

UARS Microwave limb Sounder Observations of Upper Atmosphere Ozone and Chlorine Monoxide.

Dennis A. Flower, Lucien Froidevaux, Robert F. Jarnot, William G. Read, Joe W. Waters
 Jet Propulsion Laboratory, California Institute of Technology
 4800 Oak Grove Drive MS 183-701
 Pasadena California 91109-8099 USA
 Tel: (818) 354-4151, Fax: (818) 393-5065, Email: flower@jplrac.jpl.nasa.gov

ABSTRACT

UARS MIS observations of stratospheric ozone and chlorine monoxide are described. Enhanced concentrations of ClO, the predominant form of reactive chlorine responsible for ozone depletion, are seen within both the northern and southern winter polar vortices. In the southern hemisphere, this leads directly to the development of the annual Antarctic ozone hole. While ozone depletion is also observed in the north, it is less severe and there is considerable interannual variability.

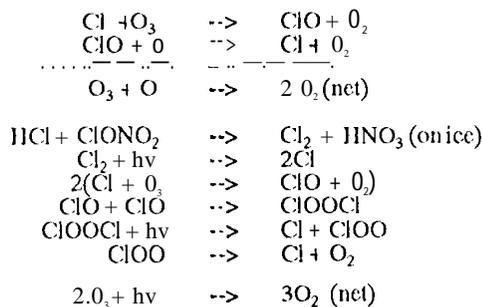
INTRODUCTION

The Microwave Limb Sounder (MLS) (Barath et al, 1993) on the Upper Atmosphere Research Satellite (UARS) has provided a nearly continuous set of daily global observations of ozone (O₃) and chlorine monoxide (ClO) since launch in September 1991. A vertical profile of each atmospheric parameter is obtained every 65 seconds, day and night, and the measurements are unaffected by clouds or aerosols. The O₃ and ClO measurements, together with MLS measurements of temperature and water vapor, and observations by other instruments on UARS, provide the basis for an improved understanding of the chemistry and dynamics of the Earth's upper atmosphere (Reber, 1993).

The abundance of chlorine in the stratosphere has grown over the past half century due to man's use of chlorofluorocarbons (CFCs), and has been recognized as a serious threat to the Earth's protective ozone layer, especially since the discovery of severe ozone depletion over the south pole (Farman et al, 1985). Total chlorine in the stratosphere is now at about 3.6 parts per billion - some six times the natural level. CFCs are very stable compounds, but once they diffuse into the upper atmosphere they are photolyzed by solar ultraviolet radiation to release chlorine atoms. The chlorine atoms react in catalytic cycles, Figure 1, to destroy ozone, where each chlorine atom is able to destroy tens to hundreds of thousands of ozone molecules before it is eventually washed out of the atmosphere in the form of HCl.

The chlorine monoxide radical is a short-lived participant in these catalytic cycles and its abundance is a direct measure of the rate of destruction of ozone. When temperatures in the polar winter vortices fall below the 195 K threshold for the formation of polar stratospheric clouds (PSCs), the concentration of chlorine monoxide is dramatically enhanced. The Antarctic ozone hole is a direct result of the rapid ozone destruction indicated by these high levels of ClO.

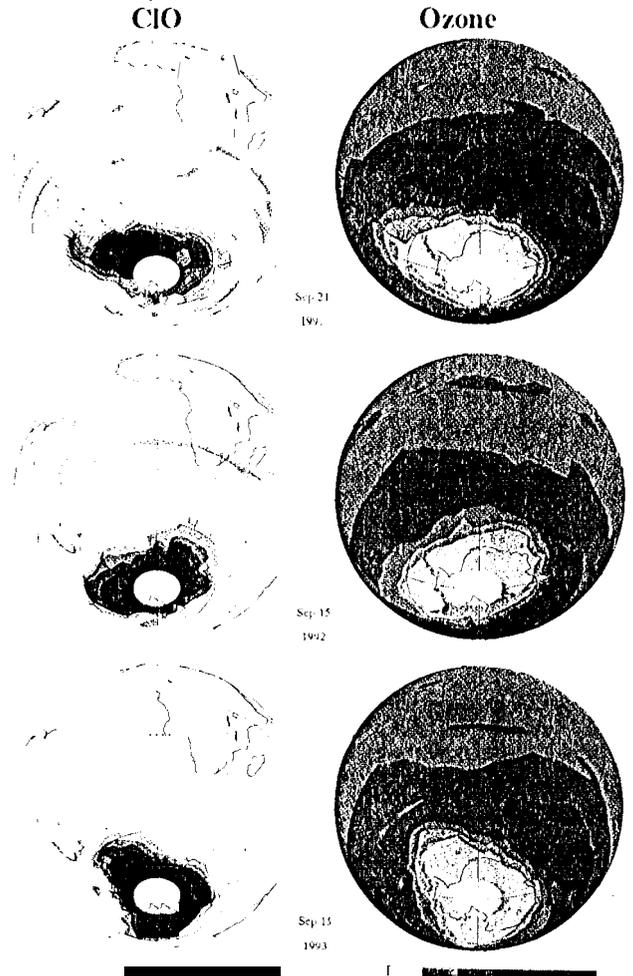
Figure 1. Predominant catalytic cycles that destroy ozone involving the chlorine monoxide radical.



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Figure 2 shows MIA measurements of southern hemisphere ozone and ClO in 1991, '92 and '93 when the annual ozone loss nears its late winter maximum. The measurements on September 21, 1991 were obtained within 10 days of launch, and showed an ozone distribution in line with expectations based on earlier satellite data. However, UARS provided for the first time a daily look at vertical structure throughout the ozone hole. The ClO map was our first view of the areal extent of the chlorine problem since previous information was limited to results from ground-based measurements (de Zafra, 1987) and an instrumented aircraft flight into the edge of the ozone hole in 1987 (Anderson, 1989). Correlation between the enhanced chlorine monoxide and depleted ozone fields is remarkable, and the absolute value of the concentration indicates that virtually all chlorine in the lower stratosphere has been converted to the active form (Waters, 1993a).

Figure 2. Southern hemisphere ClO and O₃ in September 1991, 1992 and 1993. Quantities mapped are column totals obtained by integration of the MIS retrieved profiles above 100 hPa. The ozone column is in Dobson Units (2.69 x 10²⁰ molecule m⁻²) and ClO units are 10¹⁹ molecule m⁻².



Analysis of MI S data (Waters et al, 1993b) has shown both the Antarctic ozone hole and the greatly enhanced ClO to be well contained in a dynamically defined polar vortex. The southern hemisphere plots for September 1992 and 1993 follow this pattern with only minor differences from year to year. In 1992 the ozone level outside the vortex is seen to be significantly reduced from the 1991 level. The level recovers somewhat in 1993, suggesting that part of the 1992 decrease may be due to residual effects of the June 1991 Mt Pinatubo volcanic eruption.

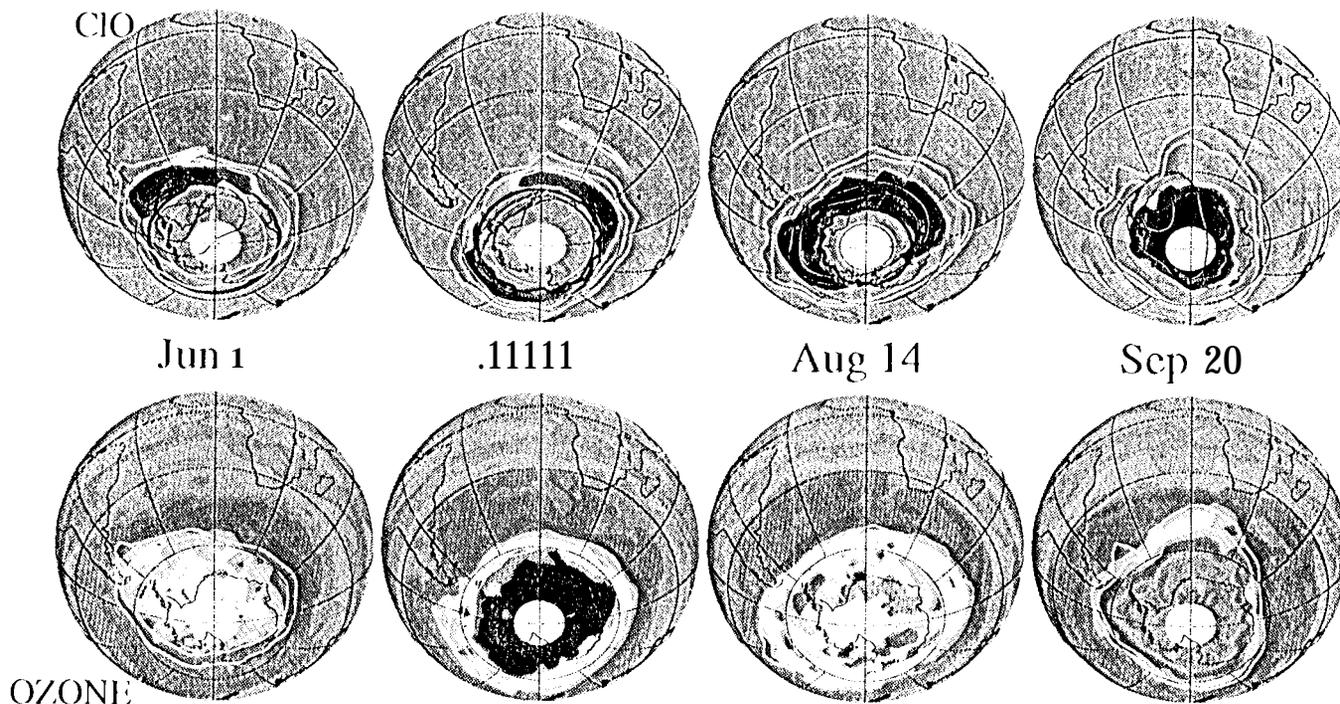
EVOLUTION OF OZONE IN THE SOUTHERN HEMISPHERE WINTER

Southern hemisphere observations from June to September 1992 provided the first opportunity to witness in detail the chemical and dynamical processes which lead to the formation of the Antarctic ozone hole. (Manney et al, 1993.) Figure 3 shows abundances of ozone and chlorine monoxide on four days in this period,

Measurements as early as June 1 show the presence of enhanced ClO in regions of the polar vortex where temperatures are below the 195 K threshold for PSC formation, and where there is sunlight to break down the chlorine monoxide dimer, ClOOCl. There is no clear evidence of ozone destruction at this time; indeed, the abundance of ozone is seen to increase in the interval to July 11. The chemical destruction implied by the large ClO abundances appears to be more than balanced by a dynamic influx of ozone.

However, by the middle of August ozone has been eaten away in a collar at 60 to 70 deg latitude, clearly coincident with the highest values of ClO. By late September, with ClO present throughout the polar stratosphere, large losses of ozone are observed.

Figure 3. The evolution of lower stratosphere chlorine monoxide and ozone over four months in the southern hemisphere winter of 1992. Measurements shown are retrievals interpolated to the $\Theta = 465$ K potential temperature surface. ClO values are parts per billion by volume, and ozone values are parts per million by volume.



NORTHERN HEMISPHERE

The polar stratosphere in the Northern Hemisphere is dynamically very different from the south. The polar vortex is less stable, due to the more intense atmospheric waves which arise primarily from the underlying distribution of northern land masses. Air within the vortex generally does not get as cold, or stay below the PSC threshold for so long; and there are large variations in the dynamics from year to year.

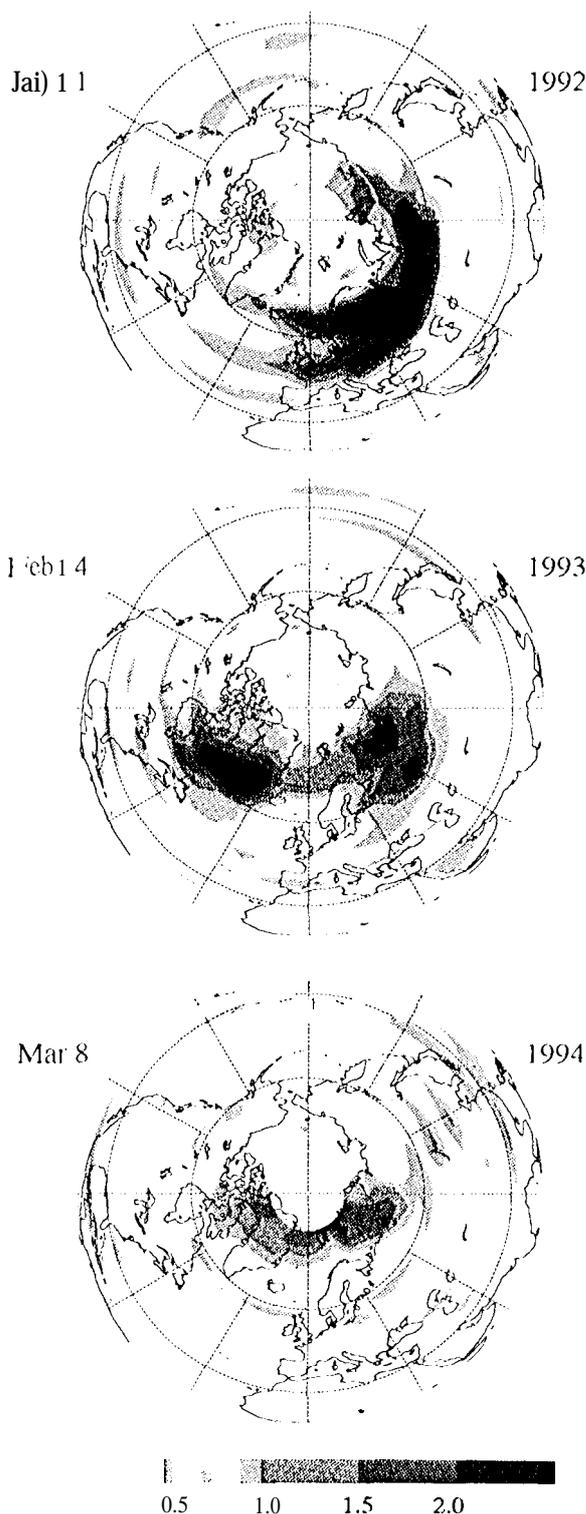
The first MI S observations of the northern winter stratosphere showed enhanced ClO forming in mid December 1991, and by early January 1992 (Figure 4) it had spread to cover an area similar in size to that seen over Antarctica. The enhanced ClO is seen in areas downwind of the PSCs, in air which has passed through the coldest part of the vortex within the previous few days. The vortex was displaced from the pole and this region of enhanced ClO covered much of northern Europe. By late January, stratospheric temperatures had risen above the PSC threshold and the region of enhanced ClO had almost totally disappeared.

In the next northern winter, enhanced ClO was observed from early December 1992 until the first week in March 1993, and some evidence was noted of ozone depletion. In the northern winter of 1993/94, the largest quantities of enhanced ClO occurred in mid February and early March, when temperatures were coldest.

DISCUSSION

Enhanced ClO is observed when temperatures in the lower stratosphere fall below the PSC threshold of about 195 K. The enhanced ClO exists in vortex regions which have been exposed to the PSCs, and its presence indicates that ozone is being chemically destroyed by the processes in Figure 1. However, the ozone concentration does not immediately decline, because of the seasonal influx of ozone rich air.

Figure 4. Maps of enhanced chlorine monoxide, in the northern hemisphere in three consecutive winters. These plots show the measured abundance in parts per billion by volume on the 46 hPa pressure surface (about 20 km altitude.).



In the northern hemisphere, low temperatures and enhanced ClO exist for a few weeks and the ozone destruction is not sufficient to produce a hole. In the southern hemisphere, where low temperatures continue for many months, the ozone hole appears annually.

The production of CFCs is being phased out by international agreement because it threatens the health of the stratospheric ozone. But total chlorine in the stratosphere will not peak until the next decade and will not decline to natural levels for more than a century. It is by no means clear that we adequately understand the processes by which this chlorine can destroy ozone. The continuing MLS measurements of stratospheric ozone and chlorine monoxide will help us to understand more of the chemistry and dynamics involved in ozone depletion.

ACKNOWLEDGEMENTS

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