Q20: When is the ozone layer expected to recover?

The ozone layer is expected to recover by the middle of the 21st century, assuming global compliance with the Montreal Protocol. Chlorine- and bromine-containing gases that cause ozone depletion will decrease in the coming decades under the provisions of the Protocol. However, volcanic eruptions in the next decades could delay ozone recovery by several years and the influence of climate change could accelerate or delay ozone recovery.

Halogen source gas reductions. Ozone depletion caused by human-produced chlorine and bromine gases is expected to gradually disappear by about the middle of the 21st century as the abundances of these gases decline in the stratosphere. The decline will follow the reductions in emissions that are expected to occur under the provisions of the Montreal Protocol and its Adjustments and Amendments (see ***Figure Q16-1***). The emission reductions are based on the assumption of full compliance by the developed and developing nations of the world. The slowing of the increases in the atmospheric abundances of several halogen gases and the substantial reduction of one principal halogen gas, methyl chloroform, has already occurred. Natural chemical and transport processes limit the rate at which halogen gases can be removed from the stratosphere. The atmospheric chemical lifetimes of the halogen source gases range up to 100 years (see ***Table Q7-1***). Chlorofluorocarbon-12 (CFC-12), with a lifetime of 100 years, will require about 200 to 300 years before it is removed (less than 5% remaining) from the atmosphere (see ***Figure Q16-1***).

Ozone predictions. Computer models of the atmosphere are used to assess past changes in global ozone and predict future changes. Two important measures of ozone considered by scientists are global total ozone averaged between 60°N and 60°S latitudes, and minimum ozone values in the Antarctic "ozone hole." Both measures show ongoing ozone depletion that began in the 1980s (see ***Figure Q20-1***). The range of model predictions shows that the lowest ozone values are expected to occur before 2020 and that substantial recovery of ozone is expected by the middle of the 21st century. The range of predic-

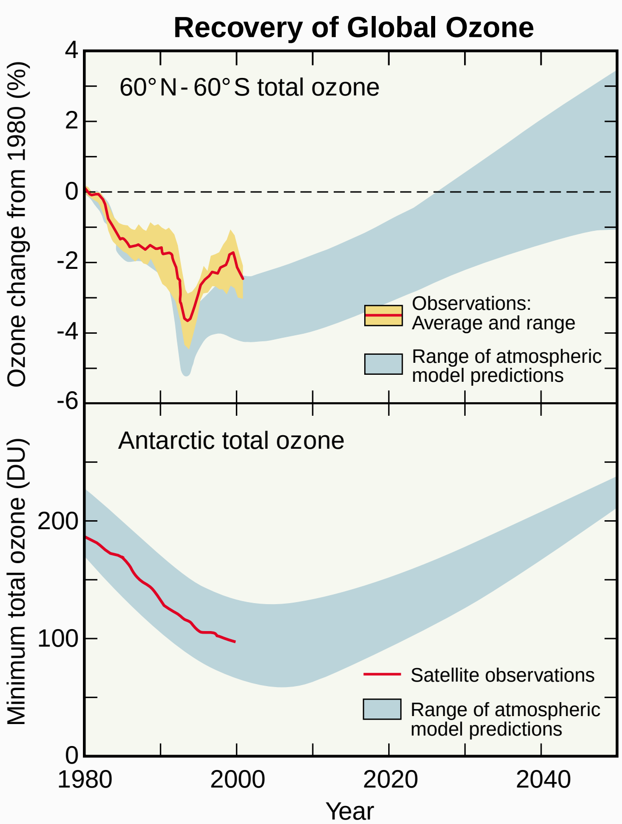

Figure Q20-1. Global ozone recovery predictions. Observed values of global total ozone (top panel) and minimum total ozone over Antarctica (bottom panel) have decreased beginning in the early 1980s. As halogen source gas emissions decrease in the early 21st century, ozone values are expected to increase and recover toward pre-1980 values. Atmospheric computer models that account for changes in halogen gases and other atmospheric parameters can be used to predict how ozone amounts will increase. These model results show that recovery is expected to be significant by 2050, or perhaps earlier. The range of model predictions comes from the use of several different models that have different assumptions about the future climate and composition of the atmosphere. These assumptions are an attempt to account for estimated differences in atmospheric composition and other parameters between 1980, before the "ozone hole" began, and 2050.

tions comes from several computer models of the atmosphere that have different assumptions concerning the future climate and composition of the atmosphere. Some of these models indicate that recovery of total ozone may possibly come well before midcentury.

A different atmosphere in 2050. By the middle of the 21st century, halogen amounts in the stratosphere are expected to be similar to those present in 1980 before the onset of the ozone hole (see ***Figure Q16-1)***. However, other aspects of the global atmosphere will not be the same in 2050 as in 1980. The ozone recovery evaluations in ***Figure Q20-1*** attempt to take these differences into account. For example, since 1980 human activities have increased the abundance of important greenhouse gases, including carbon dioxide, methane, and nitrous oxide. The accumulation of these gases is expected to cause warmer surface temperatures and colder stratospheric temperatures. Colder temperatures may accelerate ozone recovery in the upper stratosphere (about 40 kilometers (25 miles) altitude). Colder winter temperatures over polar regions will increase the occurrences of polar stratospheric clouds (PSCs) and chemical ozone destruction (see *Q10*). Water vapor increases that have occurred in the stratosphere over the last two decades also will lead to increased PSC occurrences and associated ozone destruction. A cooler, wetter polar stratosphere could delay ozone recovery beyond what would be predicted for the 1980 atmosphere. Increased methane and nitrous oxide abundances due to human activities also cause some change in the overall balance of the chemical production and destruction of global stratospheric ozone. Finally, an outcome not included in models is the occurrence of one or more large volcanic eruptions in the coming decades. In that case, stratospheric particles may increase for several years, temporarily reducing global ozone amounts (see *Q14*) and delaying the recovery of the ozone layer.