## Q16: Has the Montreal Protocol been successful in reducing ozone-depleting gases in the atmosphere?

*Yes, as a result of the Montreal Protocol, the total abundance of ozone-depleting gases in the atmosphere has begun to decrease in recent years. If the nations of the world continue to follow the provisions of the Montreal Protocol, the decrease will continue throughout the 21st century. Some individual gases such as halons and hydrochlorofluorocarbons (HCFCs) are still increasing in the atmosphere, but will begin to decrease in the next decades if compliance with the Protocol continues. By midcentury, the effective abundance of ozone-depleting gases should fall to values present before the Antarctic "ozone hole" began to form in the early 1980s.*

**Effective stratospheric chlorine.** The Montreal Protocol has been successful in slowing and reversing the increase of ozone-depleting gases in the atmosphere. An important measure of its success is the change in the value of *effective stratospheric chlorine.* Effective chlorine is based on measured or estimated abundances of both chlorine- and bromine-containing gases in the stratosphere. The two groups of gases are not simply added together, because bromine gases are much more effective on a per-atom basis than chlorine in depleting ozone (see *Q7*). Instead, the amounts for bromine gases are multiplied by a factor that accounts for their greater effectiveness and then added to the total amount of chlorine. Bromine atoms are much less abundant in the stratosphere than chlorine (see ***Figure Q7-1***), but are about 45 times more effective than chlorine in chemically destroying ozone molecules. Increases in effective chlorine in the past decades have caused stratospheric ozone depletion. Accordingly, ozone is expected to recover in the future as effective chlorine values decrease.

**Effective stratospheric chlorine changes.** In the latter half of the 20th century up until the 1990s, effective chlorine values steadily increased (see ***Figure Q16-1***). The values shown were calculated using halogen source gas abundances obtained from measurements, historical estimates of abundance, and future projections of abundance. As a result of the Montreal Protocol regulations, the long-term increase in effective chlorine slowed, reached a peak, and began to decrease in the 1990s. This small and continuing decrease means that the potential for stratospheric ozone depletion has begun to lessen as a result of the Montreal Protocol. The decrease in effective chlorine is projected to continue throughout the 21st century if all nations continue to comply with the provisions of the Protocol. Once halogen gas emissions from human activities have ceased, the decrease in effective chlorine will continue as natural destruction processes gradually reduce halogen gas abundances in the global atmosphere. Significant reduction requires decades because the lifetimes of halogen source gas molecules in the atmosphere range up to 100 years (see ***Table Q7-1***).

**Individual halogen source gases.** Reductions in effective chlorine follow directly from decreases in the emission of individual halogen source gases. The regulation of human-produced halogen source gases under the Montreal Protocol is considered separately for each class of one or more gases and is based on several factors. The factors include (1) the effectiveness of each class in depleting ozone in comparison to other halogen source gases; (2) the availability of suitable substitute gases for domestic and industrial use; and (3) the impact of regulation on developing nations.

The change in atmospheric abundance of a gas in response to regulation also depends on a number of factors that include (1) how the gas is used and released to the atmosphere; (2) how rapidly the gas is chemically destroyed in the atmosphere; and (3) the total amount of the gas that has accumulated in the atmosphere.

**Methyl chloroform and CFCs.** The largest reduction in the abundance of a halogen source gas has occurred for methyl chloroform ($CH_3CCl_3$). As shown in ***Figure Q16-1***, atmospheric methyl chloroform values dropped abruptly as a result of the provisions of the Montreal Protocol that reduced global production to near zero. Atmospheric abundances subsequently dropped rapidly because methyl chloroform has a short atmospheric lifetime (about 5 years). In addition, methyl chloroform is used mainly as a solvent and therefore has no significant long-term storage reservoir, as do refrigerants, for example. The reduction in effective chlorine in the 1990s came primarily from the reduction in methyl chloroform abundance in the atmosphere. Significant emissions reductions have also occurred for the chlorofluorocarbons CFC-11, CFC-12, and CFC-113 starting in the 1990s. As a result, the atmospheric increases of these gases have slowed, and CFC-11 and CFC-113 abundances have decreased slightly (see ***Figure Q16-1***). Because of longer lifetimes in the atmosphere (see ***Table Q7-1***), CFC abundances decrease more slowly than methyl chloroform as their emissions are reduced.

**HCFC substitute gases.** The Montreal Protocol allows for the use of hydrochlorofluorocarbons (HCFCs) as short-term substitutes for CFCs. As a result, the abundances of HCFC-22, HCFC-141b, and HCFC-142b continue to grow in the atmosphere (see ***Figure Q16-1***). HCFCs are desirable as CFC substitutes because they are partially destroyed in the troposphere by chemical processes, thus reducing the overall effectiveness of their emissions in destroying stratospheric ozone. Under the Montreal Protocol, HCFC production will reach zero in developed nations by 2030 and in developing nations by 2040. Thus, the future projections in ***Figure Q16-1*** show HCFC abundances reaching a peak in the first decades of the 21st century and steadily decreasing thereafter.

**Halons.** The atmospheric abundances of Halon-1211 and Halon-1301 are significant fractions of all bromine-containing source gases (see ***Figure Q7-1***) and continue to grow despite the elimination of production in developed nations in 1994 (see ***Figure Q16-1***). The growth in abundance continues because substantial reserves are held in fire-extinguishing equipment and are gradually being released, and production and consumption are still allowed in developing nations. Release of stored halons could keep atmospheric halon abundances high well into the 21st century.

**Methyl chloride and methyl bromide.** Both methyl chloride ($CH_3Cl$) and methyl bromide ($CH_3Br$) are unique among halogen source gases because a substantial fraction of their sources are associated with natural processes (see *Q7*). The average atmospheric abundance of methyl chloride, which is not regulated under the Montreal Protocol, is expected to remain nearly constant throughout this century. At century's end, methyl chloride is expected to account for a large fraction of remaining effective stratospheric chlorine because the abundances of other gases, such as the CFCs, are expected to be greatly reduced (see ***Figure Q16-1***). The abundance of methyl bromine, which is regulated under the Protocol, is projected to decrease in the first decades of this century as a result of production phaseouts in developed and developing countries. In the remaining decades of the century, methyl bromide abundances are expected to be nearly constant.

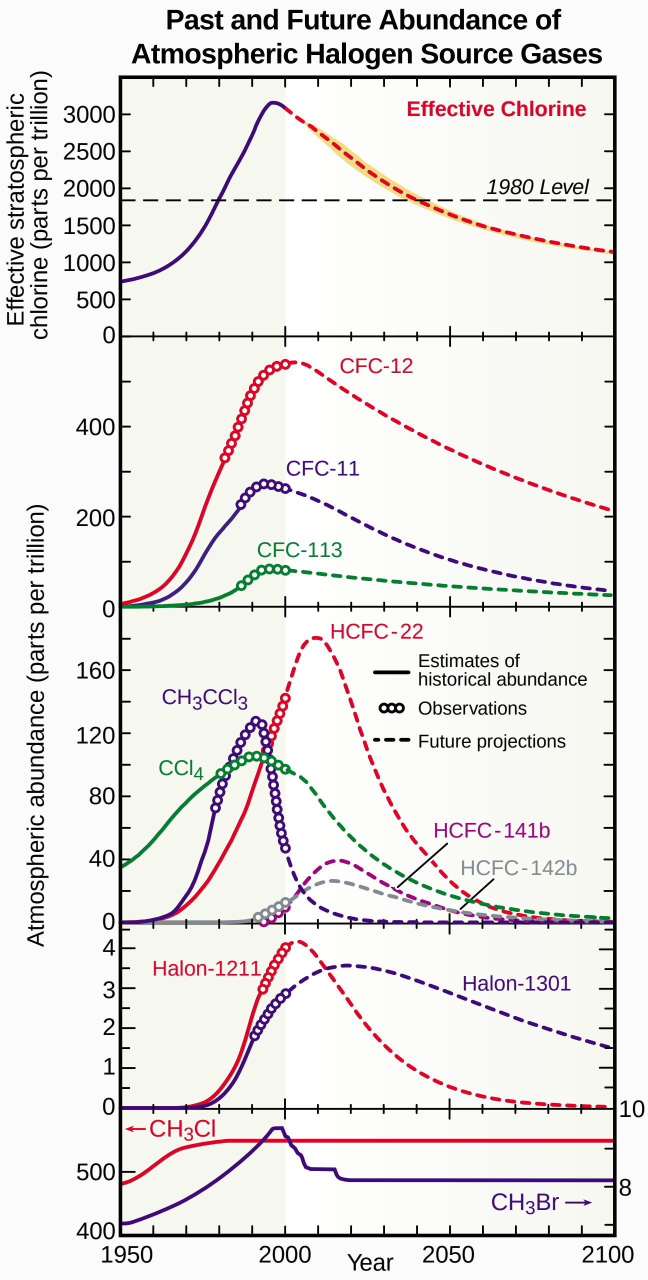


**Figure Q16-1. Halogen source gas changes.** The rise in effective stratospheric chlorine values in the 20th century has slowed and reversed in the last decade (top panel). Effective chlorine values combine the measured or projected abundances of chlorine-containing gases with those of bromine-containing gases in a way that properly accounts for the greater effectiveness of bromine in depleting stratospheric ozone. As effective chlorine decreases in the 21st century, the potential for ozone depletion from halogen gases will also decrease. The decrease in effective chlorine values is a result of reductions in individual halogen source gas emissions. The emissions decreased because of the Montreal Protocol, which restricts production and consumption of manufactured halogen gases. The changes in the atmospheric abundance of individual gases are shown in the lower panels using a combination of direct atmospheric measurements, estimates of historical abundance, and future projections of abundance. The increases of CFCs, along with those of $CCl_4$ and $CH_3CCl_3$, have either slowed significantly or reversed in the last decade. HCFCs, which are being used as CFC substitutes, will continue to increase in the coming decades. Some halon abundances will also grow in the future while current halon reserves are being depleted. Smaller relative decreases are expected for $CH_3Br$ in response to restrictions because it has substantial natural sources. $CH_3Cl$ has large natural sources and is not regulated under the Montreal Protocol. (See ***Figure Q7-1*** for chemical names and formulas. The unit "parts per trillion" is defined in the caption of ***Figure Q7-1***.)