OZONE IN THE 21ST CENTURY : INCREASE OR DECREASE ?

by

A. DE RUDDER and G. BRASSEUR
Institut d'Aéronomie Spatiale de Belgique
3, avenue Circulaire, B-1180 Brussels, Belgium.

1. INTRODUCTION

In order to assess the global atmospheric and climatic response to the release of various chemical pollutants, numerical models are commonly used as prognostic tools. The purpose of this paper is to use a fully coupled 1-D radiative/chemical model to simulate the future of the ozone layer and the temperature, assuming a realistic scenario of the emission of several gases such as CO_2, CH_4, N_2O, NO_x and the chlorocarbons. Another objective is to study the effect of an hypothetical high chlorine perturbation. With the present and projected emissions of CFCs, such a high Clx load is not expected. Nevertheless, this problem will be considered here since it reveals the non-linear behavior of the chemical system in the middle atmosphere (Cicerone et al, 1983).

2. RESPONSE OF OZONE AND TEMPERATURE TO A GIVEN MAN-MADE PERTURBATION

The present study considers a perturbation scenario which is described in detail by Brasseur et al (1984). The chlorocarbons CCl_4, $CFCl_3$, CF_2Cl_2 and CH_3CCl_3 are increased according to historical data until present time and a constant emission is assumed for the future : 10^5 T/yr for CCl_4, 3.2 x 10^5 T/yr for $CFCl_3$ and 4 x 10^5 T/yr for CF_2Cl_2. Only the release rate of CH_3CCl_3 is assumed to increase, reaching a maximum value of 4 x 10^6 T/yr in year 2070. This scenario therefore accounts for the possibility of an unexpected enhancement in the release of chlorine atoms and therefore leads probably to an overestimated stratospheric response. The corresponding odd chlorine mixing ratio at 50 km altitude is 2.8 ppbv in year 1984, 4.4 ppbv in 2000, 8.2 ppbv in 2050 and 9.5 ppbv in 2080. Carbon dioxide, whose mixing ratio is assumed to be equal to 270 ppmv in year 1850 and 335 ppmv in year 1979, increases in the model by 0.56 percent per year to reach about 575 ppmv in year 2080.

Methane whose actual mixing ratio is close to 1.5 ppmv is assumed to increase by 1.5 percent/year from the present day, reaching consequently a relative concentration of 7.5 ppmv in year 2080. A value of 1 ppmv is assumed between year 1850 and 1950. Nitrous oxide shows a systematic increase of about 0.25 percent per year. A mixing ratio of 285 ppbv is adopted as preindustrial value. The present amount is close to 330 ppmv and the value reached in year 2080 is 425 ppbv. Aircraft emissions of nitrogen oxides are introduced after year 1950 according to the scenario suggested by Wuebbles et al (1983). After year 2000, the NO_x release, whose maximum is located between 10 and 12 km, is assumed to remain constant.

The response of several atmospheric and climatic parameters to the scenario described above, is predicted using a 1-D chemical model which takes into account the key reactions related to the oxygen, hydrogen, nitrogen, chlorine and carbon chemistry in the range 0 to 100 km. The vertical transport of the long-lived trace species is simulated by an "eddy diffusion" approach. The model is coupled with a radiative routine which considers the attenuation of the solar radiation as well as the emission and absorption of terrestrial infrared radiation. For the latter computation in the troposphere and stratosphere, a wide-band model similar to that in Morcrette (1983) is used. Figure 1 shows the predicted changes in the ozone column as well as the expected variations in the temperature at the Earth's surface and at the stratopause. Prior to 1980 or so, ozone increases slightly due to the gradual positive trend in the CO_2 amount and the related temperature decrease in the upper stratosphere. This enhancement in the ozone content is not a direct chemical effect but results from the high dependence of the ozone destruction rate to the temperature leading to the well-known anticorrelation between temperature and O_3 above 30 km. After year 1980, the predicted decrease has to be attributed to the chlorocarbons and the chlorine atoms which are produced by photodissociation. After year 2000, the effect of the rapid growth in the methane concentration plays a key role : it leads to an enhanced production of tropospheric O_3 and to a transfer of active chlorine (Cl, ClO...) to inactive chlorine (HCl) by reaction $Cl + CH_4 \rightarrow HCl + CH_3$. This second process reduces the efficiency of chlorine for depleting

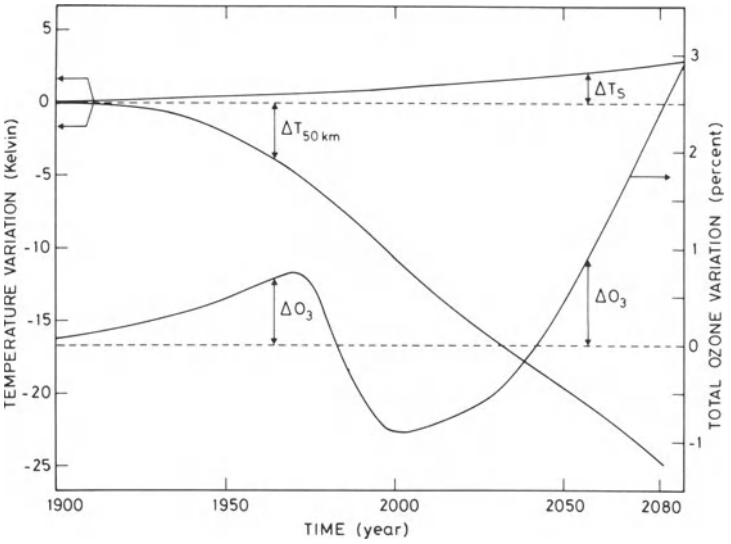

Fig. 1.- Changes in the ozone column (ΔO_3-in percent) and in the temperature (Kelvin) at the Earth's surface (ΔT_s) and at the stratopause (ΔT_{50km}), for the adopted perturbation scenario.

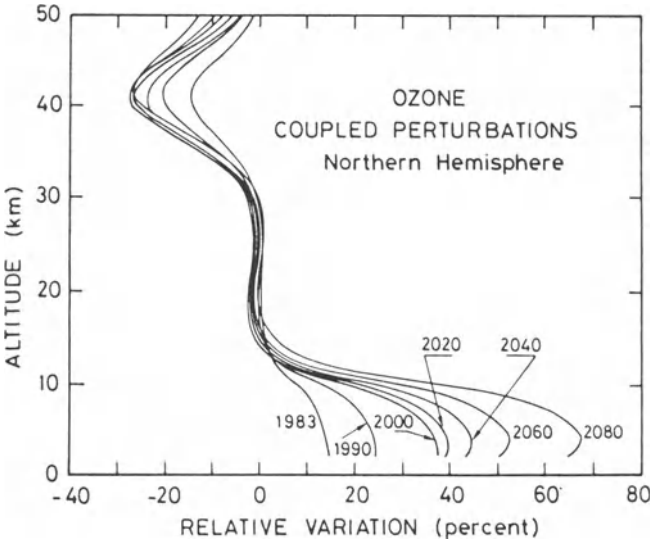

Fig. 2.- Relative variation in the ozone concentration relative to the preindustrial atmosphere, prèdicted from 0 to 50 km altitude for years 1983 to 2080, adopting the perturbation scenarios as described in the text.

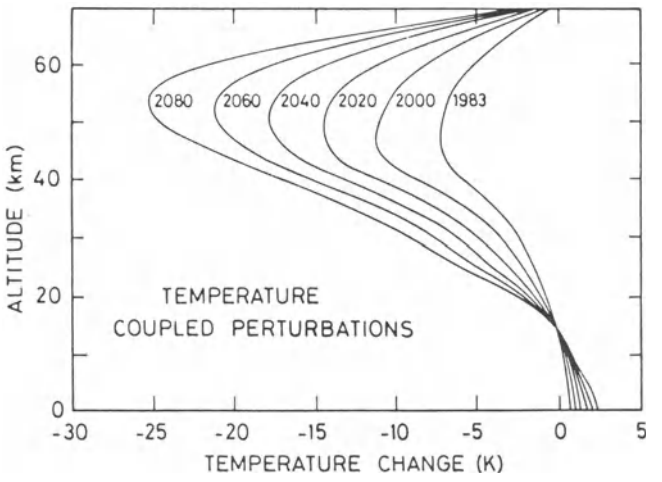

Fig. 3.- Same as figure 2 but for the vertical temperature distribution.

ozone. Finally the slow growth in N_2O leads to a weak ozone depletion while the injection of NO_x by aircraft engines contributes to the ozone increase in the troposphere. Figure 1 also shows that the temperature is expected to be reduced by about 25 K at the stratopause in year 2080, which should generate significant changes in the general circulation; at the Earth's surface a temperature increase of about 2.3 K is expected. This value, however, is a lower limit since the direct greenhouse effect due to N_2O, CH_4 and the CFCs is not yet considered in the radiative scheme. Figure 2 and 3 shows the corresponding ozone and temperature changes as a function of altitude. It should be noted that, although variations in the ozone column are expected to be small, local changes can be quite large.

3. HIGH CHLORINE PERTURBATIONS

The behavior of the chemical system in the atmosphere for high chlorine increases has been recently discussed by Prather et al (1983). Figure 4 shows that the response of the ozone column becomes highly non linear for Cl_x mixing ratio becoming of the order of the NO_y mixing ratio. The explanation of this effect involves complex coupling mechanisms between odd nitrogen and odd chlorine species ($ClONO_2$), non linear response of the OH radical in the middle and lower stratosphere, where it is destroyed essentially by HNO_3 and HO_2NO_2, and the self-healing effect of ozone, especially when large amounts are destroyed at high altitude. The calculation of the ozone response due to high chlorine perturbations requires therefore an accurate knowledge of the total odd nitrogen amount which is present at a specified altitude and latitude. The temperature response at 45 km for large ozone depletion is also shown in figure 4.

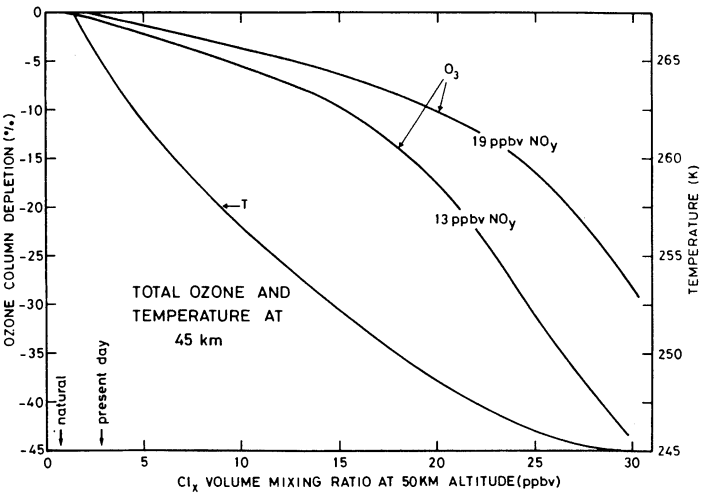

Fig. 4.- Change in the ozone column for high chlorine injections (Cl_x mixing ratio up to 30 ppbv) and for 2 values of the ambient NO_y mixing ratio (13 and 19 ppbv). The temperature variation at 45 km (NO_y = 19 ppbv) is indicated.

ACKNOWLEDGMENTS

This work was supported by the Chemical Manufacturers Association under contract 83-468.

REFERENCES

BRASSEUR, G., A. DE RUDDER and Chr. TRICOT, Stratospheric response to chemical perturbations, to be submitted to the Journal of Atmospheric Chemistry (1984).

CICERONE, R.J., S. WALTERS and S.C. LIU, Non linear response of stratospheric ozone column to chlorine injections, J. Geophys. Res., 88, 3647, 1983.

PRATHER, M.J., M.B. McELROY and S.C. WOFSY, Reductions in ozone at high concentrations of stratospheric halogens, Paper presented at the WMO/NASA workshop, Starnberger See, FRG, June 11-16, 1984.

WUEBBLES, D.J., F.M. LUTHER and J.E. PENNER, Effect of coupled anthropogenic perturbations on stratospheric ozone, J. Geophys. Res., 88, 1449, 1983.