

The Causes, Effects, and Future of Stratospheric Ozone Depletion

Measures gradually improving atmospheric conditions

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To get *HPAC Engineering* readers on the same page, so to speak, regarding the stratospheric ozone layer, this article summarizes key reports, data, and charts pertaining to stratospheric ozone depletion and the recovery of the ozone layer since the Montreal Protocol was adopted and amended. The purpose of this update is to put the variable size of the “ozone hole” in a credible context, encourage patience as measures already in place gradually improve atmospheric conditions, and emphasize that reader attention needs to be attuned to the topic of global climate change, which will be covered in a future issue of *HPAC Engineering*.

WHAT IF ...

The ozone layer helps protect the earth from excessive amounts of ultraviolet (UV-B) radiation, which could be harmful to humans, phytoplankton (the foundation of the marine food chain), and plant life. In 1980, a “hole” (actually, a significant thinning) in the ozone layer first appeared. This led to the adoption of the Montreal Protocol in 1987.

Compliance with the Protocol, its amendments, and earlier voluntary measures, such as the 1978 decision to phase out chlorofluorocarbon (CFC) aerosols in the United States, has helped

keep numerous adverse effects of UV-B radiation, such as skin-cancer-related deaths and increases in cataract damage, from spiraling out of control.

Without the Protocol, surface UV-B radiation at midlatitudes in the Northern

be at least 50 and 70 percent, respectively, about 10 times higher than it is today.¹

Levels of chlorine in the atmosphere had the Protocol and its amendments, which intensified the control of ozone-depleting substances, not been adopted are projected in Figure 1.

Because of measures taken in response to the Montreal Protocol and its amendments, the ozone layer should return to its pre-1980 level by about 2050. Total recovery is not expected for more than a century.¹

EMISSIONS AND OZONE DEPLETION

Emissions of chlorine and bromine from CFCs and halons are to blame for excessive stratospheric ozone depletion. The combined abundance of anthropogenic (man-made) chlorine-containing and bromine-containing ozone-depleting substances in the lower atmosphere peaked in 1994 and is in decline. Because of the time delay of mixing tropospheric and stratospheric

air and atmospheric chemical reactions, total stratospheric loading of ozone-depleting substances was expected to peak around 2000.

Primary sources of anthropogenic stratospheric chlorine are CFCs, carbon tetrachloride (CCl₄), and methyl chloroform (CH₃CCl₃). The latter two are used as industrial solvents. Bromine is used in halons, which are used as fire-extinguishing agents, and in methyl

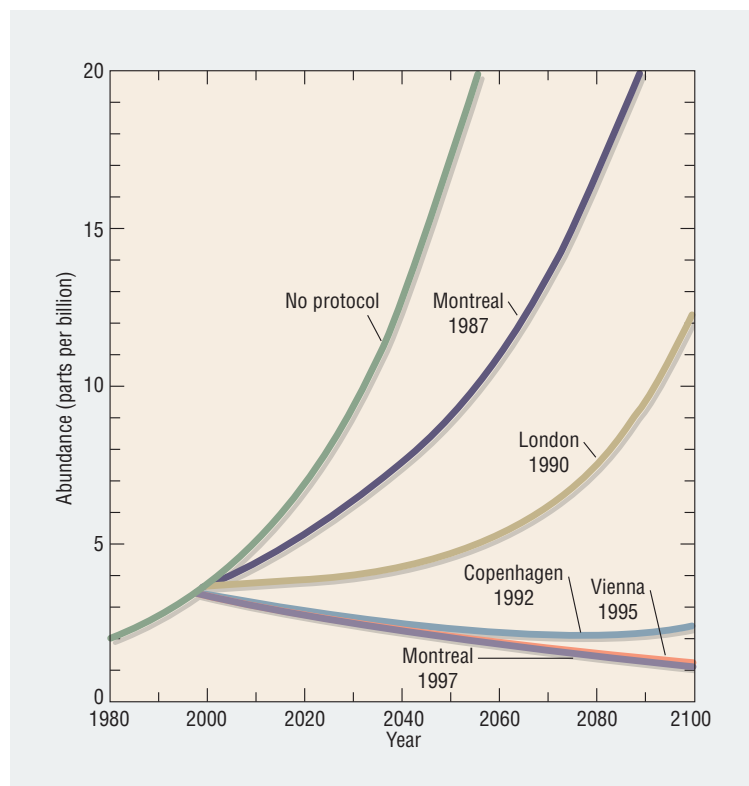


FIGURE 1. The projected impact of ozone-depleting substances and reductions under the Montreal Protocol and its amendments. Source: World Meteorological Organization, “Scientific Assessment of Ozone Depletion: 1998.”

and Southern hemispheres, where the vast majority of the earth’s population resides, would have doubled and quadrupled from 1980 levels, respectively. Even with the Protocol, however, UV-B radiation has increased 5 percent and 8 percent in the Northern and Southern hemispheres, respectively, since 1980.¹

If not for the Protocol, by 2050, ozone depletion at midlatitudes in the Northern and Southern hemispheres would

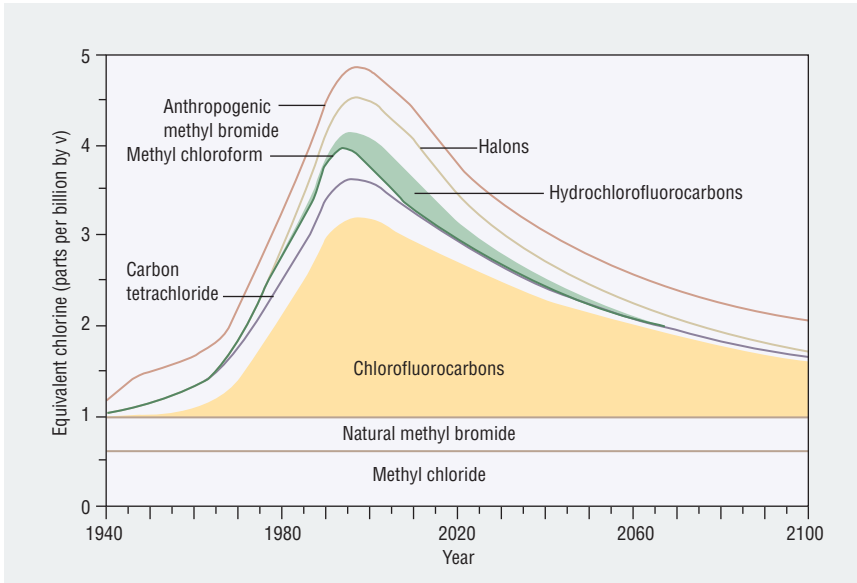


FIGURE 2. Chlorine/bromine loading expressed as equivalent chlorine loading through 2100. Source: Calm, J.M., D.J. Wuebbles, and A.K. Jain. June 1999. "Impacts on global ozone and climate from use and emission of 2,2-Dichloro-1,1,1-trifluoroethane (HCFC-123)." Journal of Climatic Change. Copyright 1999, James M. Calm, PE, Engineering Consultant. Reprinted with permission.

bromide, which is a common pesticide and fumigant.² Due primarily to reductions in emissions of methyl chloroform, chlorine abundance is in decline. Chlorine from the major CFCs was increasing slightly in 1998.¹ The delay was because of the time (years) for CFCs to break down and for the released chlorine to eventually wash out of the stratosphere.³

According to the 1998 Scientific Assessment of Ozone Depletion,¹ a consensus report prepared by 304 scientists from 35 countries, the ozone layer will remain at its most vulnerable state for the next few decades. Figure 2 projects equivalent chlorine concentrations through 2100.⁴

All other things being equal (e.g., weather, emissions of particulate and other contributing gases, etc.), the current stratospheric-ozone impacts are close to the peak.¹ These losses are approximately:

- Six percent at Northern Hemisphere midlatitudes during winter and spring.
- Three percent at Northern Hemisphere midlatitudes during summer and fall.
- Five percent at Southern Hemisphere midlatitudes on a year-round basis.

- Fifty percent during the Antarctic spring.
- Fifteen percent during the Arctic spring.

Antarctic losses are severe because of the effects of climate, chemistry, and atmospheric-transport effects.³

HOLE VARIABILITY

According to the 1998 Scientific Assessment of Ozone Depletion,¹ the "ozone holes" of today are about the same size as the ones of the early 1990s (Figure 3). In Antarctica, the monthly total ozone in September and October continued to be 40- to 55-percent below the pre-ozone-hole values of approximately 320 Dobson units, with up to a 70-percent decrease for periods of a week or so.

The size (area and depth) of ozone holes varies from year to year because of changes in weather, polar oscillations, and the strength of the resulting polar vortices^{3,5} (figures 4 and 5). For the general public, it is easiest to understand that low stratospheric air temperatures reduce ozone levels, so unusually cold Antarctic winters and/or prolonged polar vortices make for unusually large and/or prolonged ozone holes. It is because of this that the possibility of more severe

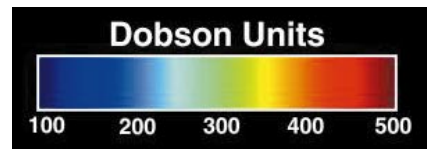
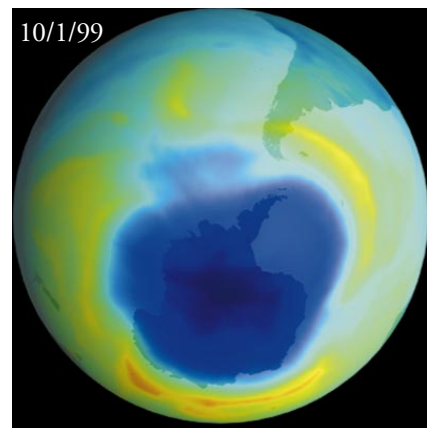
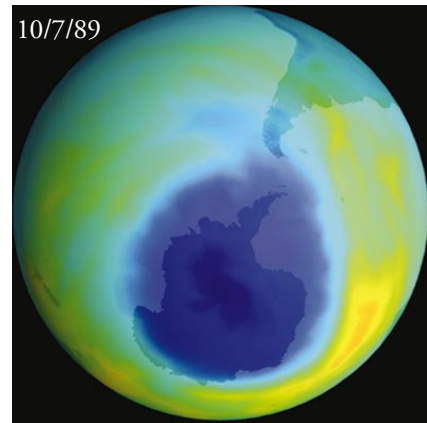
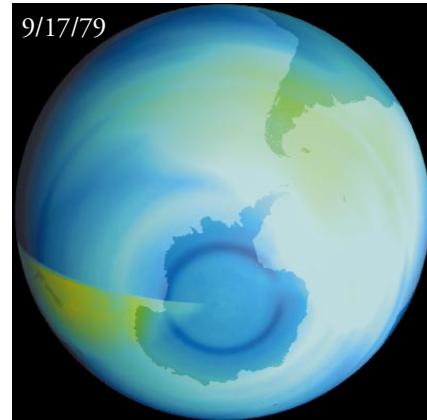


FIGURE 3. Total-ozone concentrations on the date of minimum Antarctic ozone for 1979, 1989, and 1999. Images courtesy of NASA.

ozone-hole occurrences will continue for at least a decade, even though there is evidence that recovery has begun.

REFRIGERANTS: NEXT STEPS

The next key step in protecting the stratospheric ozone layer is phaseout of R-141b—a hydrochlorofluorocarbon (HCFC)—as a foam-blowing agent for refrigerators, freezers, and other uses. Manufacturers are actively planning alternatives.

For refrigerants, the next major step is phaseout of R-22 (also a HCFC), the most widely used refrigerant in new equipment. The primary replacement for it will be R-410A, a hydrofluorocarbon (HFC) blend. R-134a and—for service of existing equipment especially—R-407C (both HFCs) will be other replacements. HFCs have zero ozone-depleting potential. The use of hydrocarbons and other options is being investigated.⁶

With very low ozone-depleting and global-warming potential, R-123 will be allowed in new equipment in the United States and Canada until 2020. Use of both R-22 and R-123 in existing equipment will continue for decades with stocked and recovered supplies.⁶

ONE ATMOSPHERE

It will be one or two decades before the

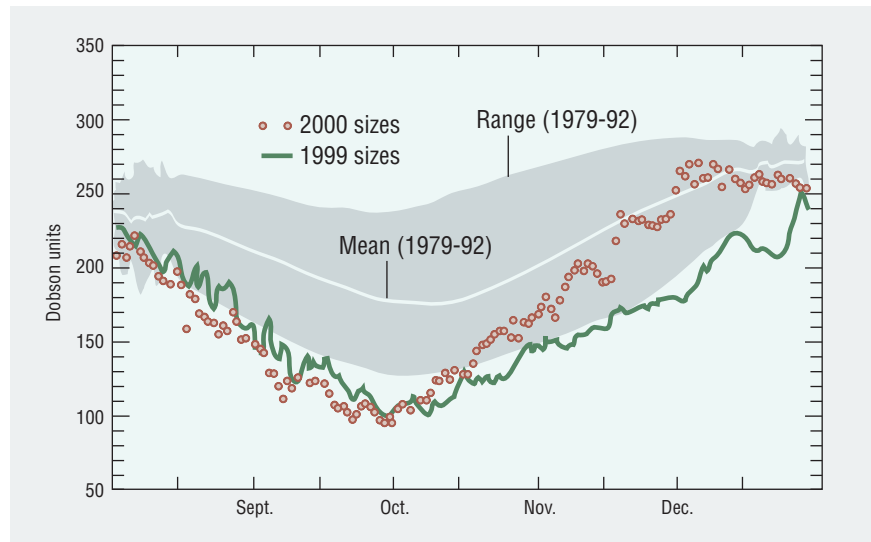


FIGURE 4. Daily total-ozone minimums in the Southern Hemisphere. Source: toms.gsfc.nasa.gov/eptoms/dataqual/ozone.html.

Antarctic ozone hole no longer occurs regularly. Meanwhile, the size and duration of the hole will grow and shrink in relation to the severity of Antarctic winter temperatures and the time it takes the winter polar vortex to break up each year. The gradually declining chlorine levels mean that the probability of larger ozone holes will decrease over time in direct relation to climate and weather effects.

The rate of “repair” of the ozone layer is linked to global climate change. As the

earth warms, the stratosphere cools,¹ which makes ozone destruction more efficient; thus, global warming could prolong ozone-layer recovery.

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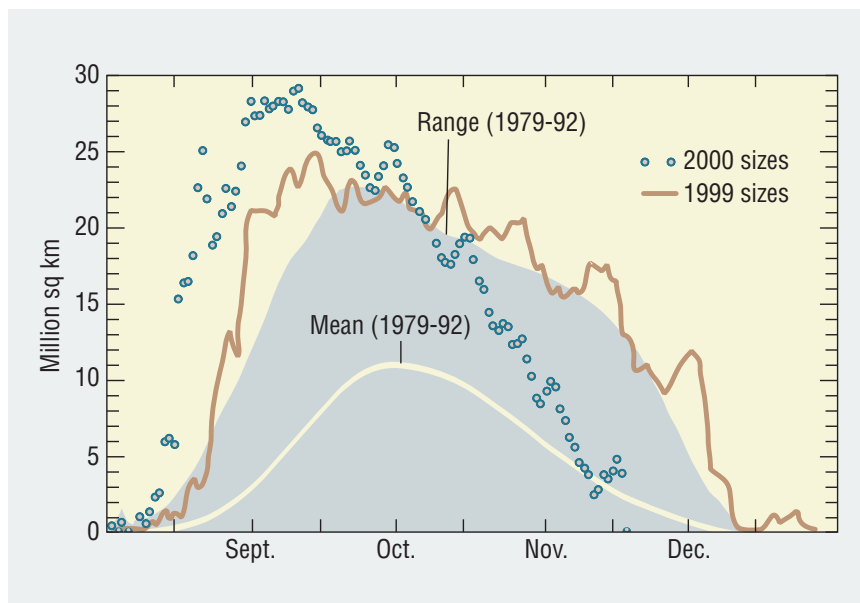


FIGURE 5. Daily estimates of ozone-hole area. Source: toms.gsfc.nasa.gov/eptoms/dataqual/ozone.html.