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THEORETICAL PREDICTION OF PERTURBATIONS IN THE MIDDLE ATMOSPHERE RELATED TO THE INCREASING EMISSIONS OF GREENHOUSE GASES

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INTRODUCTION

Radiative transfer in the earth's atmosphere is essentially controlled by the presence of water vapor, carbon dioxide and ozone. Between the absorption bands of these gases, several "windows" allow the radiation emitted by the earth's surface to escape to space. Trace gases such as methane, nitrous oxide, the chlorofluorocarbons (CFCs) and others have strong absorption coefficients in some of these windows and, despite their relatively small concentration, contribute significantly to the greenhouse effect of the atmosphere. The release of these gases, essentially a result of human activity, is expected to modify the radiative budget of the atmosphere and possibly produce climatic changes which could be as large as the variations expected from the observed trend in the CO_2 concentration.[1]

CH_4, N_2O and the chlorofluorocarbons also initiate a number of chemical reactions which affect the composition of the atmosphere and, in particular, the ozone density. For example, the photodecomposition of the CFCs produce inorganic chlorine which catalyzes the destruction of ozone in the stratosphere. The mixing ratio of inorganic chlorine, which was slightly over 1 ppbv in 1970, has reached in 1985 a level close to 2.8 ppbv and is expected to reach 8 ppbv (at steady-state) if the present level of the chlorofluorocarbons emission remains constant. Nitrous oxide (N_2O) produces nitrogen oxides (NO_x) in the stratosphere, which also destroy ozone catalytically. Methane (CH_4) initiates a complex reaction chain, which leads to the production of ozone in the troposphere. Carbon dioxide has no direct chemical influence below the mesopause but an increase in its concentration leads to a cooling of the stratosphere. As the ozone destruction rate is temperature dependent, the observed CO_2 increase should lead to an increase in the ozone concentration above 30 km altitude.

The purpose of this paper is to briefly present calculations of the ozone and temperature response to continuous release in the atmosphere of chlorofluorocarbons with simultaneous increase in the concentration of other trace gases. Calculations are performed with a one-dimensional coupled chemical-radiative-transport model.[2,3] The chemical reaction rates used in the model are essentially those recommended by NASA [4] and involves about 35 species belonging to the oxygen, hydrogen, carbon, nitrogen and chlorine families. The radiative scheme is similar to the model described by Morcrette.[5] The vertical transport of the trace gases and of heat (potential temperature) is parameterized by an eddy diffusion representation.

The model integration is started in year 1910 but the results are represented only after 1940. The ozone and temperature changes are calculated relative to their value in 1940.

SCENARIOS FOR CHANGES IN TRACE GAS. CONCENTRATION OR EMISSION

The temporal variation of the concentrations of carbon dioxide, methane and nitrous oxide is based on the reference scenarios suggested by Wuebbles et al. [6] and is represented in Figure 1. In the future, methane is assumed to increase by 1%/yr, and nitrous oxide by 0.25%/yr. The growth rate of CO_2 is variable with time such that its mixing ratio reaches 600 ppmv in year 2062. For the chlorocarbons (CFC-11, CFC-12, CFC-113, CCl_4 and CH_3CCl_3), the emissions in the past are based on historical

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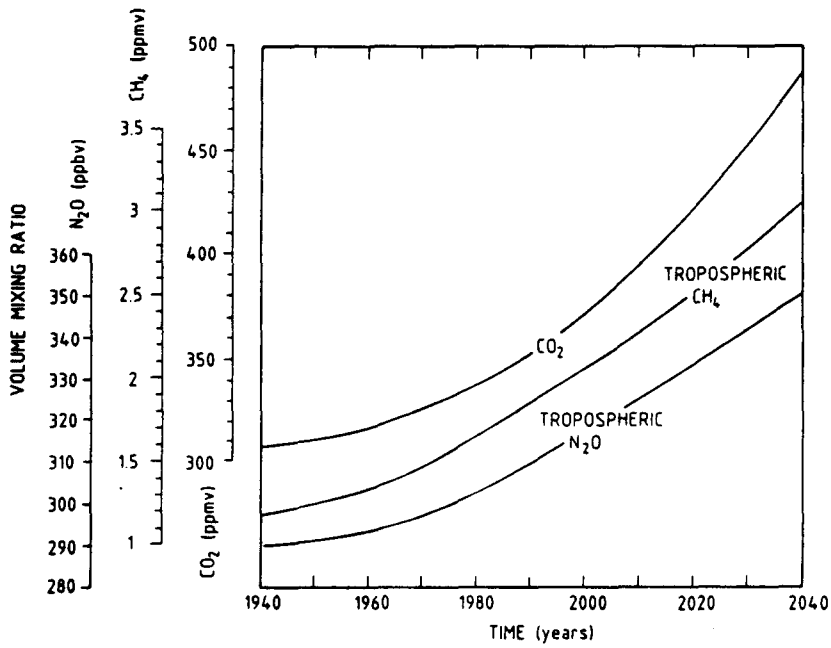

Fig. 1. Variation in the mixing ratio of CO_2, tropospheric CH_4 and tropospheric N_2O adopted in the model for the 1940-2040 period.

release rates provided by industry.[7] For the future, releases of CCl_4 and CH_3CCl_3 are assumed to remain equal to their level in 1984. For the other organic compounds (CFC-11, CFC-12 and CFC-113), 4 different scenarios are considered (see Fig. 2). Case I assumes that the industrial production of CFC-11 and CFC-12 remains constant at the 1984 level. Case II corresponds to a 3%/yr increase in the 2 compounds but with a capacity cap equal to 1.5 times their production in 1984. In cases A and B, an increase of 3%/yr and 6%/yr respectively is adopted for the emission of CFC-113 with a capacity cap equal to the production (expressed in mass units) of CFC-11.

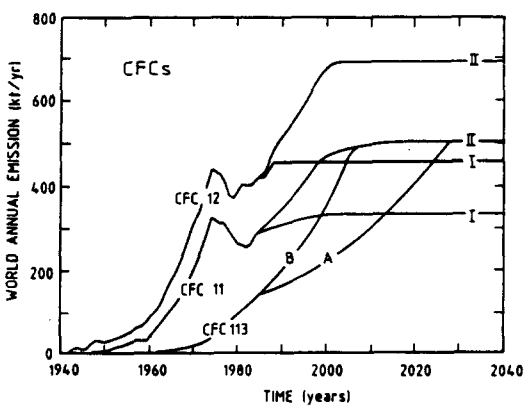

Fig. 2. Scenarios of the world emission of CFC-11, CFC-12 and CFC-113 for the 1940-2040 period.

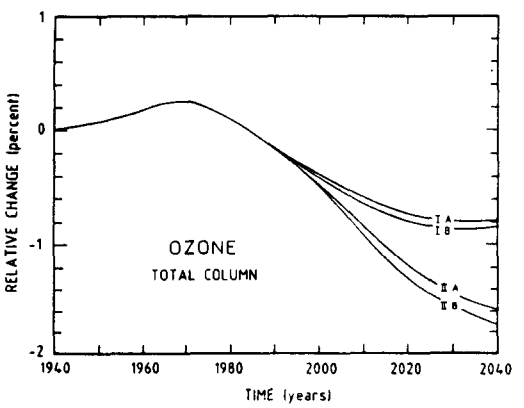

Fig. 3. Variation as a function of time of the relative change in the ozone column abundance for scenarios IA, IB, IIA and IIB.

CALCULATED OZONE AND TEMPERATURE CHANGES

The relative change in the ozone column abundance calculated for scenarios IA, IB, IIA and IIB is shown in Figure 3. Between 1940 and 1970, total ozone slightly increases since, during this period, the effects of carbon dioxide and methane largely compensate the action of the CFCs and of nitrous oxide. This increase however is never larger than 0.3%. After 1970, the ozone column starts to be reduced, essentially by anthropogenic chlorine. The rate of decrease is significantly larger in cases IIA and IIB than in cases IA and IB, but is not considerably affected by the choice of the scenario which is adopted for CFC-113. In year 2040, the calculated ozone depletion is never larger than 2 percent. In fact, in the last years of the simulation, the effect of methane (which produces ozone in the troposphere) becomes significant and the decrease calculated in the upper stratosphere is partly compensated by the increase calculated at the lower levels. The vertical distribution of the relative change in the ozone concentration is illustrated in Figure 4 for scenario IA. Although the variation in the ozone column remains limited, local changes can be as large as 60%. Such dramatic perturbations lead to important variations in the heat budget of the atmosphere and consequently in the temperature, especially in the upper stratosphere (Fig. 5). Again, in this latter case, the amplitude of the variation is a strong function of the altitude. The model calculates a 20 K cooling in year 2020 and a 26 K cooling in year 2040 at 45 km altitude, if scenario IA is adopted. Changes in the vertical gradient of the temperature are expected to perturb the dynamics of the atmosphere (general circulation) with potential consequences on climate.

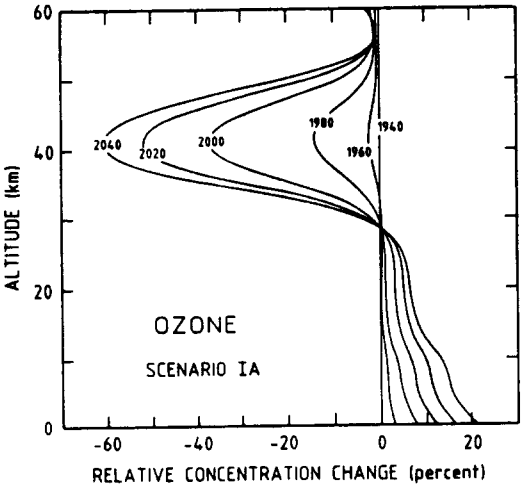

Fig. 4. Relative variation in the ozone concentration calculated as a function of altitude for different years, in the case of scenario IA.

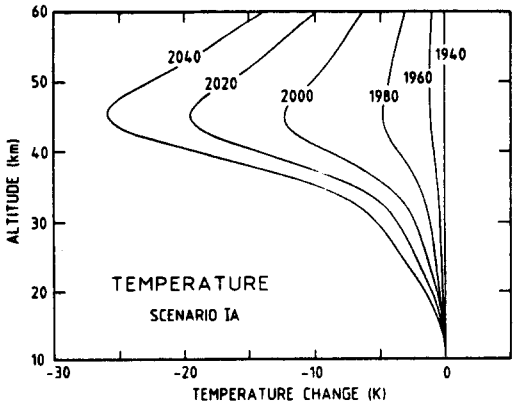

Fig. 5. Variation in the temperature calculated as a function of altitude for different years, in the case of scenario IA.

CONCLUSIONS

The total amount of ozone in the atmosphere is expected to decrease in the future, essentially as a result of the continuous emission of chlorofluorocarbons. The reduction in the ozone column however is expected to remain limited, especially if the amount of other species, such as methane and carbon dioxide, further increases. The calculated depletion in total ozone appears to be sensitive to the adopted growth rate in the industrial production of CFC-11 and -12, especially after year 2000, but is largely insensitive to the adopted trend in the production of CFC-113, if the mass of CFC-113 yearly injected in the atmosphere never exceeds that of CFC-11.

Significant variations in the local ozone concentration and temperature are noticeable, especially in the upper stratosphere. Enhanced concentrations of tropospheric ozone are predicted as a consequence of the rapid increase in the concentration of methane.

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