

Executive Summary

In its six earlier reports the Stratospheric Ozone Review Group (SORG) has presented assessments of the scientific issues underlying the world-wide changes taking place in the ozone layer and the causes of these changes.

The reports showed that there had been a steady decrease in stratospheric ozone over all latitudes outside the tropics since the late 1970s, with the largest reductions in total ozone occurring over Antarctica each spring – the “ozone hole”. Over the same period there had been a steady increase in the amounts of chlorine and bromine present in the stratosphere as a result of human activity. In SORG 1993 it was reported that the rate of increase of chlorine had slowed in response to regulation under the Montreal Protocol and, in SORG 1996, that the chlorine loading of the troposphere had started to decline.

It has been demonstrated unequivocally that chlorine and bromine compounds lead to chemical destruction of stratospheric ozone and that their presence could account quantitatively for the formation of the ozone hole. The 1996 report showed that chemical destruction of ozone had occurred in the Arctic stratosphere and that chlorine and bromine compounds were also implicated in the decline of ozone in middle latitudes.

Early reports noted that ultraviolet radiation at the earth’s surface was expected to increase as a result of ozone loss and this had been observed under the ozone hole, where the effect is large. Ozone depletion had also been at least partly responsible for observed decreases in stratospheric temperatures as well as offsetting, in part, the surface warming effect arising from increases of greenhouse gases.

The implications of increased ultraviolet radiation (UV) at the surface were addressed in the first report of the Ultraviolet Measurements and Impacts Review Group (UMIRG) in 1996. This discussed the effects of UV on human and animal health, terrestrial and aquatic ecosystems, tropospheric chemistry and material degradation. Those aspects of the first UMIRG report not within the SORG remit have been updated in this report by UMIRG.

Update on ozone measurements

- The Antarctic ozone hole in each late winter and spring continues unabated. By early October, large areas over Antarctica in the altitude range from 14 to 21 km are practically devoid of ozone. The ozone hole has lasted longer during the 1990s.
- Observable chemical loss of ozone has occurred in all Arctic winters since 1991/92 despite the very different meteorological conditions. In stratospheric winters with long periods of low temperatures, conditions which are conducive for ozone depletion, the Arctic loss has been severe (estimated at around 50% near 20 km altitude in 1996/97). Even in the warmer stratospheric winters smaller but significant loss has been reported (estimated at around 25% near 20 km in 1997/98). The ozone loss is broadly consistent with our understanding and strengthens the conclusion of earlier SORG reports that, despite reductions in halogen loading, large ozone loss in the Arctic can be expected into the 21st century, depending on the meteorological conditions in individual winters.
- In the late 1990s annually averaged total ozone values from the TOMS satellite and ground-based measurements at northern mid-latitudes (25°-60°N) were 4-6% lower

than those around 1980. The low values in 1992/93 following the eruption of Mt Pinatubo in 1991 have been a dominant feature of total ozone in the 1990s.

- Globally, annually averaged (60S-60N) total ozone values derived from ground-based measurements alone were 3-4 % lower in the late 1990s than in the 1970s. The ground-based measurements indicate that similar losses have been observed in the southern mid-latitudes as in the northern mid-latitudes. (The calibration of TOMS measurements since 1996 is preliminary. There is a 1-2% discrepancy between TOMS and ground-based measurements at low latitudes and in the southern hemisphere in this period. We have chosen to use the ground-based data here.)
- The observed mid-latitude ozone decline is broadly consistent with halogen-catalysed chemical destruction being the primary cause. Model studies can now explain the trend in ozone in middle latitudes since 1980 in terms of reactions involving chlorine and bromine compounds. However, other studies show that meteorological factors have also contributed to the trend. The precise quantification of the different processes is still required.
- The interpretation of the observed changes in total ozone since the eruption of Mt. Pinatubo is difficult and in recent years depends quite strongly on the assumptions made about the influence of natural variability on ozone. The low ozone immediately following the eruption can be explained. The high ozone at northern mid-latitudes in 1998 is probably due to stronger atmospheric transport of ozone rich air. The updated observational record since WMO (1999) shows values closer to, but slightly above, the long term linear trend extrapolated from 1979-1991. However, we do not think that the observational record to date contains any evidence of an ozone recovery in response to reductions of ozone-depleting substances.
- Fifteen years of water vapour measurements above Colorado show an increase of 1%/year between 18 and 28 km. Satellite measurements over a shorter period suggest that an increase has occurred globally throughout the stratosphere. The lack of a complete explanation for the increase, which exceeds that expected from the increase in methane, is of concern because stratospheric water vapour is important for both climate and stratospheric chemistry.

Halocarbons in the Atmosphere

- The chlorine loading of the atmosphere should continue to fall and bromine loading is expected to peak early in the 21st century.
- There are substantial quantities of ozone depleting substances still in equipment which are likely to be released to the atmosphere in the future. Given the existing controls, the largest additional reduction that can be made to future chlorine and bromine loadings would be gained if these materials were removed and destroyed when the equipment containing them is decommissioned. Over the next 50 years, such reductions could amount to 5% in total cumulative chlorine loading and 25% in bromine.
- HCFC releases have a relatively small effect on stratospheric chlorine loading. A proposed regulation in the EU seeks to reduce production and use of HCFCs beyond the provisions of the Montreal Protocol with a phase-out early next century. If such a regulation were applied globally it would enhance the reduction in total cumulative chlorine loading by slightly less than 1% over the next 50 years.

- Methyl bromide is the largest contributor of bromine to the stratosphere. Its budget is still uncertain despite a number of improvements in understanding since the 1994 WMO assessment.
- The methyl bromide ozone depletion potential (ODP) has been reevaluated downwards since the WMO 1994 report, based on a decreased estimate of the methyl bromide lifetime (which reduces the ODP) and an increased estimate of the ozone-depleting efficiency of bromine (which increases the ODP). The reduction in the lifetime also implies a larger flux of methyl bromide into the atmosphere than was assumed previously. Overall, there is no reduction in our assessment of the importance of methyl bromide in stratospheric ozone destruction.
- Analysis of air in Antarctic firn (unconsolidated snow) suggests concentrations of methyl bromide have increased by 20-25% during the 20th Century, with the most rapid growth occurring in the 1970s and 1980s. Despite the uncertainties in the atmospheric budget of methyl bromide, the firn air data suggest concentrations of methyl bromide to have been strongly influenced by human activities. It seems likely that less than half of the anthropogenic methyl bromide emissions are controlled under the Montreal Protocol.

Atmospheric Impacts

- For the period 1979-1997, the annual, global average temperature has decreased by 0.6 K/decade in the lower stratosphere and 3 K/decade in the upper stratosphere. Calculations indicate that much of the observed temperature trend in the lower stratosphere can be explained by the observed ozone trend. In the upper stratosphere, the cooling is due largely to increases in CO₂ and decreases in ozone.
- Stratospheric ozone loss is estimated to have offset around 30% of the surface warming effect of increases in greenhouse gases since the late 1970s. One serious uncertainty in estimates of the global climate effect of ozone loss arises from inadequate knowledge of the vertical profile of ozone change in the tropics.
- Stratospheric halogen loading is not expected to return to a similar value to that which occurred before 1980 (when the ozone hole became clearly evident in the observational record) until about 2050. With the reduction in halogen loading, stratospheric ozone should slowly recover towards its pre-1980 concentrations. However, the future abundance of ozone will also be influenced by changes in other atmospheric gases and aerosols, and by interactions with the climate system, so that ozone recovery may not be a simple, slow return to earlier values.
- Spring Arctic and Antarctic ozone depletions are predicted to reach their peaks up to about 15 years later than the peak in halogen loadings because of the coupling between stratospheric climate change and ozone chemistry. The amount of maximum depletion and its timing are uncertain due to the complexity of this interaction.
- Sufficient observations exist to show a statistically significant anticorrelation between surface ultraviolet radiation (UV) and total ozone. Spectrally-resolved UV data from Antarctica and an increasing number of northern mid-latitude stations have shown increases in UVB radiation during the last decade, consistent with the locally observed ozone depletion.

Impacts of UV Change on the Biosphere

- The dose of UVB received by the human population is strongly dependent on behaviour. Social changes over several decades have served to increase exposure to UVB, which would have been exacerbated by ozone depletion.
- Climate change may modify ambient UV, for example by changes in cloud cover. Alterations in UK climate (such as warmer weather) are likely to further influence patterns of behaviour and thus doses of UV.
- Increased UVB would modify interactions between organisms in both terrestrial and aquatic systems, with unpredictable consequences for ecosystem function and diversity. Further uncertainty arises from the interaction between UVB and other environmental pressures.
- Localised extreme increases in UVB, for example over the Antarctic, may have wider consequences via aquatic food webs.