MODELING OF OZONE LAYER DEPLETION

Akanksha, S. Raghunamdan Murthy, V.K. Srivastava

Indian Institute of Technology, Delhi
Hauz Khas, New Delhi-110016

Widespread use of chlorofluorocarbons has led to about 3% ozone depletion by the end of the 80's. This fact has resulted in sharp decline in subsequent chloroflurocarbon use and manufacture in conformation to Montreal Protocol (1987). Turco and Whitten(1975) have reported dynamic solution to establish quantitative effect of chloroflorocrbons. A one dimensional time dependant model was used and results were arrived at considering the prevalent increase of chloroflorocarbon production and emmision at that time. Miller et al. (1978) described a far more detailed model and presented results for a wide variety of species with time and altitude. Taking cognizance of this fact, the ozone layer stability and the projected ultimate equilibrium condition has been studied in this paper. The steady state solution of the system outlined the fact that the ozone layer can reach a steady state for any pollutant concentration values. The natural limit of the ozone concentration, as well as the upper limits for the pollutant concentration was calculated. The procedure suggested a way of assessing the effect of anthropogenetic activities on ozone layer. The transmission coefficients of the UV radiation were calculated establishing the lower limits of the “permitted” pollution. Ozone layer stability was studied in the framework of irreversible thermodynamics.The following 16 chemical reactions describing the ozone creation and destruction processes in the stratosphere were considered

$O_2 + hv \rightarrow 2O$,

$O + O_2 + M \rightarrow O_3 + M$,

$O_3 + hv \rightarrow O_2 + O^*$,

$O_3 + O^* \rightarrow 2O_2$,

$HO + O_3 \rightarrow HO_2 + O_2$,

$HO_2 + O \rightarrow OH + O_2$,

$NO_2 + hv \rightarrow NO + O$,

$NO + O_3 \rightarrow NO_2 + O_2$,

$NO_2 + O \rightarrow NO + O_2$,

$Cl + O_3 \rightarrow ClO + O_2$,

$ClO + O \rightarrow Cl + O_2$,

$ClO + NO \rightarrow NO_2 + Cl$,

$HO_2 + Cl \rightarrow HCl + O_2$,

$HCl + OH \rightarrow H_2O + Cl$,

$CF_2Cl_2 + hv \rightarrow CF_2Cl + Cl$,

$CFCl_3 + hv \rightarrow CFCl_2 + Cl$

In the above, M stands for a catalyst.

Species continuity equation was applied for 11 relevant species taking into account vertical motion through eddy diffusion term. This gave set of 11 partial and coupled differential equations dependent on time and altitude. For various species, the basic species continuity equation is given as

$$\frac{dX_i}{dt} = J_i C_i + \sum_{n=1}^{l} k_n \prod_m C_m^{\nu_m}$$

where n — any single reaction

ν — stoichiometric coefficient

m — number of species in nth reaction

l — number of reactions

The eleven species considered were O, O_3, HO, Cl, ClO, NO, NO_2, HO_2, F-11, F-12, HCl. The model of ozone layer lead to a system of non-linear differential equations. To solve these equations, numerical discretization method was employed using semi-implicit finite difference schemes. The simultaneous equations thus obtained were solved using matrix inversion technique for a tridiagonal matrix wherein the MxM matrix is transformed to Mx3 matrix reducing the computer storage memory and time. Steady state solution of the system indicated that ozone layer stability is independent of pollutant concentration viz Freon-11 and Freon-12 and is instead strongly dependent on the relation between HO_2 and NO_2 concentration in the stratosphere. Hypothetical fluctuations appearing in the system were also studied to get a better measure of the stability of the system. Real and negative eigen values were obtained indicating good damping characteristics. Natural limits of pollutants have been calculated knowing ozone lifetime. Thereafter, putting a condition on change in UV transmission coefficient, which is consonant with the risk of skin cancer, the upper limits of pollutants were also obtained which indicated that current concentrations of Freons were well within the permitted range. Dynamic simulation has been carried out which gave predicted future concentrations of all species with altitude. Despite halt in production of CFC's, the concentration does not show much decline. Consequently, because of the photochemical dissociation of the molecules already in the stratosphere, free chlorine concentration keeps on increasing. However, the increasing free chlorine seems to take the HCl route rather than the depletion causing ClO route (Fig 1). Solution indicated that ozone will reach normal levels by 2050 (Fig 2). Freon concentrations owing to their large

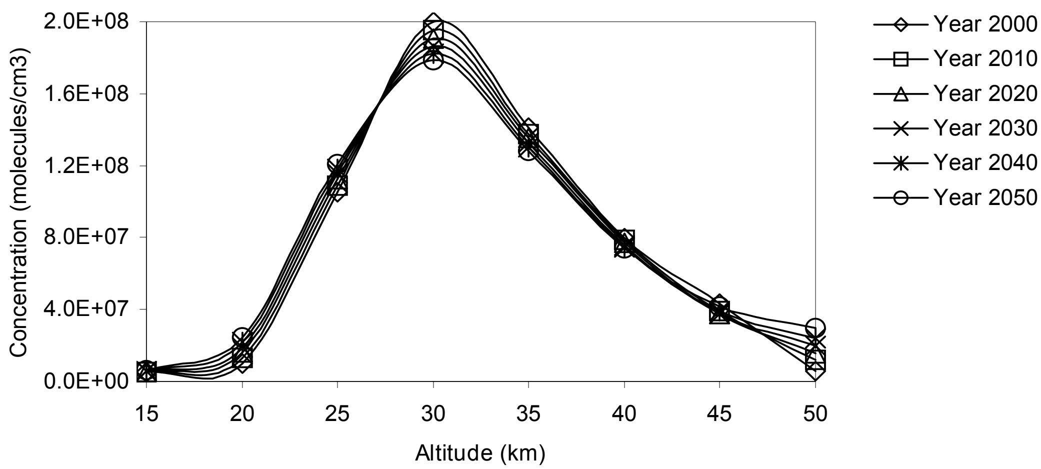

Figure 1. Predicted future ClO concentration with altitude

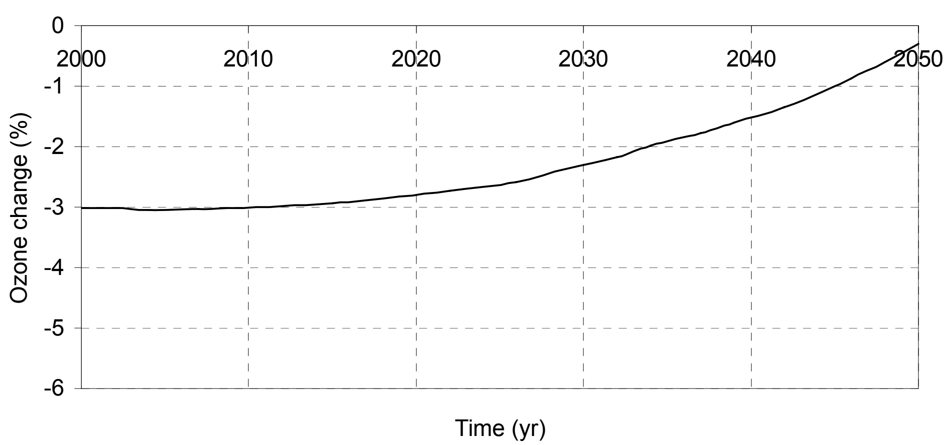

Figure 2 Predicted total column ozone depletion

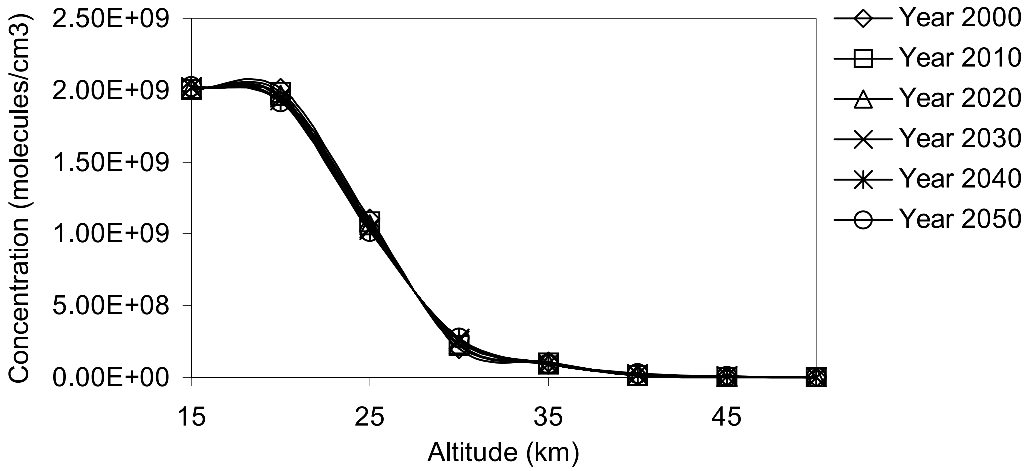

Figure 1. Predicted future $CFCl_3$ concentration with altitude

lifetimes may take much longer to reach accepatable levels (Fig 3).

References:

Turco R.P., Whiten R.C., Chlorofluoromethanes in the atmosphere andd some possible consequences for ozone, Atmospheric Environment (1975),9, 1045-1061.

Miller C, Meakin P., Franks R.G.E., Jesson, J.P., The fluorocarbon Ozone Theory V One-dimensional modeling of the atmosphere: The base case, Atmospheric Environment (1978), 12, 2481-2500.