GREENHOUSE EFFECT DUE TO ATMOSPHERIC NITROUS OXIDE

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Abstract. The greenhouse effect due to nitrous oxide in the present atmosphere is about 0.8°K. Increase in atmospheric N_2O due to perturbation of the nitrogen cycle by man may lead to an increase in surface temperature as large as 0.5°K by 2025, or 1.0°K by 2100. Other climatic effects of N_2O are briefly discussed.

In the present day atmosphere nitrous oxide is a minor constituent with mixing ratio equal to about 2.8×10^{-7} by volume (Bates and Hays, 1967). The gas is produced mainly by the decay of organic material under anaerobic conditions and removed from the atmosphere by photodissociation, by reaction with $O(^1D)$, and possibly by another unknown tropospheric sink (McElroy et al, 1976a; Crutzen, 1976). The importance of N_2O for stratospheric chemistry has been pointed out by Crutzen (1971), McElroy and McConnell (1971), and Nicolet and Vergison (1971). In this article we shall investigate the greenhouse effect due to N_2O and the associated climatic implications.

The molecule N_2O has three fundamental bands in the infrared: ν_1 at 7.78 μm, ν_2 at 17.0 μm, and ν_3 at 4.5 μm. For our purposes the most important bands are the ν_1 and ν_2 bands. In a normal atmosphere H_2O plays a most important role in these spectral regions. The atmospheric opacity due to H_2O for outgoing thermal radiation near 7.8 μm is about 0.5. Near 17 μm, absorption by H_2O e-type continuum band (Burch, 1970) is also significant. The presence of absorbing N_2O molecules in the atmosphere provides additional trapping for the emergent radiation and results in an increase of the surface temperature.

We shall estimate the magnitude of this greenhouse effect with a one-dimensional radiative-convective model (Manabe and Wetherald, 1967; Wang and Domoto, 1974). We use a Malkmus type band model (Malkmus, 1967) with band parameters derived from line-by-line data given by McClatchey et al (1973). Each N_2O fundamental band is approximated by a number of sub-bands (usually 4 to 6) constructed in this manner. Our model assumes a fixed relative humidity and thus allows for a positive feedback by water vapor. Possible strong feedbacks due to ice-cover, cloud-cover, and stratospheric chemistry are not included. The results of our calculation are presented in Figure 1. The surface temperature T_s has been computed as a function of N_2O abundance. With the present atmospheric concentration of N_2O T_s equals 287.77°K. With no N_2O T_s assumes a lower value 286.96°K. It is clear that the present amount of atmospheric N_2O contributes about 0.81°K to the warming of the atmosphere and the surface. Most of the contribution (57%) to the greenhouse effect is due to the ν_1 band, with additional contributions from ν_2 band (35%) and ν_3 band (8%).

Recently there has been concern that the extensive use of chemical fertilizers and combustion of fossil fuels may significantly speed up the nitrogen cycle and lead to an increase in the level of atmospheric N_2O (McElroy, 1976; McElroy et al, 1976b). The issue has been examined also by Crutzen (1976), Liu et al (1976), and Sze and Rice (1976). A quantitative assessment of the magnitude of increase in N_2O in the next hundred years appears to be difficult because of a number of uncertainties such as the atmospheric lifetime of N_2O, the delay time for denitrification to take place in the soil, and future prospects for the world's agricultural economy.

We shall consider seven models for future increase in atmospheric N_2O. Models M_1 and M_2 are taken from McElroy et al (1976b); C_1 and C_2 from Crutzen (1976); L from Liu et al (1976); S_1 and S_2 from Sze and Rice (1976). The models are chosen to encompass the high yield and low yield cases in the various models examined by these authors. The projections for values of N_2O mixing ratio f_{N_2O} are summarized and compared in Table 1. Liu et al (1976) and Sze and Rice (1976) did not quote a value for f_{N_2O} in 1975. We assume it to be 2.8×10^{-7} (v/v).

The results of our calculation on the greenhouse effects for models M_1 through S_2 are shown in Figure 2. The increase in surface temperature could be as large as 0.5°K by 2025, 1.0°K by 2100 according to model M_1. We may note that these values are comparable to those estimated by Ramanathan (1975) for the greenhouse effect due to 2 parts per billion of chlorofluorocarbons. The coincidence is hardly surprising. Although the

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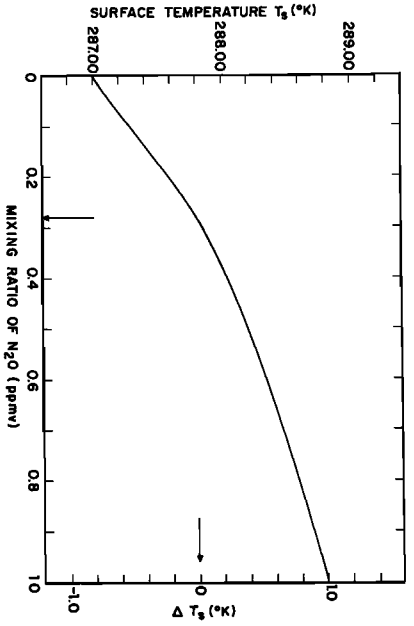

Figure 1. Mean surface temperature T_S as estimated by one-dimensional radiative-convective model for various concentrations of N_2O. Results are for a fixed 50% cloud cover at a constant altitude of 5.5 km, and maximum tropospheric lapse rate -6.5°K km^{-1}. The water vapor content of the atmosphere is parametrized as follows: (1) Above 20 mb we assume a fixed water vapor mixing ratio equal to 3 x 10^{-6} by mass. (2) Below 20 mb we take the relative humidity profile from Manabe and Wetherald (1967). The relative humidity at the surface is 75%. The unperturbed temperature in these calculations is 287.77K. If, in place of (2), we had assumed a fixed absolute humidity for water vapor, all the results in these figures should be lowered by a factor of 2. On the other hand, the results should be amplified by a factor of 1.5 if the cloud top temperature is held fixed. The two arrows indicate unperturbed N_2O concentration and T_s respectively. ΔT_s is the net greenhouse effect with respect to the unperturbed atmosphere. We use N_2O vertical profile given by McElroy et al, (1976a) in these calculations.

two Freons have five strong bands close to the 10 μm peak emission region, N_2O is about 100 times more abundant than the concentrations assumed for the Freons. Of course, for larger concentrations N_2O rapidly becomes optically thick (See Figure 1) whereas the Freons remain optically thin. Models C_2, L and S_2 appear to give considerably lower values. The difference reflects the uncertainties in the current understanding of the N_2O chemistry and biochemistry.

It is of interest to note that the concentration of atmospheric N_2O has probably not been constant over the past history of the Earth. Production of N_2O is supplied mainly by bacterial organisms on land (McElroy et al 1976a), and is sensitive to a variety of environmental factors such as pH, aeration, and ambient soil temperature (Focht, 1974). Geological records show that the Earth has passed through warm epochs with tropical climates extending to a much wider belt than today's (Durham, 1959), and ice ages with glaciers covering large parts of the continents (Dyson, 1962). It is clear that production of N_2O should vary with the fraction of land covered by vegetation. The dependence of N_2O yield on temperature (under laboratory conditions) has been estimated by Focht (1974) to be proportional to $e^{-E/RT}$, where E ≃ 8,000 KCal, R = Gas Constant, T = Soil temperature (°K). Taken literally, this implies an increase of 6% in the yield of N_2O for each degree increase in temperature near 289°K, or a 3% positive feedback on the temperature.

This result assumes that all the other factors controlling the production of N_2O remain unchanged, and that the possible unknown tropospheric sink does not depend on temperature. The latter assumption is certainly not true if the ocean were a major sink for N_2O (McElroy et al 1976a).

Summarizing, we have demonstrated that the greenhouse effect due to N_2O is important for the radiative budget of our atmosphere, especially in view of a potential increase of this trace gas due to anthropogenic activities. We speculate that N_2O concentration has probably fluctuated in the past, and contributed a positive feedback to climatic changes.

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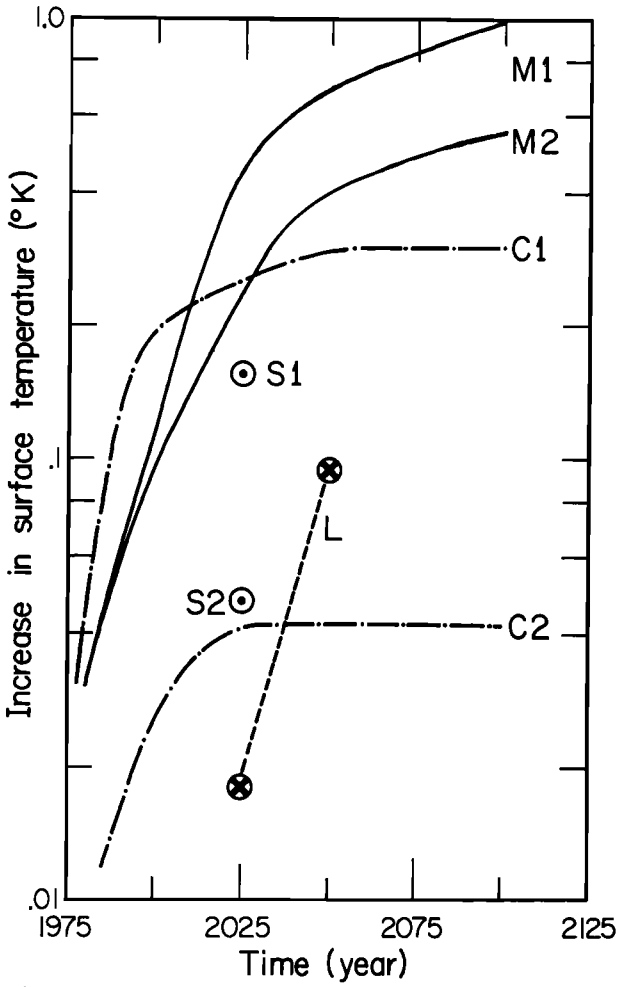

Figure 2. Increase in the mean surface temperature computed by using the results in Figure 1 for the seven models discussed in Table 1.

Table 1. Summary and comparison of various current models for the growth of atmospheric nitrous oxide.

Year	fN_2O (10^{-7} v/v)						
	Model M_1	Model M_2	Model C_1	Model C_2	Model L	Model S_1	Model S_2
1975	2.80	2.80	2.50	2.50	2.80	2.80	2.80
2000	3.50	3.40	4.00	2.65	-	-	-
2025	5.60	4.30	4.30	2.75	2.91	3.72	3.08
2050	7.50	5.30	4.30	2.75	3.36	-	-
2100	10.3	6.40	4.30	2.75	-	-	-
Reference	McElroy et al (1976b) Model A_1	McElroy et al (1976b) Model B_2	Crutzen (1976) Model III	Crutzen (1976) Model I	Liu et al (1976)	Sze and Rice(1976) Model B	Sze and Rice(1976) Model A

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