth's protective ozone layer.

Earth Science Enterprise

Selected Missions to Study Ozone

Mission	Launch	Scientific Objectives
Nimbus Series: Monitor of Ultraviolet Solar Energy (MUSE) Backscatter Ultraviolet Spectrometer (BUV) Solar Backscatter Ultraviolet/Total Ozone Mapping Spectrometer (SBUV/TOMS)	1969-1978	Monitored solar energy controlling stratospheric ozone Mapped total global ozone and the vertical distribution of ozone in the atmosphere
Stratospheric Aerosol and Gas Experiments: (SAGE II)/Earth Radiation Budget Satellite (ERBS) (SAGE III)/Meteor-3M (Russia)	 1984 1998	Map ozone at all latitudes
NOAA-9, 11, 14, L, N, (SBUV/2)	1984-2001	Map total ozone and the vertical distribution of ozone in the stratosphere
Shuttle Solar Backscatter Ultraviolet (SSBUV)	1989-2000	In-orbit calibration checks of satellite instruments
Total Ozone Mapping Spectrometer (TOMS) /Meteor-3 (Russia) /Earth Probe (U.S.) /ADEOS (Japan) /Meteor-3M (Russia)	1991-2000	Daily high-resolution global mapping of total ozone (TOMS was first flown on Nimbus-7 in 1978)
Upper Atmosphere Research Satellite (UARS)	1991	Monitor solar energy, upper atmospheric chemistry and dynamics
ATLAS/STS Payloads	1992-1995	Monitor solar energy, upper atmospheric chemistry and dynamics
Earth Observing System (EOS)	1998-	Comprehensive investigations of ozone processes, particularly with data from the EOS-Chemistry mission beginning in 2002, and SAGE III starting in 1998