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PROCESSES WHICH AFFECT OZONE AND OTHER CLIMATICALLY IMPORTANT TRACE GASES

[Editor's Note - This TA summarizes information from a recent NASA publication [1] representing an assessment of the state-of-knowledge of the upper atmosphere as of January 1986.]

For several decades scientists have sought to understand the complex interplay among the chemical, radiative and dynamical processes that govern the structure of the atmosphere. As knowledge of these processes improves, there is growing concern that the total column and vertical distribution of ozone (O_3), the vertical temperature structure, and eventually the climate, will be modified by changes in the atmospheric concentrations of several trace gases. There is now compelling observational evidence indicating increases in the concentration of these trace gases which affect O_3. These gases include chloroflourocarbons (CFC), carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), and nitrogen oxides (NO_x), which are precursors to hydrogen, nitrogen, and chlorine oxides, which catalyze the destruction of ozone.

Most ozone in the earth's atmosphere resides in the stratosphere, as shown in Figure 1. Ozone is important because it is the only gas that prevents harmful ultraviolet radiation from reaching the surface of the earth. Unlike some localized environmental problems such as acid rain, ozone layer modification is a global phenomenon. Changes in the ozone layer, together with changes in other trace gases, could contribute to a change in climate on a global scale. The ozone issue and greenhouse warming are strongly coupled because ozone and the above mentioned trace gases are strong absorbers of infrared (IR) radiation.

The importance of these trace gases cannot be overstated. Their effects on O_3 are not additive, although their direct radiative effects on atmospheric temperature are approximately additive. For example, increases in CFCs and N_2O are predicted to decrease ozone, while CO_2 and CH_4 are predicted to increase ozone. However, increases in these same gases are predicted to increase atmospheric temperature cumulatively. Observational evidence indicates that these trace gases are increasing from 0.2-5.0% annually. Another important aspect of the ozone and global warming issue is that the lifetimes of many of these trace gases are long (75-150 years). Therefore, if a significant climatic change is triggered by these gases, recovery may take tens to hundreds of years after emissions have been terminated.

Models have been developed to calculate how the ozone layer will change over the next 100 years. In these models, the current rates of increase of the trace gases (except for the CFCs) are held constant. The CFCs are increased at rates of 0.0%, 1.5%, and 3% in different model runs. The CFCs are singled out because these gases are primarily of industrial origin and can be controlled. As shown in Figure 2, when the growth rates of the CFCs exceed those of the CH_4 and CO_2, ~~the latter gases can no longer buffer the impact of the CFCs. However, even when~~ the predicted total column ozone changes are small, as in scenario B of Figure 2, major changes in the vertical distribution of O_3 are still predicted (Figure 3). In this case, ozone is predicted to decrease in the mid to upper stratosphere due to increasing CFCs, and increase in the troposphere due to increasing CH_4. The predicted values in Figure 3 would modify the lower atmosphere and surface temperatures via two competing processes. Less stratospheric O_3 implies less absorption of solar radiation in the stratosphere, allowing more radiation to reach the lower atmosphere and surface (warming). However, less stratospheric absorption will reduce the downward flux of infrared radiation (cooling). Current models also predict that as the total content in the O_3 column decreases, the greatest depletion will occur in the higher latitudes.

It's important to assess the extent of changes in global ozone that have already taken place and compare with changes predicted by theory. The search for small secular changes on a global scale is difficult due to natural variations that occur on many time scales. Although total column content and vertical distribution of O_3 have been measured for decades, different observation techniques have certain limitations, such as geographical continuity and reliable calibration, which restrict confidence.

In general, ground-based networks have shown no significant trend in the total column content of O_3 since 1970, which agrees well with model estimates for the same period, when changes in the trace gases are accounted for. However, vertical distributions of O_3 from ground-based networks indicate a 2-3% decrease in the mid to upper stratosphere from 1970-1980. This is consistent with models which predict that CFCs will have maximum effect at this altitude. Preliminary Nimbus 7 satellite observations indicate a total column decrease and a decrease in the mid to upper stratosphere of O_3 between 1978-1984, with most changes occurring since 1981. It is still not certain whether these latter observations have been interpreted correctly, or whether the decreases were due to natural causes such as the 1982 El-Chichon eruption or the 1982-83 El Nino event.

Important new observational evidence has been obtained from Antarctica. A ground-based instrument has indicated a greater than 40% decrease in the O_3 total column content above the Antarctic, during the late August to November period, since 1957. Most of the decrease has occurred since the mid 1970s. Nimbus 7 instruments have verified this trend since 1979. Similar changes have not been observed over the Arctic. It is not yet evident whether the behavior of O_3 above Antarctica is a precursor to global O_3 change, or whether this anomaly is the result of special geophysical conditions that exist there. However, there is a need for concern; more observational data are needed.

In summary, observations now indicate increases in the concentration of gases that affect ozone, changes in the vertical distribution of O_3 and changes in the total column content of O_3 on a regional and possibly global scale. The observed increase in trace gases also have a direct implication on the earth's radiative balance, since these gases absorb IR radiation in a part of the spectrum which is otherwise transparent. In the last several years, much attention has been centered on CO_2 and its relation to the greenhouse effect. However, it is now apparent that the concentration of other trace gases will contribute to greenhouse warming by an amount about equal to CO_2 alone. Thus, the problems of ozone change and climate change should be considered together. What was previously thought of as a CO_2-climate problem should be more properly addressed as a trace gas - chemistry-climatic problem.

Reference:

[1] Watson, R.T., M. A. Geller, R. S. Stolarski, and R.F. Hampson, 1986: "Present State of Knowledge of the Upper Atmosphere: An Assessment Report", NASA Reference Publication 1162, May.

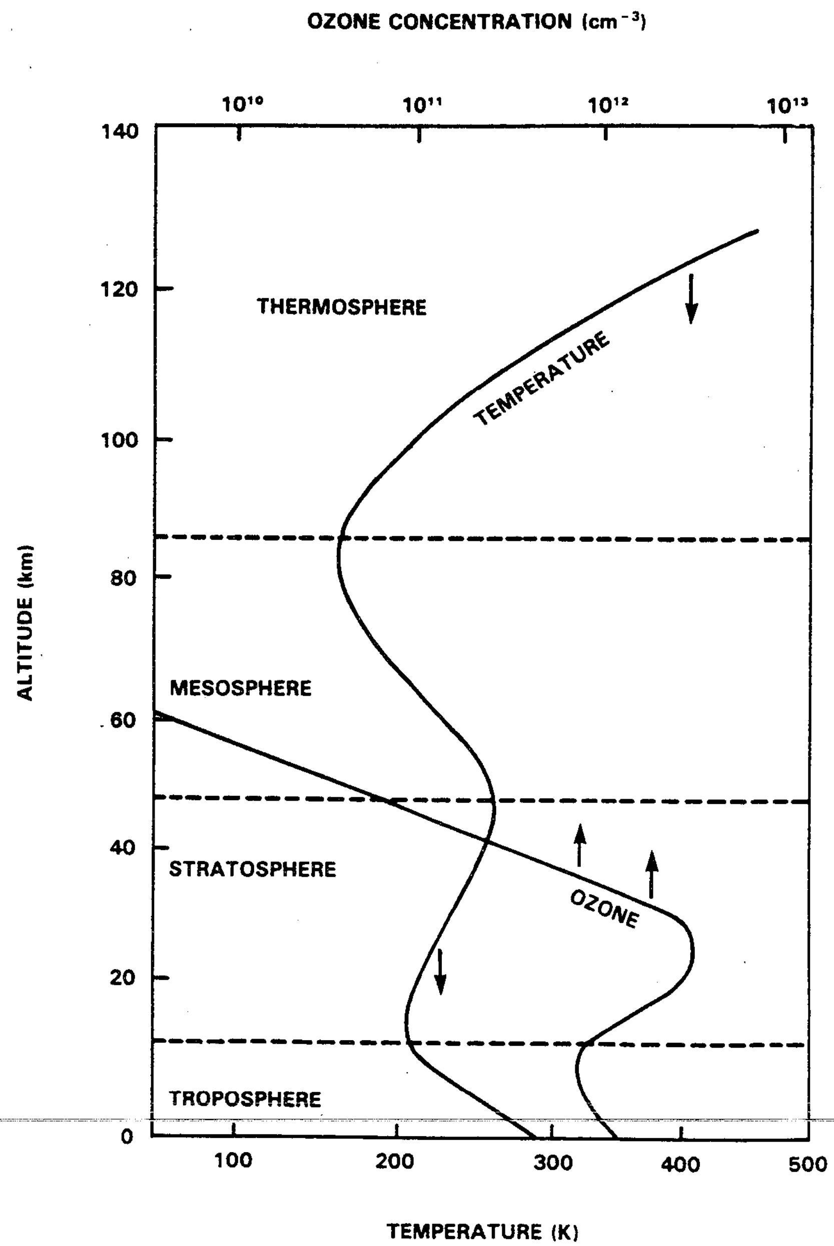

Figure 1. Temperature profile and ozone distribution in the atmosphere.

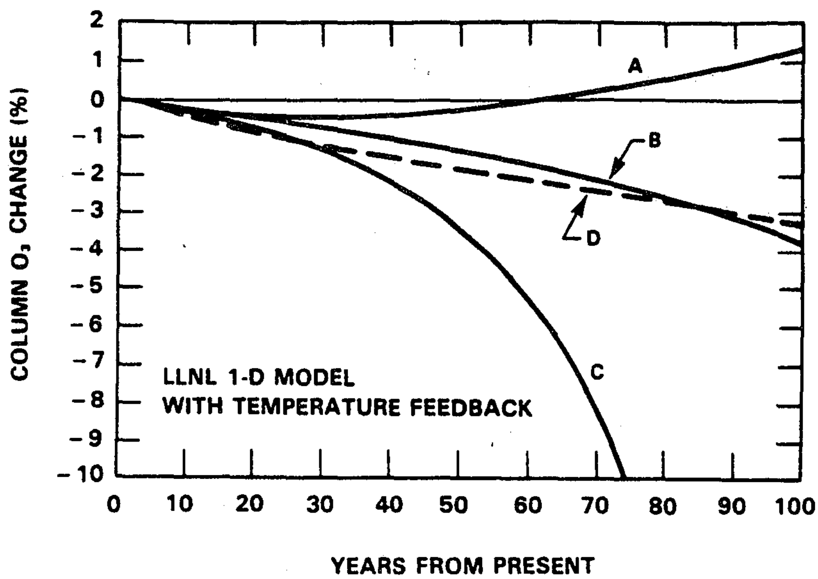

Figure 2 . Calculated changes in ozone column with time for time-dependent scenarios: A (CFC flux continues at 1980 level, CH_4 increased 1% per yr, N_2O increases 0.25% per yr, and CO_2 increases according to the DOE scenario); D (same as A but without increases in CH_4 and N_2O); B (CFC emissions begin at 1980 rates and increase at 1.5% per yr, other trace gases change as with A); C (same as B except CFC emissions increase at 3% per yr).

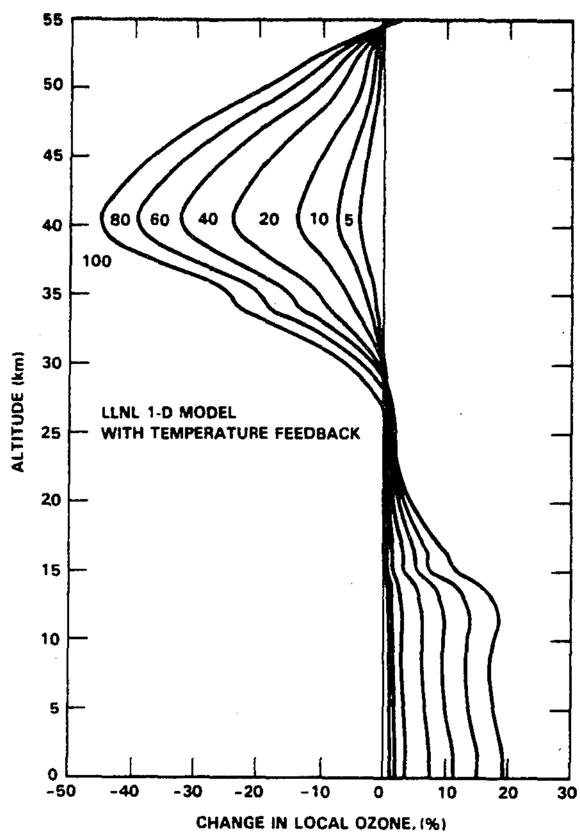

Figure 3 Calculated percentage change in local ozone at selected times (5 to 100 years) for scenario B of Figure 28 (CFC emissions begin at 1980 rates and increase at 1.5% per yr, CH_4 increases at 1% per yr, N_2O increases at 0.25% per yr, and CO_2 increases according to the DOE scenario).