The twentieth Quadrennial Symposium on Atmospheric Ozone coincides with the 20th anniversary of the discovery of the springtime Antarctic ozone hole. It also marks two decades of intensified basic research in atmospheric chemistry and physics and in global atmospheric monitoring. The progress in our understanding of the impact of human activities on the chemistry and physics of the global stratosphere since the previous Quadrennial Ozone Symposium was presented among the 690 research papers at the XX Quadrennial Ozone Symposium, held in Kos, Greece, 1-8 June 2004.

Important topics discussed at the symposium included:

1) The search for ozone recovery in long-term data records of ozone

We have already observed the decline of many of the ozone-depleting CFCs in the lower atmosphere. We have now also observed the leveling off of the chlorine content of the stratosphere. The next major step is the search for the response of ozone to this change in chlorine.

Overall, it appears that ozone in the last few years is a little higher than we expect from earlier projections based on sensitivity of ozone to influences of aerosols, halogen compounds and the solar cycle. There may be the beginning of a recovery in the data, but normal variability could still cause a downward turn as the meteorology of the stratosphere varies over the next few years.

Making an early detection of ozone response to the leveling off and decline of chlorine compounds requires a clear definition of terms. We can define at least three stages of recovery for ozone. These are:

1) statistically significant slowing of the downward trend
2) statistically significant upward trend after removal of all other known influences such as solar cycle and volcanic aerosols
3) reaching pre-chlorofluorocarbon levels (or pre 1980 levels) of ozone in the stratosphere

It has been shown that achieving the second of these stages will take more decades of well-calibrated instruments and measurements. The discussion at this Ozone Symposium has centered around the criteria for stage 1. Has the trend slowed down by a statistically significant amount? It was emphasized that the search for the response of ozone is complicated by a number of issues:

a) Year-to-year variability in meteorology atmospheric dynamics
b) Response of meteorology to changes in ozone, greenhouse gases and changes in the radiation balance
c) Recovery in the 1990s from the Pinatubo eruption that perturbed ozone
d) Interference between volcanic eruptions of El Chichon in 1982 and Pinatubo in 1991 and the 11-year solar cycle

Most participants at the Conference agreed that the detection of ozone recovery still requires patience. Its detection will depend on continued quality observations.

2) The use of satellite and ground-based data to evaluate models of ozone loss and recovery

Indeed, in the past four years significant developments have been achieved in quality satellite observations based on the continuation of international collaboration involving ESA and NASA and JAXA. In the stratosphere and mesosphere new measurements described the Antarctic sudden warming of September 2002 and the excited mesospheric OH. Significant data from European ENVISAT instruments such as GOMOS, SCIAMACHY, MIPAS was reported along with data from the Swedish/Canadian/French ODIN/OSIRIS, the Japanese ILAS/ILAS II, and the United States' TOMS/SBUV, SAGE, HALOE, and AIRS. Several contributions addressed the rapid development of chemical data assimilation techniques. The validation of these measurements has emphasized the need for quality long term ground-based data as provided by the Network for the Detection of Stratospheric Changes (NDSC).

3) The extension of long-term quality data records made by satellites and by ground-based stations around the world

Satellite records of ozone on a global scale are now more than 25 years in length. TOMS and SBUV improved version 8 was officially released at the Symposium. The GOME instrument now has 9 years of data that have been evaluated for trend quality and can be added to the record. The ground-based data extends, in a few places, back several more decades, especially the Dobson spectrophotometer, ozonesondes and Brewer networks. The continued maintenance of the calibration of the ground-stations was discussed with emphasis on expanded intercomparisons and comparisons with satellite records.

4) Evaluation of the future of ozone recovery in a changing climate and the effect of ozone on that climate using coupled climate/chemistry models

Numerous chemisty/climate models were presented at the conference. They address the problem of how changes in the meteorology or climate interact with changes in the chemistry of ozone. One problem is how changes in meteorology over the last 25 years may have contributed to observed ozone changes and feedback mechanisms. Models can then be used to extrapolate that knowledge to what may happen in the future with the expected increase in methane, nitrous oxide, and carbon dioxide.

Understanding of ozone loss and its future recovery requires knowledge of the distributions and budgets of the compounds that contribute to ozone loss. Significant new work that combines satellite and *in situ* observations with model calculations was presented at the Symposium providing an insight into the budget of oxides of nitrogen and a range of halogen species, which are indispensable to our understanding of the global carbon and hydrological cycles. Water vapour presents a particularly important challenge. Satellite data, shown at the meeting, is not consistent in trend with previous ground-based data. Understanding the feedback mechanism between water vapour content, ozone, and polar stratospheric clouds is critical to the evaluation of predictions of ozone in a future warmer climate.

5) The developing capability of satellites to measure the global scale composition of the troposphere and observe the effects of long-range transport of pollution

The tropospheric ozone budget is influenced by a variety of ozone precursor sources, long-range transport in the troposphere and intrusions from the stratosphere. The evaluation of these processes at global scale makes the determination and attribution of trends in tropospheric ozone difficult. Yet, significant progress was made with the development of new satellite retrieval techniques combined with the use of tropospheric models.

A whole fleet of satellites has provided significant new information in monitoring tropospheric pollutants (TOMS, GOME, MOPPIT, SCHIAMACHY, MERIS, MODIS and AIRS). NASA's satellites and balloons revealed that seasonal episodes of high ozone over south Atlantic begin with pollution sources located thousands of miles away. Changes in tropospheric ozone are complicated. The variability of tropospheric ozone makes trend determination difficult. In addition, diverse of sources of tropospheric ozone, including transport from the stratosphere, make attribution of trend to cause complex. Examination of the long-range transport of tropospheric pollution and its coupling to climate is being studied using climate/chemistry models. Long-range transport of pollutants maintains regionally high back ground levels of tropospheric ozone.

6) Measurement and present trends in the UV radiation reaching the surface of the Earth and its relationship to ozone change, cloudiness, and aerosols

Future UV-B levels for 2000-2019 are predicted to decrease for all seasons but the trends are typically not statistically significant, except during spring over both hemispheres. UV-B trends are mainly caused by the total ozone trends because in the future cloud changes are predicted to be small in the coupled chemistry climate model used in these results. Nonetheless, there is a region over western Europe which is predicted to show an increase in UV-B due primarily to a decrease in cloudiness. The complexity of interference of cloud and other physical parameters in influencing UV-B level at ground level was targeted in several papers.

7) General Remarks

The Montreal Protocol and its amendments led to a fast decrease of the emissions of ozone depleting substances (ODS). There is evidence that the effect of anthropogenic emissions of ODS peaked in the last years of the 20th century. A very slow decrease of stratospheric ODS concentrations is expected to take place in the coming decades. Assuming undisturbed climatological and physical atmospheric conditions, model calculations presented expectations that the ratification of the Montreal Protocol will lead to the recovery of the ozone layer. However, due to the large interannual variability connected e.g. with long-term climate variability the documentation of the turn around of stratospheric ozone trends is a challenging task.

The ozone layer will remain particularly vulnerable during the next decade or so, even with full compliance, especially in the polar regions. With the atmospheric abundances of ozone-depleting substances being near their highest, the human-influenced perturbations will be at or near their largest. Relative to the pre-ozone-hole abundances of 1980, the losses in total column ozone amounts are:

- 3-4% at northern midlatitudes in wither/spring and
- about 6% at southern midlatitudes on a year-round basis.

Continued compliance with the Montreal Protocol is expected to lead to a recovery of the ozone layer. The meeting highlighted the progress toward that goal and how the future of ozone may evolve in a changing climate.