[**Ozone**](http://earthguide.ucsd.edu/virtualmuseum/Glossary_Astro/gloss_m-r.shtml#ozone)**: Good Up High, Bad Nearby**

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Actually, there are two �ozone problems,� and both are linked to the [greenhouse effect](http://earthguide.ucsd.edu/virtualmuseum/Glossary_Climate/gloss_g-l.shtml#greenhouseeffect) in some ways. The first problem is the pollution of the lower [atmosphere](http://earthguide.ucsd.edu/virtualmuseum/Glossary_Astro/gloss_a-f.shtml#atmosphere), called the troposphere, with ozone which largely results from photochemical reactions involving man-made emissions from industry and automobiles ("smog" or "photo-smog"). This ozone (the chemical formula for ozone is O3) is "bad" because it produces [respiration](http://earthguide.ucsd.edu/virtualmuseum/Glossary_Life/gloss_m-r.shtml#respiration) problems in people and damages plants. The link to the greenhouse effect is that the same activities which release most of the carbon dioxide also release most of the nitrogen-oxide gases which provide the source materials for making ozone when the Sun shines brightly. In addition, ozone itself is a [greenhouse gas](http://earthguide.ucsd.edu/virtualmuseum/Glossary_Climate/gloss_g-l.shtml#greenhousegas).   
  
The second problem � the one usually thought of when referring to the �ozone problem� � concerns the [ozone layer](http://earthguide.ucsd.edu/virtualmuseum/Glossary_Astro/gloss_m-r.shtml#ozonelayer) in the lower stratosphere, centered on about 20 km up. The stratosphere has about ten times more ozone than the troposphere. This ozone is �good,� because it intercepts much of the UV radiation from the Sun which is close to the violet (called UV(B)) and which would otherwise reach the surface of Earth and bother people, animals and plants. The link to the greenhouse story emerges because [global warming](http://earthguide.ucsd.edu/virtualmuseum/Glossary_Climate/gloss_g-l.shtml#globalwarming) in the troposphere leads to cooling in the stratosphere (by mechanisms which need not concern us here) and this cooling favors the destruction of ozone within the ozone-rich layer.

**The Ozone Hole**

The "ozone hole" was first discovered in Antarctica by Joseph Farman and colleagues at the British Antarctic Survey in 1985. They observed the [radiation](http://earthguide.ucsd.edu/virtualmuseum/Glossary_Astro/gloss_m-r.shtml#radiation) coming from the Sun and noting the increase in UV(B) radiation. This increase is especially strong during the southern spring (September and October), when an "ozone hole" develops. (Similar observations were first made by [NASA](http://earthguide.ucsd.edu/virtualmuseum/Glossary_Astro/gloss_m-r.shtml#nasa) scientists using satellite sensors. However, these scientists doubted what their instruments told them, because the observations were entirely unexpected and out of the ordinary.)   
  
The ozone loss in the Antarctic has to do with photochemical reactions favored by the presence of certain types of ice particles on whose surface unstable chlorine compounds are produced from chlorofluorocarbons (CFCs), a family of long-lived industrial gases whose [molecules](http://earthguide.ucsd.edu/virtualmuseum/Glossary_Astro/gloss_m-r.shtml#molecule) can work their way up through the troposphere and end up in the stratosphere. The unstable chlorine compounds deliver the chlorine which helps destroy ozone, when sunlight returns to the Antarctic after the long winter. The chemical reactions were worked out by [Paul Crutzen](http://earthguide.ucsd.edu/virtualmuseum/Glossary_Climate/gloss_a-f.shtml#crutzenp) and other scientists studying atmospheric chemistry.

**The Ozone Depletion Process**

Step 1. CFCs originate entirely from human activities. They are chemically inert, that is, they do not normally react with anything they come in contact with. This is one important reason why they were so useful for many commercial applications. However, being inert, they stay in the atmosphere for a long time. Step 2. CFCs rise into the ozone layer in the stratosphere. Step 3. In the stratosphere, high-[energy](http://earthguide.ucsd.edu/virtualmuseum/Glossary_Astro/gloss_a-f.shtml#energy) UV radiation from the Sun breaks apart the CFC molecules, providing a source of free chlorine (Chlorine, or Cl, is the chloro-part of chlorofluorocarbons). Step 4. The free chlorine [atoms](http://earthguide.ucsd.edu/virtualmuseum/Glossary_Astro/gloss_a-f.shtml#atom) react with ozone, helping to convert it to plain molecular oxygen (which does not intercept UV). In the process, the chlorine only acts as a helper and is preserved for additional reactions. Through its "catalytic" action (= chemical helper action) a single chlorine atom can destroy up to 15,000 ozone molecules. In this manner even minute quantities of CFCs reaching the stratosphere can have disastrous effects on the ozone layer there. Step 5. A depleted ozone layer means that more UV radiation can get through. Step 6. Increased exposure to UV radiation has negative consequences for humans, animals and plants.

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| [http://earthguide.ucsd.edu/virtualmuseum/images/OzoneDepletion.jpg](javascript:popup2())  Schematic of the ozone depletion process in the stratosphere, Steps 1-6 are explained in detail in the text below. |

When it became clear that ozone was being destroyed on a large scale, international agreements (like [Montreal Protocol](http://earthguide.ucsd.edu/virtualmuseum/Glossary_Climate/gloss_m-r.shtml#montprotocol)) were made to phase out the chlorofluorocarbon compounds which are responsible for the damage to this shield. Following these agreements, the concentration of the ozone-destroying gases has leveled off, and they are expected to decrease in the future.   
  
The phasing out of these gases also will prevent an increase of the [greenhouse effect](http://earthguide.ucsd.edu/virtualmuseum/Glossary_Climate/gloss_g-l.shtml#greenhouseeffect) from this source, although proposed replacements for the CFCs, while less dangerous to the ozone layer, are as powerful in terms of their greenhouse potential as are the CFCs themselves.   
  
A great site on the Ozone Hole for teachers: [Centre for Atmospheric Sciences](http://www.atm.ch.cam.ac.uk/tour/) You�ll even see movies of the ozone hole developing over Antarctica.